GUIDANCE NOTES ON

'SAFEHULL-DYNAMIC LOADING APPROACH' FOR CONTAINER CARRIERS

(FOR THE 'SH-DLA' CLASSIFICATION NOTATION)

APRIL 2005

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

This Page Intentionally Left Blank.

Foreword

These Guidance Notes provide information about the optional classification notation, SafeHull-Dynamic Loading Approach (**SH-DLA**), which is available to qualifying "Vessels Intended to Carry Containers". In the text herein, this document is referred to as "these Guidance Notes".

Part 1, Chapter 1, Section 3 of the ABS *Rules for Building and Classing Steel Vessels* (*Steel Vessel Rules*) contains descriptions of the various, basic and optional classification notations available. Part 5, Chapter 5 of the ABS *Steel Vessel Rules* gives the specific design and analysis criteria applicable to container carriers. In case of a conflict between these Guidance Notes and the ABS *Steel Vessel Rules*, the latter has precedence.

These Guidance Notes are the updated edition of the "Analysis Procedure Manual for The Dynamic Loading Approach (DLA) for Container Carriers, April 1993" and represents the most current ABS DLA analysis procedure for container carriers.

These Guidance Notes are issued April 2005. Users of these Guidance Notes are welcome to contact ABS with any questions or comments concerning these Guidance Notes. Users are advised to check periodically with ABS to ensure that this version of these Guidance Notes is current.

This Page Intentionally Left Blank.

GUIDANCE NOTES ON

SAFEHULL-DYNAMIC LOADING APPROACH' FOR CONTAINER CARRIERS

CONTENTS

SECTION 1 Introduction

1 Background

The design and construction of the hull, superstructure and deckhouse of an ocean-going vessel are to be based on all applicable requirements of the ABS *Rules for Building and Classing Steel Vessels* (*Steel Vessel Rules*). The design criteria for a container carrier type vessel are located in Part 5, Chapters 5 and 6 of the ABS *Steel Vessel Rules*. Part 5, Chapter 5 is applicable to vessels of 130 meters (427 feet) or more in length, while Part 5, Chapter 6, applies to vessels under 130 meters in length.

The criteria in Part 5, Chapter 5 of the ABS *Steel Vessel Rules* are referred to as ABS *SafeHull*-based criteria. The SafeHull criteria in the ABS *Steel Vessel Rules* entail a two-step procedure. The main objective of the first step, referred to as Phase A, is scantling selection to accommodate global and local strength requirements. The scantling selection is accomplished through the application of design equations that reflect combinations of probable extreme dynamically-induced loads; durability considerations; expected service, survey and maintenance practices; and structural strength considering the failure modes of material yielding and buckling. Also, a part of Phase A is an assessment of fatigue strength primarily aimed at connections between longitudinal stiffeners and transverse web frames in the hull structure. The second step of the SafeHull criteria, referred to as Phase B, entails the performance of structural analyses using the primary design Loading Cases of Phase A. The main purpose of the Phase B analyses is to confirm that the selected design scantlings are adequate (from a broader structural system point of view) to resist the failure modes of yielding, buckling and ultimate strength and fatigue.

The Dynamic Loading Approach (DLA) provides an enhanced structural analysis basis to assess the capabilities and sufficiency of a structural design. A fundamental requirement of DLA is that the basic, initial design of the structure is to be in accordance with the Rule criteria, as specified in the ABS *Steel Vessel Rules*. The results of the DLA analyses cannot be used to reduce the basic scantlings obtained from the direct application of the Rule criteria scantling equations. However, should the DLA analysis indicate the need to increase any basic scantling, this increase is to be accomplished to meet the DLA criteria. The **SH-DLA** notation signifies the satisfaction of the DLA analysis procedure of these Guidance Notes.

The objective of these Guidance Notes is to provide a description of the analysis procedures to be pursued to obtain the optional **SH-DLA** notation. Emphasis is given here on the determination of dynamic loads, rather than the structural FE analysis procedure. This has been done mainly because structural analysis practices are well-established and understood among designers, but the dynamic load determination is a less familiar subject. Therefore, the procedures for FE analysis will be only briefly described in these Guidance Notes.

3 The Concepts and Benefits of DLA Analysis

3.1 General

DLA is an analysis process, rather than a step-wise design-oriented process such as SafeHull. The DLA Analysis emphasizes the completeness and realism of the analysis model in terms of both the extent of the structure modeled and the loading conditions analyzed. The DLA modeling and analysis process relies on performing multiple levels of analysis that start with an overall or global hull model. The results of each previous level of analysis are used to establish which areas of the structure require finer (more detailed) modeling and analysis, as well as the local loads and 'boundary conditions' to be imposed on the finer model.

The Load Cases considered in the DLA Analysis possess the following attributes:

i) Use of container-loading patterns, other loading components and vessel operating drafts that reflect the actual ones intended for the vessel (note that the Load Cases in SafeHull comprise mainly those intended to produce 'scantling design controlling' situations).

ii) Load components that are realistically combined to assemble each DLA Analysis Load Case. The dynamically related aspects of the components are incorporated in the model, and the combination of these dynamically-considered components is accommodated in the analysis method.

3.3 Benefits

The enhanced realism provided by the DLA Analysis gives benefits that are of added value to the Operator/Owner. The most important of these is an enhanced and more precise quantification of structural safety based on the attributes mentioned above. Additionally, the more specific knowledge of expected structural behavior and performance is very useful in more realistically evaluating and developing inspection and maintenance plans. The usefulness of such analytical results when discussing the need to provide possible future steel renewals should be apparent. A potentially valuable benefit that can arise from the DLA Analysis is that it provides access to a comprehensive and authoritative structural evaluation model, which may be readily employed in the event of emergency situations that might occur during the service life of the vessel, such as structural damage, repairs or modifications or long distance ocean transit to a repair facility.

3.5 Load Case Development for DLA Analysis

The basic concept, which must be understood to grasp the nature of DLA, concerns the creation of each Load Case used in the analysis. A Load Case considered for analysis comprises combinations of a Dominant Load component and the other significant load components that are considered to be accompanying the Dominant Load component. Each Load Case contains the load components accompanying the Dominant Load component and a Dominant Load component that is characterized by a defining parameter, referred to as the Dominant Load Parameter (DLP).

A load component consists of dynamic and static parts. For example, the load component "external fluid pressure on the vessel's hull in the presence of waves" has a hydrostatic component that combines with a dynamically-considered pressure component. The determination of the static part of the load component is basic. The dynamically-considered part reflects the wave-induced motion effects, which are the product of an inertial portion of the load and a portion representing the motion-induced displacement of the load relative to the structure's axis system.

Examples of Dominant Load Parameters are "Vertical Hull Girder Bending Moment Amidships" and "Vertical Acceleration at the Vessel's Forepeak Frame". The specific Dominant Load Parameters that are recommended for inclusion in the DLA Analysis of a container carrier are given in Subsection 2/5. The other significant load components accompanying the Dominant Load component in a Load Case include internal and external fluid pressures, lightship weights including structural self-weight.

The combination of the load components composing a Load Case is done through a process where each Dominant Load is analyzed to establish its Response Amplitude Operator (RAO). Using a combination of ship motion analysis, involving ocean wave spectra, and extreme value analysis of the Dominant Load Parameter, an equivalent sinusoidal wave is derived. The wave (defined by wave amplitude, frequency, heading and phase angle with respect to a selected reference location) is considered equivalent in the sense that when it is imposed on the structural model, it simulates the extreme value of the DLP. The process to perform this derivation is given in Sections 4 and 5.

In these Guidance Notes, emphasis is given to the essential elements of Load Case creation using DLPs and the equivalent wave to obtain the other load components accompanying the DLP. It is assumed that the user has the needed background in the procedures and computational tools that are used for Spectral-based Ship Motion and Wave-Induced Load Analysis and Extreme Value Analysis, both of which are required in the establishment of DLPs.

From the RAOs of the dynamic portions of the other load components and the equivalent wave derived for the DLP, the magnitude and spatial distributions of the other load components accompanying the Dominant Load component are obtained. The procedures to establish these load components accompanying the DLP are given for the various other load component types in Sections 6, 7 and 8.

Using the described basic procedure, there are many additional considerations and refinements that can be included and accommodated in DLA Analysis. These include items such as the following:

i) Operational considerations of the vessel in extreme waves

ii) Directionality of waves

iii) Energy spreading of sea spectra

iv) Various formulations to characterize the sea spectra

v) Various exceedance probability levels to characterize extreme values of Dominant Load Parameters.

The point to bear in mind is that the procedure is robust enough to accommodate these items.

