

‘DYNAMIC LOADING APPROACH’ FOR FLOATING PRODUCTION, STORAGE AND OFFLOADING (FPSO) INSTALLATIONS

MAY 2010

The following summarizes the colors corresponding to Rule Changes, Corrigenda items and editorial changes in the Guide files which are available for download.

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GUIDE FOR

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MAY 2010 (Updated January 2017 – see next page)

**American Bureau of Shipping
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- February 2014 version plus Corrigenda/Editorials

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- May 2010 version plus Corrigenda/Editorials

Foreword

This Guide provides information about the optional classification notation, Dynamic Loading Approach (**DLA**), which is available to qualifying ship-type “Floating Production Installations” (FPIs). This type of offshore installation is usually referred to as a “Floating Storage and Offloading (FSO) System”; or “Floating Production, Storage and Offloading (FPSO) System”, and “FPSO” is the term that will be used herein to denote these ship-type Floating Production Installations. Also, in the text herein, this document is referred to as the “Guide”.

Section 1-1-2 of the ABS *Rules for Building and Classing Floating Production Installations (FPI Rules)* contains descriptions of the various, basic and optional classification notations available. Part 5A of the *FPI Rules* gives the specific design and analysis criteria applicable to ship-type FPIs (new build ship-type installations and conversions to FPI).

In addition to the Rule design criteria, Dynamic Loading Approach based on first-principle direct calculations is acceptable with respect to the determination of design loads and the establishment of strength criteria for ship-type FPIs. In case of any conflict between this Guide and the *FPI Rules*, the latter has precedence.

This Guide represents the most current and advanced ABS DLA analysis procedure including linear and nonlinear seakeeping analysis. This Guide is issued May 2010, and is an extended edition of the ABS *Guidance Notes on SafeHull-Dynamic Loading Approach for Floating Production, Storage and Offloading (FPSO) Systems*, published in December 2001. Users of this Guide are welcomed to contact ABS with any questions or comments concerning this Guide. Users are advised to check periodically with ABS that this version of this Guide is current.



GUIDE FOR

'DYNAMIC LOADING APPROACH' FOR FLOATING PRODUCTION, STORAGE AND OFFLOADING (FPSO) INSTALLATIONS

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SECTION 1 Introduction

1 Background

The design and construction of the hull, superstructure, and deckhouses of a ship-type FPI that can be a new build or conversion are to be based on all applicable requirements of the ABS [Rules for Building and Classing Floating Production Installations \(FPI Rules\)](#). The design criteria for these structures, as given in the [FPI Rules](#), reflect the structural performance and demands expected of a floating production installation which is moored at a particular site on a long-term basis.

The design criteria for a ship-type installation are located in Part 5A, Chapters 1 through 4 of the [FPI Rules](#). Part 5A, Chapters 1, 2, and 3 are applicable to vessels of 150 meters (492 feet) or more in length, while Part 5A, Chapter 4, applies to vessels under 150 meters (492 feet) in length.

The FPI criteria contained in Part 5A of the [FPI Rules](#) entail a two-step procedure. The first step, referred to as the *Initial Scantling Evaluation (ISE)*, 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 *ISE* 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 FPI criteria, referred to as the *Total Strength Assessment (TSA)*, requires the performance of finite structural analysis using either a three cargo tank length model or cargo block length model, to validate the selected scantlings from the initial *ISE* phase. The main purpose of the *TSA* analysis 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 [FPI 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.

This Guide is applicable to ship-type installations of all size and proportions including new build ship-type FPI and conversions to FPI.

3 Concepts and Benefits of DLA Analysis

3.1 Concepts

The structural design portions of the [FPI Rules](#) (i.e., see especially Part 5A, Chapter 3) are intended to provide an appropriate and sufficient basis for the design and analysis of the hull structure of an FPSO. This was done by modifying tanker structural design criteria to reflect site-specific environmental loadings and other design features of an FPSO. The other design features include such items as possible turret based mooring, deck-mounted hydrocarbon processing equipment, etc. The [FPI Rules](#) includes provisions that address these matters with emphasis on the sequence, process and objectives of design, not on the structural analysis itself.

DLA is an analysis process, rather than the step-wise design oriented process that *FPI Rules* criteria is. 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. In a manner that is the converse of the *FPI Rules* criteria, in DLA the modeling and analysis process relies on performing multiple levels of analysis that start with an overall or global hull model, and the results of each previous level of analysis are used to establish areas of the structure requiring finer (more detailed) modeling and analysis, the local loading to be re-imposed and the 'boundary conditions' to be imposed on the finer model.