3.7 General Modeling Considerations – Structural and Hydrodynamic

In general, it is expected that the inaccuracies and uncertainties, which can arise from use of partial or segmented models, will be minimized by the use of models that are sufficiently comprehensive and complete to meet the goals of the analysis. This specifically means that to the maximum extent practicable, the overall model of the vessel should comprise the entire hull structure. The motion analysis should consider the effect of all six degrees-of-freedom motions. There is also to be sufficient compatibility between the hydrodynamic and structural models so that the application of fluid pressures onto the finite element mesh of the structural model can be done appropriately.

The results of overall (global) model analysis are to be directly employed in the creation and analysis of the required finer mesh, local structural models. Appropriate 'boundary conditions' determined in the larger scale model are to be imposed on the local models to assure appropriate structural continuity and load transfer between the various levels of models.

For the load components and structural responses of primary interest in DLA, analysis formulations derived from linear idealizations are deemed to be sufficient with appropriate nonlinear corrections. A wave profile correction under wave crest or through should be introduced to adjust the hydrodynamic pressure distribution below and above the mean waterline by considering the hydrostatic pressure below the instantaneous wave profile of the equivalent design waves.

However, the designer/analyst is encouraged to employ enhanced methods, especially to incorporate nonlinear loads (for example, slamming and green sea loads), if this proves to be necessary for the specific design being evaluated. The analyst needs to be aware that the adequacy of the selected software is to be demonstrated to the satisfaction of the Bureau.

5 Overview of the Following Sections

These Guidance Notes systematically introduce the assumptions in the load formulation and the methods used in the response analysis underlying the DLA Analysis for container carriers. These include the following topics:

i) Specification of the Dominant Load Parameters

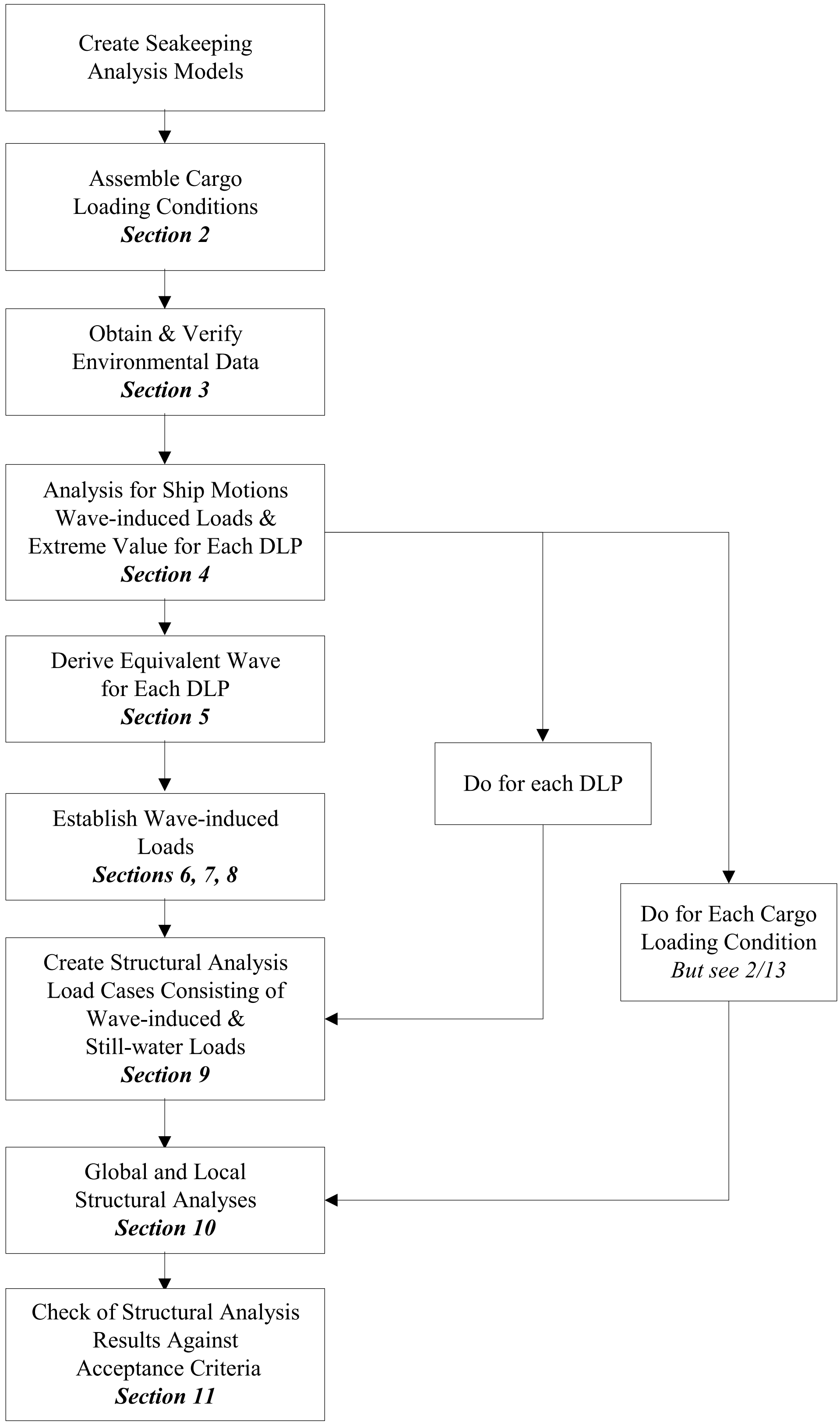
ii) Wave-induced load components and the assembly of Load Cases

iii) Structural model development

iv) The permissible stresses used in the acceptance criteria

These topics are presented in the following Sections 2 through 11. Refer to Section 1, Figure 1 for a schematic representation of the DLA Analysis Procedure.

FIGURE 1
Schematic Representation of the DLA Analysis Procedure



This Page Intentionally Left Blank.

SECTION 2 Load Cases

1 Basic Considerations

The DLA Analysis requires the development of Load Cases to be investigated using the Finite Element (FE) structural analysis. The Load Cases are derived mainly based on the operational conditions (see Section 2/3), hull loading conditions (see Subsection 2/5), dominant load parameters (see Subsection 2/7) and environmental conditions (see Section 3). The loads are to include both the static and dynamic parts of each load component.

A Load Case represents the combined effects of a dominant load and other accompanying loads due to external wave pressures, container loads, internal tank pressures and inertial loads on the structural components and equipment. In quantifying the dynamic part of a load, it is necessary to consider a range of wave frequencies and headings, which produce the considered critical responses of the structure. The developed Load Cases are then used in the FE analysis to determine the resulting stresses and other load effects within the hull structure.

3 Operational Conditions

Following the operational consideration commonly used by IACS, the vessel speed in a severe sea state is to be significantly reduced in a voluntary and involuntary manner. In these Guidance Notes, for a full form vessel with block coefficient greater than or equal to 0.7, the vessel speed is assumed to be zero in design wave conditions. For a vessel with block coefficient less than 0.7, the vessel speed is assumed to be five knots.

5 Loading Conditions

The loading conditions herein refer to container cargo conditions that should be used for DLA analysis for container carriers.

The following three cargo loading conditions, typically found in the Loading Manual, are provided as a guideline to the most representative loading conditions to be considered in the DLA analysis for container carriers.

i) Full load condition at design draft

ii) Light container full load condition with maximum SWBM amidships

iii) Partial load or jump load condition with highest GM

Other loading conditions which may be deemed critical are also to be considered in the analysis. The need to consider other conditions or additional ones should be determined in consultation with the Bureau.

7 Dominant Load Parameters (DLPs)

The term, "Dominant Load Parameter (DLP)" refers to a global load or ship motion (such as hull girder bending moment or roll motion). These parameters are to be maximized to establish Load Cases for the FE analysis.

For the DLA analysis of container carriers, five Dominant Load Parameters have been identified as necessary to develop the Load Cases. These five DLPs are as follows:

i) Vertical bending moment, (*VBM*)

ii) Horizontal bending moment, (*HBM*)

iii) Vertical acceleration at bow, (V_{acc})

iv) Torsional moment, (*TRM*)

v) Roll angle, (Φ)

The above-mentioned DLPs are to be assessed for their maximum values in two directions (i.e., hogging and sagging conditions for vertical bending moment).

7.1 Maximum *VBM*

i) Vertical bending moment, (+) hogging

ii) Vertical bending moment, (–) sagging

What is being referred to here is the DLP of maximum wave-induced VBM amidships. For the load cases including this DLP, it is to be combined with the appropriate SWBM.

7.3 Maximum *HBM*

i) Horizontal bending moment, (+) tension on the starboard side

ii) Horizontal bending moment, (–) tension on the port side

What is being referred to here is the DLP of maximum wave-induced HBM amidships.

7.5 Maximum V_{acc}

i) Vertical acceleration, (+) bow up

ii) Vertical acceleration, (–) bow up

What is being referred to here is the DLP of maximum vertical acceleration at bow. The typical reference points are shown in Section 2, Figure 1.

7.7 Maximum *TRM*

i) Torsional moment, (+) bow starboard down

ii) Torsional moment, (–) bow starboard up

What is being referred to here is the DLP of maximum torsional moment at five locations ($^1/_4$, $^3/_8$, $^1/_2$, $^5/_8$, $^3/_4$ of the vessel length).

7.9 Maximum Roll Angle

i) Starboard down

ii) Starboard up

In general, both conditions *i)* and *ii)* should be considered, as condition *i)* may not be exactly opposite to condition *ii)* in terms of the wave profile at the side shell.

9 Other Accompanying Load Components

The other accompanying load components are the load components that are considered to be simultaneously acting when the Dominant Load Parameter reaches its maximum for the equivalent design wave. The method to determine the equivalent design wave for each Load Case is presented in Section 5. Calculation methods to develop the accompanying load components are presented in later Sections as follows.

- Section 6 – external hydrodynamic pressures
- Section 7 – container cargo loads
- Section 8 – internal tank pressures
- Section 9 – inertial loads from the structural components

11 Miscellaneous Loads

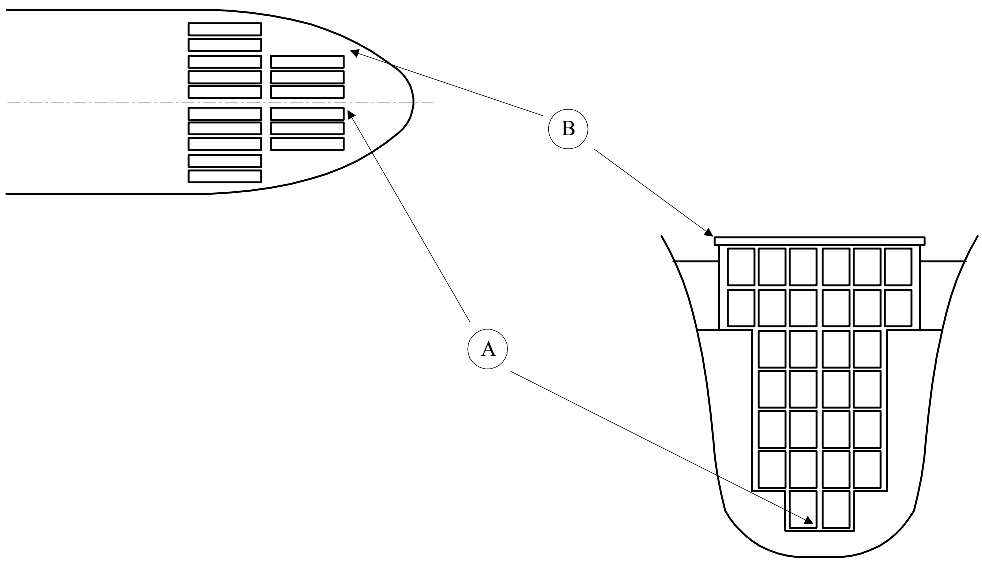
Other loads due to wave impacts on the bow flare and bottom slamming, green seas and ice floe impacts affect local structural strength and have to be treated. These are not included in this document, but the loads resulting from these considerations are to be treated in accordance with the current ABS *Steel Vessel Rules* requirements.

13 Load Cases

Load Cases are the cases to be investigated in the required structural FE analysis for DLA. Each Load Case (LC) is defined by a combination of a cargo loading condition (Subsection 2/5), a specified DLP (Subsection 2/7), other loads accompanying the DLP (Subsection 2/9) and a design wave system (Section 5) for the particular DLP of interest.

A large number of Load Cases will result (cargo loading conditions times the number of DLPs). Each LC is to be examined by performing the seakeeping and load analyses of Section 4. In general, not all the LCs may need to be included in the FE structural analysis. If necessary, the analyst may judiciously screen and select the most critical LCs for the comprehensive, global structural analyses of Section 10.

FIGURE 1
Representative Locations for Accelerations



FOUNDED 1862 ABS

SECTION 3 Environmental Condition

1 General

For a container carrier, environmentally-induced loads are dominated by waves, which are characterized by significant heights, spectral shapes and associated wave periods.

Unless otherwise specified, the vessel is assumed to operate for unrestricted service in the North Atlantic Ocean. IACS Recommendation No.34 (Nov. 2001) provides the standard wave data for the North Atlantic Ocean. It covers areas 8, 9, 15 and 16 of the North Atlantic defined in IACS Recommendation No. 34. The wave scatter diagram is used to calculate the extreme sea loads. In general, the long-term response at the level of 10^{-8} probability of exceedance ordinarily corresponds to a return period of about 25 years.

3 Wave Scatter Diagram

The wave scatter diagram provides the probability or number of occurrences of sea states in a specified ocean area. Section 3, Table 1 shows the wave scatter diagram recommended by IACS for the North Atlantic. For a given zero-crossing period, T_z, and significant wave height, H_s, each cell represents the number of occurrence of the sea state out of the 100,000 normalized sea states.

5 Wave Spectrum

The two-parameter Bretschneider spectrum is to be used to model the open sea wave conditions and the "cosine squared" spreading is to be applied to model the short-crest waves. The wave spectrum is given by:

$$S(\omega) = \frac{5\omega_p^4 H_s^2}{16\omega^5} \exp\left[-1.25(\omega_p / \omega)^4\right]$$

where

S	=	wave energy density, m^2-sec
ω	=	angular frequency of wave component, rad/sec
ω_p	=	peak frequency, rad/sec
	=	$2\pi/T_p$
H_s	=	significant wave height, m

TABLE 1
IACS Wave Scatter Diagrams for the North Atlantic

	T_z (sec)																
H_s (m)	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**	**16.5**	**17.5**	**18.5**	Sum
0.5	1.3	133.7	865.6	1186.0	634.2	186.3	36.9	5.6	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3050
1.5	0.0	29.3	986.0	4976.0	7738.0	5569.7	2375.7	703.5	160.7	30.5	5.1	0.8	0.1	0.0	0.0	0.0	22575
2.5	0.0	2.2	197.5	2158.8	6230.0	7449.5	4860.4	2066.0	644.5	160.2	33.7	6.3	1.1	0.2	0.0	0.0	23810
3.5	0.0	0.2	34.9	695.5	3226.5	5675.0	5099.1	2838.0	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0.0	19128
4.5	0.0	0.0	6.0	196.1	1354.3	3288.5	3857.5	2685.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0.0	13289
5.5	0.0	0.0	1.0	51.0	498.4	1602.9	2372.7	2008.3	1126.0	463.6	150.9	41.0	9.7	2.1	0.4	0.1	8328
6.5	0.0	0.0	0.2	12.6	167.0	690.3	1257.9	1268.6	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1	4806
7.5	0.0	0.0	0.0	3.0	52.1	270.1	594.4	703.2	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1	2586
8.5	0.0	0.0	0.0	0.7	15.4	97.9	255.9	350.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1	1309
9.5	0.0	0.0	0.0	0.2	4.3	33.2	101.9	159.9	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1	626
10.5	0.0	0.0	0.0	0.0	1.2	10.7	37.9	67.5	71.7	51.5	27.3	11.4	4.0	1.2	0.3	0.1	285
11.5	0.0	0.0	0.0	0.0	0.3	3.3	13.3	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1	124
12.5	0.0	0.0	0.0	0.0	0.1	1.0	4.4	9.9	12.8	11.0	6.8	3.3	1.3	0.4	0.1	0.0	51
13.5	0.0	0.0	0.0	0.0	0.0	0.3	1.4	3.5	5.0	4.6	3.1	1.6	0.7	0.2	0.1	0.0	21
14.5	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0.0	0.0	8
15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0.0	0.0	3
16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	1
Sum	1	165	2091	9280	19922	24879	20870	12898	6245	2479	837	247	66	16	3	1	100000

SECTION 4 Analysis for Vessel Motion, Wave Load and Extreme Value

1 Overview

This Section lists essential features about the calculation of ship motions and wave-induced loads. It is expected that such calculations will be made using the Spectral-based approach, which by definition relies on the use of Response Amplitude Operators (RAO's). Each RAO is to be calculated for regular waves of unit amplitude for ranges of wave frequencies and wave headings that will be given below. This Section also specifies the expected outcome of analysis to establish an Extreme Value of a Dominant Load Parameter.

3 Still-water Loads

With the input of Hull Loadings (see Subsection 2/5), the hull girder shear force and bending moment distributions in still water are to be computed at a sufficient number of transverse sections along the hull's length, in order to accurately take into account discontinuities in the weight distribution. A recognized hydrostatic analysis program is to be used to perform these calculations. By iteration, the convergence of the displacement, Longitudinal Center of Gravity (LCG), and trim should be checked to meet the following tolerances:

Displacement:		± 1%
Trim:		± 0.5 degrees
Draft:		
	Forward	± 1 cm
	Mean	± 1 cm.
	Aft	± 1 cm
LCG:		± 0.1% of length
SWBM:		± 5%

Additionally, the longitudinal locations of the maximum and the minimum still-water bending moments and, if appropriate, that of zero SWBM should be checked to assure proper distribution of the SWBM along the vessel's length.

5 Essential Features of Spectral-based Analysis of Motion and Wave Load

5.1 General Modeling Considerations

There should be sufficient compatibility between the hydrodynamic and structural models so that the application of fluid pressures onto the finite element mesh of the structural model can be done appropriately.

5.3 Diffraction-Radiation Methods

Computations of the wave-induced motions and loads are to be carried out through the application of seakeeping analysis codes utilizing three-dimensional potential flow-based diffraction-radiation theory. All six degrees-of-freedom rigid-body motions of the vessel are to be accounted for and the water depth is to be considered. These codes, based on linear wave and motion amplitude assumptions, make use of boundary element methods with constant-source panels over the entire wetted surface of the hull, on which the hydrodynamic pressures are computed.

5.5 Panel Model Development

Boundary element methods, in general, require that the wetted surface of the vessel be discretized into a large number of panels.

5.7 Vessel Motion and Wave Load Response Amplitude Operators

RAOs are to be calculated for the DLPs for each Load Case, selected per Subsection 2/13. Only these DLPs need to be considered for the calculation of extreme values. The RAOs should represent the pertinent range of wave headings (β), in increments not exceeding 15 degrees from following seas (0 degrees) to head seas (180 degrees). The RAOs should also represent a sufficiently broad range of wave frequencies. The recommended range is 0.2 radians/second (rad/s) to 1.8 rad/s, in increments of 0.05 rad/s.

The worst wave frequency-heading (ω, β) combination is to be determined from an examination of the RAOs for each DLP. Only the heading β and the wave frequency ω at which the RAO of the DLP is a maximum need to be used in further analysis. In general, it may be expected that *VBM* will be maximum in head seas, while maximum *HBM*, V_{acc}, *TRM* and Φ are realized in oblique seas. Precise headings at which these are maximum can be determined from the RAO analysis output. In addition, RAOs for the other load components accompanying the DLPs (see Subsection 2/7) are to be determined.

5.9 Roll Damping Model

The roll motion of the vessel in oblique waves is greatly affected by the viscous roll damping of the hull, especially near the roll resonance. For seakeeping analysis based on the potential flow theory, a proper viscous roll damping modeling should be introduced in the panel method. Experimental data or empirical methods for the roll damping model can be used for the determination of the viscous roll damping of the hull in consultation with ABS. The roll damping effects due to the rudders and bilge keels should also be considered in the seakeeping analysis. If this information is not available, a 10% of critical damping may be used for the overall viscous roll damping.

7 Extreme Values for DLA Analysis

Long-term extreme values are to be calculated for the Dominant Load Parameters described in Subsection 2/7 for various cargo loading conditions using the Dominant Load Parameter RAO's and wave data. The long-term extreme value refers to the long-term most probable value at the exceedance probability level of 10^{-8} corresponding to an approximately 25-year service life of the vessel.

The short-term responses are first to be calculated based on the Dominant Load Parameter RAO's described in Subsection 4/5 and wave spectra. Using the short-term responses and wave statistics consisting of scatter diagram, the long-term extreme values are to be calculated. The wave data to be used in the analysis are specified in Section 3.

7.1 Short-Term Response

In calculating the short-term response, the spectral density function $S_y(\omega)$ of the wave-induced response is to be calculated, within the scope of linear theory, from the following equation for a particular wave spectrum

$$S_y(\omega) = S_\zeta(\omega)|H(\omega)|^2$$

In the above equation, $S_\zeta(\omega)$ represents the wave spectral density function and $H(\omega)$ represents the response amplitude operator at the frequency denoted by ω. The zero-th and second moments of S_y, denoted by m_0 and m_2, are computed by:

$$m_0 = \int_0^\infty S_y(\omega)d\omega$$

$$m_2 = \int_0^\infty \omega^2 S_y(\omega)d\omega$$

where ω is the wave frequency. For the vessel cruising with a forward speed, U, the moments of the response spectrum are given by:

$$m_n = \int_0^\infty {\omega_e}^n S_y(\omega)d\omega$$

where ω_e is the encounter frequency defined by:

$$\omega_e = \left| \omega - U\frac{\omega^2}{g}\cos\beta \right|$$

Assuming the wave-induced response is a Gaussian stochastic process with zero mean and the spectral density function $S_y(\omega)$ is narrow banded, the probability density function of the maxima (peak values) can be represented by a Rayleigh distribution. The probability of the response exceeding x_0, $\Pr\{x_0\}$ in the short-term prediction is calculated by:

$$\Pr\{x_0\} = \exp\left(-\frac{x_0^2}{2m_0} \right)$$

7.3 Long-Term Response

Assuming the probability function for the maxima of each short-term response follows a Rayleigh distribution, the long-term probability of the response exceeding x_0, $\Pr\{x_0\}$ is calculated by a summation of the joint probability over the short-term sea states:

$$\Pr\{x_0\} = \sum_j p_j \Pr_j\{x_0\}$$

where p_j is the probability of occurrence of the j-th sea state given in the wave scatter diagram and $\Pr_j\{x_0\}$ is the j-th short-term probability of the response exceeding x_0. An equal probability of wave headings is assumed. The probability $\Pr\{x_0\}$ is related to the total number of DLP cycles in which the DLP is expected to exceed the value x_0. Denoted by N, the total number of cycles, the relationship between the probability and N is:

$$\Pr\{x_0\} = \frac{1}{N}$$

The term $1/N$ is often referred to as the probability level. Using the relation given by the last equation, the DLP exceeding the value x_0 can be obtained for a probability level.

An alternative extreme value prediction method, such as Ochi's method considering the bandwidth of the spectra may also be used. A useful reference to explain concepts and terminology associated with extreme value analysis is "Wave Statistics for the Design of Ships and Ocean Structures", by M.K.Ochi, SNAME Transactions, Vol. 86, 1978, pp. 47-76.

The relevant value to be obtained from the long-term analysis is the Long-Term Response (LTR) having an exceedance probability level of 10^{-8}. This probability level is ordinarily considered to be equivalent to the service lifetime maximum of twenty-five years.

Considering the design principle on the operational considerations commonly used by IACS, however, the extreme values of the DLPs for *HBM*, *TRM*, V_{acc} and Roll (Φ) in oblique seas or beam seas are to be annual maximum at the probability level of $10^{-6.5}$, while the extreme value of the DLP for *VBM* in head seas corresponds to the lifetime maximum.

SECTION 5 Equivalent Design Wave

1 General

An equivalent design wave is a sinusoidal wave characterized by its amplitude, length (or frequency), heading and crest position (or phase angle) relative to the Longitudinal Center of Gravity (LCG) of the hull. For each Load Case, an equivalent wave is determined which simulates the magnitude and location of the extreme value of the Dominant Load Parameter of the Load Case.

The procedure to be used to determine the equivalent design wave parameters is given below in Subsections 5/3 to 5/7. Subsection 5/9 describes the formulations to establish the magnitude and distribution of the other load components accompanying the extreme value of the Dominant Load Component in a Load Case.

3 Equivalent Wave Amplitude

The wave amplitude of the equivalent design wave is to be determined by dividing the extreme value of a DLP (see Subsection 4/7) under consideration by the RAO value of that DLP occurring at the wave frequency and wave heading corresponding to the maximum amplitude of the RAO.

The wave amplitude of the sinusoidal wave is given by:

$$a_w = \frac{LTR_j}{RAO_j^{\max}}$$

where

a_w = wave amplitude of the j-th DLP, see Section 5, Figure 1

LTR_j = Long-Term Response of the j-th DLP at given probability level

$RAO_j^{\max}$ = maximum RAO of the j-th DLP

5 Wave Frequency and Heading

The wave frequency and heading of the equivalent design wave for each DLP are determined from the peak value of the RAO of the DLP. When the RAO is maximum, the corresponding wave frequency and heading is denoted by (ω, β). The wavelength of the equivalent wave system is calculated by:

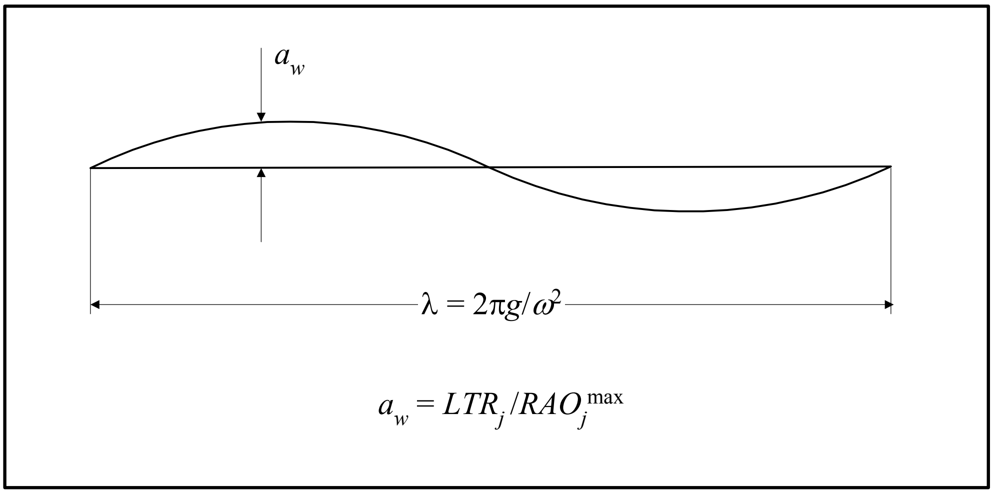
$$\lambda = (2\pi g)/\omega^2$$

where:

λ = wavelength

g = gravitational acceleration

FIGURE 1
Determination of Wave Amplitude



7 Phase Angle and Wave Crest Position

With the wavelength, amplitude and direction from Subsections 5/3 and 5/5, the wave crest position is calculated with respect to the LCG of the hull by:

$$X = (\lambda \in)/(-360 \cos \beta)$$

where

X = wave crest position with respect to the LCG for which the j-th DLP is at its extreme value

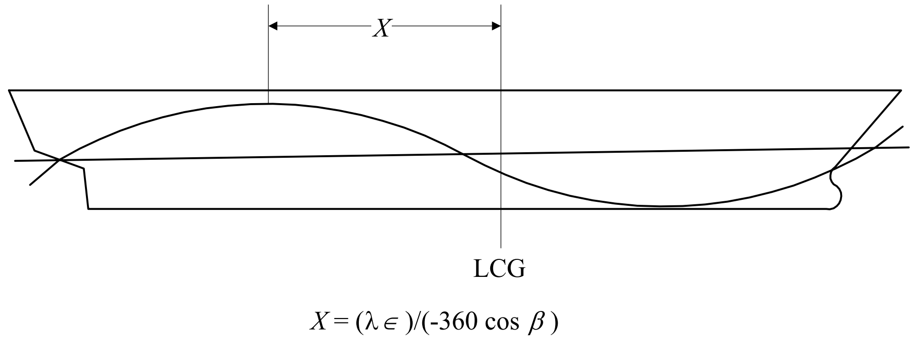
λ = wave length

$\in$ = phase angle of the j-th DLP, in degrees.

β = wave heading

Section 5, Figure 2 illustrates the crest position X.

FIGURE 2
Phase Angle and Crest Position



It should be noted that X is undefined in beam seas (β = 90° or 270°). Instead, the wave crest position from the centerline of the vessel in the y (transverse) direction is given by:

$Y = (\lambda \in)/(-360 \sin \beta)$

9 General Procedure to Determine Other Accompanying Load Components in a Load Case

For the equivalent wave, the longitudinal distribution of the other wave-induced motions and the other Load Components accompanying the Dominant Load Component in a Load Case are calculated using the following equation:

$M_i = RAO_i\, a_w \sin(\omega_e t + \in_i)$

where

M_i	=	i-th (other) load effect being considered (i.e., vertical bending moment and shear force, external and internal pressures, or acceleration at selected points)
RAO_i	=	amplitude of the other load component's RAO at the wave frequency and heading (ω, β) corresponding to the peak of the j-th DLP
a_w	=	equivalent wave amplitude of the j-th DLP
ω_e	=	encounter frequency of the equivalent wave when the RAO of the DLP reaches its maximum (See Subsection 4/7.1)
$\in_i$	=	phase angle of the other load component's RAO
t	=	specific time that the DLP under consideration reaches its maximum

The above equation is to be applied to motions, accelerations, hydrodynamic pressures and the bending moments and shear forces at the selected stations and the internal tank pressures. The specific use of this approach for particular load components is given in the next several Sections.

11 Special Procedure to Adjust EWA in Maximum Hogging and Sagging Moment Load Cases

The extreme values of DLP for wave-induced vertical bending moments of 2/7.1 are to be determined based on IACS UR S11. For the vertical bending moment Load Cases of 2/7.1, the wave-induced hogging moment of UR S11 shall be the maximum design wave-induced hogging moment to be used for the adjustment of the equivalent wave amplitude. After the pressure adjustments described in Subsection 6/9, the adjusted EWA generated wave-induced hogging moment is to equal the corresponding IACS hogging moment. To achieve this, the following iteration process of EWA adjustment is required:

i) The wave system (defined by EWA, wave frequency, wave heading angle and wave crest location) determined by the long term extreme analysis can be used as the initial wave system. The only iteration-involved parameter in the wave system is the EWA.

ii) The EWA needs to be repeatedly adjusted through an iteration scheme until its generated wave-induced hogging moment, after the pressure adjustments, equals the IACS value.

iii) This EWA iteration process is to be applied to a full load condition. The EWA determined for the full load condition shall be applied to all other cargo loading conditions for the vertical bending moment DLP load cases.

The same adjusted EWA value determined by the maximum hogging load case is also to be applied to the maximum sagging load case. Because of the finer hull form of containerships, the wave-induced sagging moment computed using the adjusted EWA value would result in a larger wave-induced sagging moment than that specified in IACS UR S11 due to the nonlinear effect of the hull form near the waterline. It should be noted that the sagging moment in UR S11 is based on tankers with full hull forms.

SECTION 6 External Hydrodynamic Pressure

1 General

The hydrodynamic pressures Response Amplitude Operators (RAO) on the wetted hull surface are to be calculated for the vessel in regular waves.

3 External Pressure Components

The total hydrodynamic pressure is to include the pressure components due to waves and the components due to vessel motion. Components of the hydrodynamic pressure are to be calculated from the panel model analysis of Subsection 4/5.

5 Pressures Accompanying the Dominant Load Component and Their Distribution

The external pressure is calculated either as a complex number or in terms of the amplitude and phase. Then, 'simultaneously' acting pressures, P_t, over the wetted surface can be represented in the form:

$$P_t = RAO_{prs}\, a_w \sin(\omega_e t + \epsilon_i)$$

where

RAO_{prs} = amplitude of the pressure RAO

ϵ_i = phase angle of the pressure RAO

a_w, ω_e and t are as defined in Subsection 5/9.

7 Pressure Loading on the Structural FE Analysis Model

The pressure distribution over a hydrodynamic panel model may be too coarse to be used in the structural FE analysis. Therefore, it is necessary to interpolate the pressures over the finer structural mesh. Hydrodynamic pressure can be linearly interpolated to obtain the pressures at the nodes of the structural FE analysis model.

9 Pressure Adjustments near the Waterline

Linear seakeeping theory only provides the hydrodynamic pressure distribution below the mean waterline. Without any pressure adjustment, the wave-induced hogging and sagging moments on a vessel will be equal but with opposite signs. Therefore, the pressure distribution obtained from the linear seakeeping analysis is to be adjusted near the mean waterline in order to better reflect the nonlinear nature of a wave in the region.

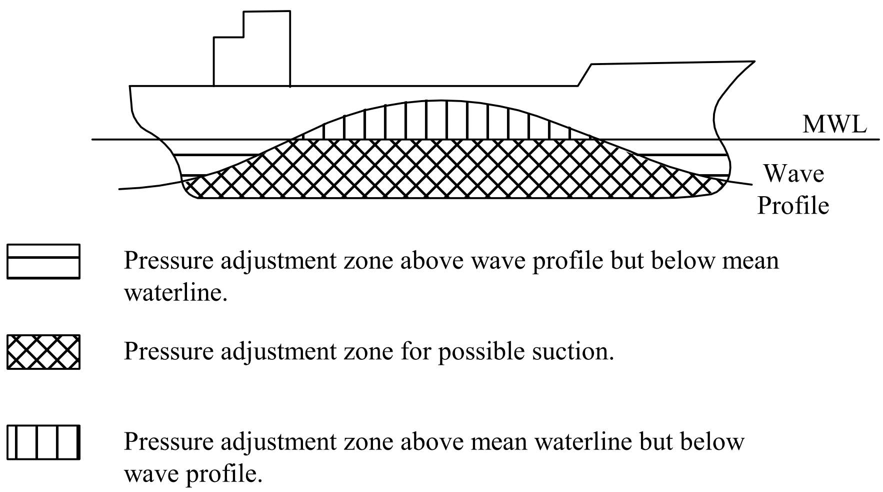
i) The pressure value must be set to zero at any pressure point above the wave surface profile but below the mean waterline.

ii) Total (hydrostatic plus hydrodynamic) suction pressure at any pressure point below the mean waterline must be set to zero. This adjustment can be done by simply setting the hydrodynamc pressure to the negative value of the hydrostatic pressure at the same point.

iii) The pressure at any point above mean waterline but below the wave surface profile needs to be accounted for in wave load calculations. This adjustment can be achieved by adding in a hydrostatic pressure calculated based on the water head measured from the wave surface profile to the pressure point. This pressure addition will be treated as wave induced pressure although it is calculated from a static pressure formula.

Section 6, Figure 1 illustrates the aforementioned pressure adjustment zones below and above the mean waterline. The wave-induced hogging and sagging moments will usually be different in both values and signs after these pressure adjustments. It should be noted that the above pressure adjustments need to be applied to all load cases, regardless of the DLPs defining the load cases.

FIGURE 1
Pressure Adjustment Zones



SECTION 7 Container Load

1 General

The loads on hull structure resulting from the containers in cargo holds and on deck are to be calculated and applied to the structural model for FE analysis. Static and dynamic container loads should be included in the analysis assuming that there is no relative motion between the hull and containers.

The ballast and fuel oil of the inner bottom and wing tanks should be calculated in the DLA analysis in accordance with the ABS *Guidance Notes on 'SafeHull-Dynamic Loading Approach' for Tankers*.

3 Load Components

The container load is composed of static and dynamic load components. The static component results from gravity, considering the instantaneous roll and pitch inclinations of the vessel. The dynamic component is due to the acceleration of the container cargo caused by the ship motions in six degrees-of-freedom. The ship motions should be obtained from the motion analysis presented in Section 4.

3.1 Static Load

The static load due to gravity can be decomposed into the vertical and transverse components of the container loads. The vertical container load on the bottom or on deck due to the roll inclination is expressed as:

$$F_V = mg \cos \alpha$$

where

m = mass of the container

α = roll angle

The vertical load due to a stack of containers may be summed and applied to appropriate nodes on the bottom plate. Total vertical load due to the containers on deck may be applied to the appropriate nodes on the hatch coaming top plates. The transverse load is expressed as

$$F_V = mg \sin \alpha$$

The transverse load due to containers may be distributed to appropriate nodes on the bulkhead structure via the container cell guide. The total transverse load due to the containers on deck may be applied to the appropriate nodes on the hatch coaming top plates via the container lashing system. The formulas given above can also be used for pitch inclination by replacing the roll angle with pitch angle.

The inclination of the hold due to roll and pitch of the vessel should be considered in the calculation of the container cargo load. The direction of gravitational forces in the vessel's fixed coordinate system varies with the roll and pitch inclination resulting in a change of the magnitude of vertical, transverse, and longitudinal loads.

3.3 Dynamic Load

The dynamic load is due to the instantaneous accelerations of the container as calculated at the CG of the container in conjunction with the maximum value of Dominant Load Parameters. In the procedure, the vertical, transverse and longitudinal accelerations due to ship motions are defined in vessel's fixed coordinate system, therefore transformation of the acceleration to the vessel system due to roll and pitch inclinations is not needed.

The dynamic load due to vertical acceleration is calculated by:

$$N_V = ma_V$$

where

N_V = vertical component of dynamic container load

a_V = vertical acceleration

The dynamic load due to transverse acceleration is calculated by:

$$N_T = ma_T$$

where

N_T = transverse component of dynamic container load

a_T = transverse acceleration

The above formula can also be used for dynamic load due to longitudinal acceleration by replacing the transverse acceleration with longitudinal acceleration. The vertical, transverse and longitudinal components of dynamic load can also be applied to FE model similarly to the static load as described in Subsection 8/3. The total load can be obtained by summing the static and dynamic container cargo loads.

FIGURE 1
Vertical and Transverse Force Components of Static Load

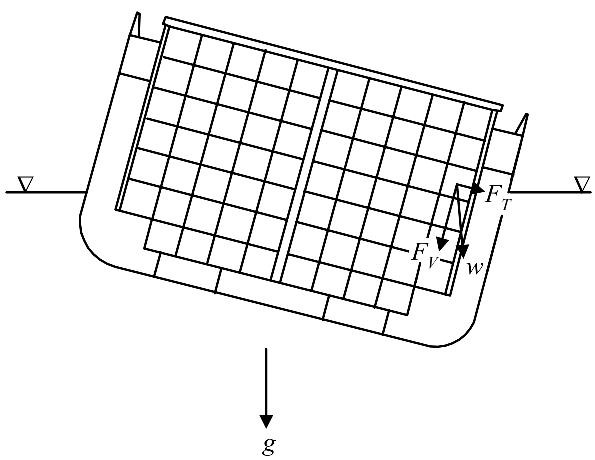
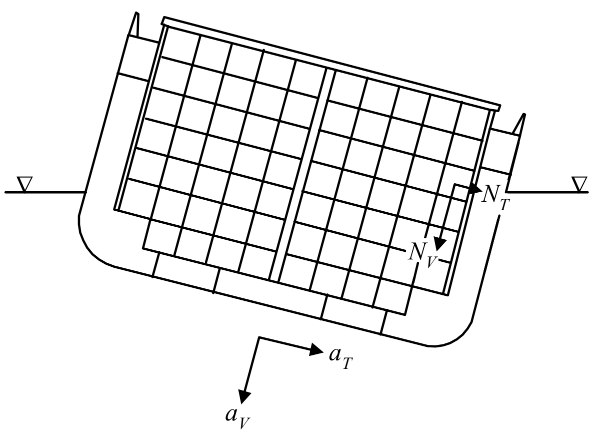


FIGURE 2
Dynamic Load due to Acceleration



5 Acceleration RAO at the CG of the Container

The acceleration RAO at the CG of a container due to the ship motions can be calculated by the following formula:

$$RAO_{acc} = (R \times \theta)\ \omega_e^2 + a$$

where

R	=	distance vector from the vessel's center of gravity (CG) to the CG of the container
θ	=	rotational motion vector
a	=	translational acceleration vector

ω_e is as defined in Subsection 5/9.

For the transverse and longitudinal acceleration RAO, the components of the gravitational acceleration due to the vessel's roll and pitch inclinations are to be included in the vessel's coordinate system.

7 Simultaneously Acting Container Load

For each load case described in Subsection 2/13, simultaneously-acting container loads (static and dynamic) are to be calculated. Each load case is defined by equivalent wave amplitude, frequency and heading angle and wave crest position as explained in Section 5. Using the wave amplitude and phase angle determined based on the RAO of a Dominant Load Parameter, the simultaneously-acting container load is calculated at the specific time when each of the DLP reaches its maximum value. These simultaneously-acting container loads are to be used in the structural FE model. The 'simultaneously'-acting three-component accelerations, A_t, at the CG of the container can be determined by an equation of the following form:

$$A_t = RAO_{acc}\ a_w \sin(\omega_e t + \epsilon_i)$$

where

RAO_{acc}	=	amplitude of the acceleration RAO
ϵ_i	=	phase angle of the acceleration RAO

a_w, ω_e, and t are as defined in Subsection 5/9.

This Page Intentionally Left Blank

SECTION 8 Inertial Loads for Lightship Weights

1 General

Local accelerations at points where the weight of the lightship structure is located should be calculated to determine their inertial loads.

3 Local Acceleration

The local acceleration RAO at a location of interest can be calculated by the following formula:

$$RAO_{acc} = (R \times \theta)\ \omega_e^2 + a$$

where:

R = distance vector from the vessel's center of gravity (CG) to the point of interest

θ = rotational motion vector

a = translational acceleration vector

Gravitational terms due to quasi-static inclination of ship motion, such as pitch and roll, should be accounted for structural loads for FE analysis.

ω_e is as defined in Subsection 5/9. For the transverse and longitudinal acceleration RAO, the components of the gravitational acceleration due to the vessel's roll and pitch inclinations are to be included in the vessel's coordinate system.

5 Inertial Loads in the FE Structural Model

The acceleration is often calculated as a complex number or in terms of the amplitude and phase angle in real numbers. Using the amplitude and phase angle of the acceleration, 'simultaneously'-acting three-component accelerations, A_t, can be determined by an equation of the following form:

$$A_t = RAO_{acc}\ a_w \sin(\omega_e t + \epsilon_i)$$

where

RAO_{acc} = amplitude of the acceleration RAO

ϵ_i = phase angle of the acceleration RAO

a_w, ω_e and t are as defined in Subsection 5/9.

Once the acceleration is calculated, the inertial load is computed by:

$F = m\ A_t$

where

m = mass of the lumped weight of structural member

A_t = 'simultaneously'-acting three-component accelerations, as determined in Subsection 8/5

The inertial forces in three (global) directions are to be calculated and applied to the structural FE model.

SECTION 9 Loading for FE Global Structural Model

1 General

The Load Cases of Subsection 2/13 are to be applied to the global (whole vessel) structural analysis model described in Section 10 of these Guidance Notes. Each load case needs to also include the static load components that have not been otherwise directly included in the load component determination performed in accordance with Sections 6 and 8. These static load components are those caused, for example, by buoyancy or gravity, and should be included in the structural FE analysis.

In the application of loads to the structural model, caution should be taken in the interpolation of the pressure loading near regions where pressure changes sign.

3 Equilibrium Check

The model of the hull girder structure should be close to equilibrium when all the loads (static and dynamic) are applied.

The unbalanced forces in the model's global axis system for each Load Case need to be determined and resolved. The magnitudes of the unbalanced forces and the procedure used to balance the structural model in equilibrium prior to solution should be fully documented.

5 Boundary Force and Moment

When the FE analysis model considers only a portion of the vessel, boundary conditions are required at the end sections of the partial model. These conditions are represented by the instantaneous vertical and lateral shear forces and three moments at the instant of time when the Dominant Load Parameter reaches its maximum. The method to calculate the instantaneous loads is described in Section 5/9.

This Page Intentionally Left Blank

SECTION 10 Structure Analysis of the Hull Structure

1 General

The structural adequacy of the hull is to be examined by the Finite Element (FE) analysis using a global FE model representing the entire hull girder structure and finer mesh models for local structures. Results of nodal displacements or forces obtained from the global FE analysis are to be used as boundary conditions in the subsequent local FE analysis of local structures. For more details of modeling, refer to the ABS report RD-88024, "ABS Specification for the Structural Analysis of Containerships".

3 Structural Members

The following structural components are listed to indicate the important regions to be investigated in detail in the DLA Analysis.

i) Hatch coaming top plates, deck plating, longitudinal stiffeners and girders

ii) Bottom and inner bottom plating longitudinal stiffeners and girders

iii) Bulkheads

- Longitudinal
- Transverse
- Stringers

iv) Side shell plating, longitudinal stiffeners and frames

- Midship
- Forward
- Aft

v) Web frames

5 Global FE Analysis

The global structural and load modeling should be as detailed and complete as practicable. In making the model, a judicious selection of nodes, elements and degrees of freedom is to be made to represent the stiffness and mass properties of the hull, while keeping the size of the model and required data generation within manageable limits. Lumping of plating stiffeners, use of equivalent plate thickness and other techniques may be used for this purpose.

The finite elements, whose geometry, configuration and stiffness closely approximate the actual structure, can typically be of three types:

i) Truss or bar elements with axial stiffness only

ii) Beam elements with axial, shear and bending stiffness

iii) Membrane and bending plate elements, either triangular or quadrilateral

The DLA procedure is based on the use of gross or as-built scantlings.

7 Analyses of Local Structure

More detailed local stresses are to be determined by fine mesh FE analysis of local structures, based on the results of the global FE analysis. In the fine mesh models, care is to be taken to represent the structure's stiffness, as well as its geometry, accurately. Boundary displacements obtained from the global FE analysis are to be used as boundary conditions in the fine mesh analysis. In addition to the boundary constraints, the pertinent local loads should be reapplied to the fine-mesh models.

As applicable, the fine mesh models are to include at least the following local structures:

i) Main deck hatch corners and continuous hatch coaming top plate corners at the critical locations, as appropriate for the design

ii) Typical web frame at the mid-hold, as appropriate for the design

iii) Centerline and off-centerline longitudinal girder structure

iv) Selected side stringers which are expected to carry relatively high loads

v) Other areas of high stress indicated from the global FE analysis.

Where the global FE analysis of the vessel is not comprehensive enough to adequately determine the total stress in the longitudinal plating (e.g., deck and shell) and transverse bulkhead plating of the vessel, additional analyses may be required. Such analyses may not require the performance of fine mesh FE analysis, where the needed results can be provided by another acceptable method.

The element size in the coarse mesh global FE analysis may not be sufficient for a detailed stress analysis of a particular detail. Thus, fine mesh local analysis should be performed for structure details. In the fine mesh FE analysis, boundary forces or displacements obtained from the coarse mesh global analysis are to be used as boundary conditions. Using spring supports for this purpose is considered unreliable. In addition to the boundary constraints, all local loads are to be reapplied to the fine mesh models.

3-D fine mesh analysis should be performed if the local structure detail involves major stiffness in all three spatial planes and 2-D fine mesh analysis is not adequate. Such an example can be seen in some designs of deck hatch corner. In making 3-D fine mesh models, care shall be taken to represent the structure's stiffness, as well as its geometry, accurately.

8 Fatigue Assessment

Fatigue analysis of containerships in areas such as hatch corners is very important. Detailed spectral fatigue analysis is outside of the scope of the DLA analysis. The global and local FE models developed for DLA analysis can be used in spectral fatigue analysis. Detailed procedures for spectral fatigue analysis and the **SFA** notation are described in the ABS *Guidance Notes on Spectral-Based Fatigue Analysis for Vessels*.

SECTION 11 Acceptance Criteria

1 General

The adequacy of the FE analysis results is to be assessed for the failure modes of material yielding and buckling. Criteria for fatigue strength are provided in other ABS publications.

The evaluation for yielding and buckling of the primary internal supporting structure of the vessel should be based mainly on the results of fine mesh models where more accurate determination of local stress is required.

3 Yielding

For a plate element subjected to biaxial stress, a specific combination of stress components, rather than a single maximum normal stress component, constitutes the limiting condition. In this regard, the following equivalent stress, given by the Hencky von-Mises theory, is to be compared to a maximum allowable percentage of the material's yield strength:

$$\sigma_{HVM} = [\sigma_X^2 + \sigma_Y^2 - \sigma_X\sigma_Y + 3\,\tau_{XY}^2]^{1/2}$$

where

σ_X = normal stress in the X direction (local axis system of the element)

σ_Y = normal stress in the Y direction

τ_{XY} = shear stress

or using principal stresses, σ_1 and σ_2:

$$\sigma_{HVM} = [\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2]^{1/2}$$

The allowable von-Mises stress obtained from the finite element stress analysis is not to exceed 95 percent of the material's yield strength. Special consideration will be given to the configuration of contour brackets and cut out details.

5 Buckling

Plate panels, stiffened panels and primary supporting members are to be checked against buckling using stresses obtained from the FE analyses. For this purpose, established analytical or empirical formulas suitable to the hull structure are to be used.

For instance, the criteria given in 5-5-5/5.3.1 and 5-5-5/5.3.2 of the ABS *Steel Vessel Rules* (SafeHull criteria) can be used for this purpose after modification. Modification is required because the SafeHull criteria is meant to be applied to stresses obtained from analysis employing net structural scantlings and component strength formulations expressed in terms of net scantlings. Therefore, sufficiently appropriate modification entails:

i) Increasing the normal and shear stress components from the DLA FE Analysis by 10 percent, and

ii) Using in the SafeHull buckling strength formulations, net scantlings that are determined as equal to the gross thickness minus a value that is the lesser of 10 percent of the gross thickness or 1.5 mm.

The local stiffness and geometric proportions given in 5-5-A2/11 of the ABS *Steel Vessel Rules* to limit local buckling failures are to be observed in highly stressed areas.

Reference can also be made to Appendix 3-2-A4 of the ABS *Steel Vessel Rules*, for situations where these more limited criteria can be validly applied.

APPENDIX **Summary of Analysis Procedure**

1 General

Most of the concepts and analysis procedure introduced in these Guidance Notes are summarized in this Appendix. The general procedure outlined below is recommended for the Dynamic Load Approach analysis of container carriers. The DLA analysis carried out in accordance with this procedure and considering the loads as defined in Section 2 is deemed to be adequate to determine the controlling dynamic loadings acting on the hull structure of container carriers.

3 Basic Data Required

The following geometric and cargo loading information is required to perform the prescribed analysis:

i) Lines Plan and/or Offset Table

ii) General Arrangement

iii) Lightship weight curve

iv) Cargo weight distribution for each cargo loading condition

v) Principal Dimensions

vi) Drafts (forward and aft) for each cargo loading condition

vii) Longitudinal Center of Gravity (LCG) for each cargo loading condition

viii) Vertical Center of Gravity (VCG) for each cargo loading condition

ix) Roll radius of gyration (k_r) for each cargo loading condition

If this information is not available, the roll radius of gyration can be estimated by:

$k_r = 0.35B$ for full load

$k_r = 0.45B$ for ballast load

5 Hydrostatic Calculations

The steps involved in the hydrostatic calculations are as follows:

i) Prepare a hull offset file of the vessel utilizing the offsets from the Offset Table

ii) Discretize the lightship weight curve into a series of trapezoidal weight blocks. It should be noted that the finer the discretization, the more accurate the numerical modeling of the lightship weight distribution will be.

iii) Prepare the cargo loading weight information by identifying the location, longitudinal center of gravity and extent of each weight item given in the loading manual for the particular loading condition. Alternatively, the cargo weight distribution curve along the vessel's length can be discretized into a series of trapezoidal weight blocks similar to the lightship weight curve.

iv) Calculate the displacement, trim, drafts (FP and AP), longitudinal center of gravity and longitudinal distribution of still-water vertical shear force and bending moment using a seakeeping program based on the information obtained above.

v) The results of the hydrostatic calculations should be within acceptable tolerances specified in Subsection 4/2.

vi) The DLA criteria require the investigation of a series of Cargo Loading Conditions as outlined in Section 2. The above hydrostatic calculations are to be repeated for each of these Cargo Loading Conditions.

7 Response Amplitude Operators (RAO's)

i) Determine the response amplitude operators for Dominant Load Parameters. A computer program which employs linear potential theory using source-sink distribution method may be adequate for determining the RAOs. It is important that a broad range of wave frequencies are considered in this calculation. The recommended range of frequencies to be considered is 0.2 rad/sec to 1.8 rad/sec in increments of 0.05 rad/sec. The computer program PRECAL can be used for this purpose.

ii) The offset data, drafts and trim determined from the hydrostatic analysis described above are to be used in the determination of the RAOs.

iii) The RAOs are to be calculated for each of the Cargo Loading Conditions as outlined in Section 2.

iv) Subsequent calculations are to be performed to obtain the RAOs of the Load Components (e.g., external pressures, container loadings and inertial loads) specified in Subsection 2/5. Only one set of wave frequency and heading values is needed for each load case, rather than the full range of wave headings and frequencies. These RAOs of the load components are to be used to calculate the instantaneous values of the load components accompanying the DLP to be applied in the FE analysis. In order to determine the container loads, the RAOs of vertical, lateral and longitudinal accelerations at the CG of the containers are to be calculated.

9 Long-Term Extreme Values

i) Establish the appropriate wave environment for the intended vessel service. (This may be for either a route-specific service or unrestricted service, depending on which is more appropriate for the vessel's required classification). For unrestricted service vessels, the wave data should be representative of realistic sea conditions in the North Atlantic Ocean. It is recommended that IACS Recommendation No.34 be used for unrestricted service vessels. For unrestricted service, the probability of wave headings is to be equal.

ii) Determine the long-term extreme values of the Dominant Load Parameters, as specified in Section 2, at 10^{-8} probability level corresponding to 25 years service life. Following the operational considerations, however, the extreme values of the DLPs for *HBM*, *TRM* and V_{acc} in oblique waves are reduced to the annual maximum. The long-term extreme value predictions are to be carried out for each of the Cargo Loading Conditions specified in Section 2.

11 Instantaneous Load Components

i) *Equivalent Design Wave (see also Section 5).* Determine an equivalent design wave system corresponding to the instant of time when the Dominant Load Parameter being considered reaches its maximum. This wave system is determined by using the results of the RAO calculations and the long-term extreme value predictions. To determine this wave system, the following information must be captured from the RAO calculations:

- Maximum amplitude of the Dominant Load Parameter RAO
- Phase angle relative to the wave crest position at LCG corresponding to the maximum amplitude of the DLP RAO
- Wave heading corresponding to the maximum amplitude of the DLP RAO
- Wave frequency corresponding to the maximum amplitude of the DLP RAO
- Wave amplitude that is equivalent to the long-term extreme value divided by the maximum amplitude of the DLP RAO. For maximum vertical bending moment DLPs, the wave amplitude is determined based on the IACS UR S11 hogging wave moment. The procedures for the adjustment of EWA are described in Subsections 5/11 and 5/13.

ii) *External Pressure (see also Section 6).* Determine the external pressure loads corresponding to the instant of time when the Dominant Load Parameter being considered reaches its maximum. The RAO of the external pressures and the DLP, along with the equivalent design wave system, are used in the determination of the instantaneous external pressures, which are part of the input to the FE analysis.

The instantaneous external pressures at the nodes of the FE model are to be determined by interpolating the instantaneous external pressures calculated at the nodes of the hydrodynamic model. A computer program which employs three-dimensional linear interpolation techniques will be adequate for the determination of the external pressures on FE model. Also, the instantaneous external pressure near the mean waterline should be adjusted according to the procedure, as specified in Subsection 6/9.

iii) *Container Loads (see also Section 7).* Determine the container cargo loads at the hold boundaries or on deck corresponding to the instant of time when the Dominant Load Parameter being considered reaches its maximum. The container loads are to account for both the static and dynamic components. The static component of container loading is the load due to the gravitational acceleration of the container, taking into account the instantaneous roll and pitch inclinations. The formulae to calculate the static and dynamic components of container cargo loads are defined in Subsection 7/3.

iv) *Inertial Loads (see also Section 8).* Determine the local accelerations at points where the weight of the lightship structure is located corresponding to the instant of time when the Dominant Load Parameter being considered reaches its maximum. These instantaneous accelerations are used to calculate the inertial loads of the lightship structure which is an input to the FE analysis.

v) The DLA criteria require that a series of Load Cases based on the combination of Dominant Load Parameters and Cargo Loading Conditions are to be investigated. These Load Cases are outlined in Section 2.

13 Dynamic Loads as Input to the FE Analysis

The dynamic load components, as calculated in the above steps, are to be applied to the FE analysis for each of the Load Cases defined in Section 2. The dynamic load components to be applied in the analysis are as follows:

i) External pressure at the nodes of the FE models

ii) Container loading at the hold boundaries or on deck

iii) Inertial loads due to the acceleration of the vessel's lightship weight

15 Equilibrium Check

A check for the unbalanced forces from the application of the static and dynamic loads on the FE model is to be performed to determine whether or not they are within the following recommended allowable limits:

i) Load Cases for head sea conditions should be within 1% of the vessel's displacement

ii) Load Cases for oblique sea conditions should be within 2% of the vessel's displacement

iii) Load Cases for beam sea conditions should be within 2% of the vessel's displacement

These unbalanced forces, if any, should be accounted for by adding a suitably distributed inertial force to the vessel's loading prior to carrying out the FE analysis. This check of unbalanced force is performed to assure that the structure is in dynamic equilibrium with the applied instantaneous static and dynamic loads.

17 Global FE Analysis

i) Prepare a global FE model of the vessel, taking into account the structural and material properties of the vessel. It is recommended that the entire vessel be modeled. The global FE analysis allows detailed investigation of the structure at any location, thereby providing assurance that potential problem areas are identified at the earliest possible stage.

ii) The input loading to the global FE analysis consists of both static and dynamic components. The static components considered are the external pressures exerted on the hull in still water, the weight of the lightship structure, cargo and ballast water. The dynamic components are calculated in Subsection A/13.

iii) The global FE analysis is carried out to determine the global stresses and deflections due to the aforementioned static and dynamic loads. The global stresses are reviewed to determine which structural components are highly stressed. The high stress areas are identified as candidate structural components for in-depth examination via fine mesh local FE analysis, wherein the global deflections from the global FE analysis, are applied as input.

iv) The DLA criteria require that a series of Load Cases, as given in Section 2, be investigated in the global FE analysis.

19 Local FE Analysis

i) Prepare the finer mesh models as determined from the global FE analysis. These FE models are to be accurate numerical representations of the specific structural components, taking into account the actual geometry and stiffness characteristics of the structure.

ii) The input to such analysis consists of the deflection and boundary conditions identified from the global FE analysis.

iii) The finer mesh FE analysis for each structural detail is carried out to accurately identify the stresses. These stresses, in addition to identifying areas which may require modification to comply with the Rules criteria, can be used to refine the design of the structure while assuring the structural integrity of the vessel. The criteria to which the stresses are reviewed are outlined in Section 11. It should be noted that both the stress magnitude and stress range are to be considered in DLA analysis for hatch corners.

iv) The maximum stresses determined for each structural detail are to govern the design and determination of the structure's integrity.

21 Closing Comments

The primary intent of this analysis procedure is to address the necessary steps needed to generate the dynamic loads to be used in the FE analysis of a container carrier. The procedure for dynamic loading of container carriers described above outlines the "state-of-the-art" methods presently employed by ABS. As research in hydrodynamics identifies more advanced methods of analysis and as experience with newer designs for container carriers increases, modification of this procedure may be issued.

This Page Intentionally Left Blank