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

- i) Use of tank-loading patterns, other loading components, and vessel operating drafts that reflect the actual ones intended for the vessel (note that the Load Cases in the *FPI Rules* criteria comprise mainly those intended to produce 'scantling design controlling' situations).
- ii) Load components are combined to assemble each DLA Load Case. The dynamic related aspects of the components are incorporated in the model, and the combination of these dynamically considered components is accommodated in the analysis method.
- iii) The use of environmental and other load effects for the installation site directly considers the functional role of the FPI as a site-dependent structure, using 'design return' periods appropriate to this function. Also, the phasing and relative directionality that exist between environmental effects and the structure itself can be directly considered.
- iv) Because of the required extent of the structural modeling, the direct effects and the interaction between structural subsystems (such as mooring turret and main deck supported equipment modules) can be directly assessed.

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. An under-appreciated, but 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 FPI, such as structural damage, repairs or modifications, long distance ocean transit to a repair facility or redeployment to another installation site.

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 FPSO'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.

Note: This Guide considers dynamic effects produced almost exclusively by waves. As appropriate, the effects of wind may need to be combined with waves when developing some Load Cases, such as ones involving the DLP "Maximum Roll Angle." (see 2/7.9)

Examples of Dominant Load Parameters are “Vertical Hull Girder Bending Moment Amidships” and “Lateral Acceleration at the Vessel’s Forepeak Frame”. The specific Dominant Load Parameters that are recommended for inclusion in the DLA analysis of an FPSO are given in Subsection 2/7. 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, topside equipment weights, and mooring system forces.

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 vessel 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 this Guide, 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 Vessel 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 7, 8, and 9.

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 ‘Return Periods’ (or ‘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

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 hull structure should comprise the entire hull, the topside equipment support structure and the interface with a turret mooring system. The motion analysis may consider the effect of shallow water depth on vessel motions if its effect turns out to be critical in determining the vessel responses. There is also to be sufficient compatibility between the hydrodynamic and structural models so that the application of fluid pressures onto the Finite Element (FE) mesh of the structural model can be done appropriately.

For the load component types and structural responses of primary interest in the DLA, analysis software formulations derived from linear idealizations are deemed to be sufficient. However, the designer/analyst is encouraged to employ enhanced bases for the analysis, especially to incorporate non-linear loads (for example hull slamming), if this proves to be necessary for the specific design being evaluated. The designer/analyst needs to be aware that the adequacy of the selected software is to be demonstrated to the satisfaction of ABS.

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.

5 Notations

The **DLA** notation signifies the satisfaction of the DLA analysis procedure of this Guide. The notation DLA signifies:

- i) The design is based on an analysis which more explicitly considers the loads acting on structure and their dynamic nature, and
- ii) In no case is an offered design scantling to be less than that obtained from other requirements in the *FPI Rules*.

In this regard, all the supporting data analysis procedures and calculated results are to be fully documented and submitted for review. The submittals for review should include:

- i) A contract which clearly defines owner's specification other than standard requirement, or other critical information
- ii) Site meteorological data
- iii) Principal Dimensions, Lines and Trim/Stability booklet
- iv) Key drawings (General Arrangement, Midship section, Shell expansion, Construction profile and Deck plan)
- v) More drawings for Forebody/Aftbody, Typical bulkhead and Engine room
- vi) DLA analysis report detailing findings and identifying any inconsistencies, assumptions, and corrective actions
- vii) Seakeeping input/output files including DLPs' RAO and their extreme values
- viii) Structural FE model and its analysis results

7 Scope and Overview of the Following Sections

This Guide provides a description of the analysis procedure to be pursued to obtain the optional classification notation 'Dynamic Loading Approach', **DLA**. Emphasis is given here to 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 dynamic load determination is a less familiar subject. Therefore, the procedures for FE analysis are only briefly described for the purpose of ready reference and completeness.

The Dynamic Loading Approach uses explicitly determined dynamic loads, and the results of the analysis are used as the basis to increase scantlings where indicated, but allows no decreases in scantlings from those obtained from the direct application based on *FPI Rules* scantling equations.

While outside the scope of this Guide, any local impact pressure and global whipping loads due to slamming are to be separately addressed for the strength assessment of the hull structure. Also, any green sea loads due to the ingress of green water on deck is to be addressed for scantlings of the forecandle deck and breakwater. For this purpose, the adequacy of the selected software may need to be demonstrated to the satisfaction of ABS.

This Guide systematically introduces the assumptions in the load formulation and the methods used in the response analysis underlying the DLA Analysis for FPSOs. These include the following topics:

- i) Specification of the loading conditions
- ii) Specification of the Dominant Load Parameters
- iii) Response Amplitude Operators and extreme values
- iv) Equivalent design waves
- v) Wave-induced load components and the assembly of Load Cases
- vi) Structural FE model development; and

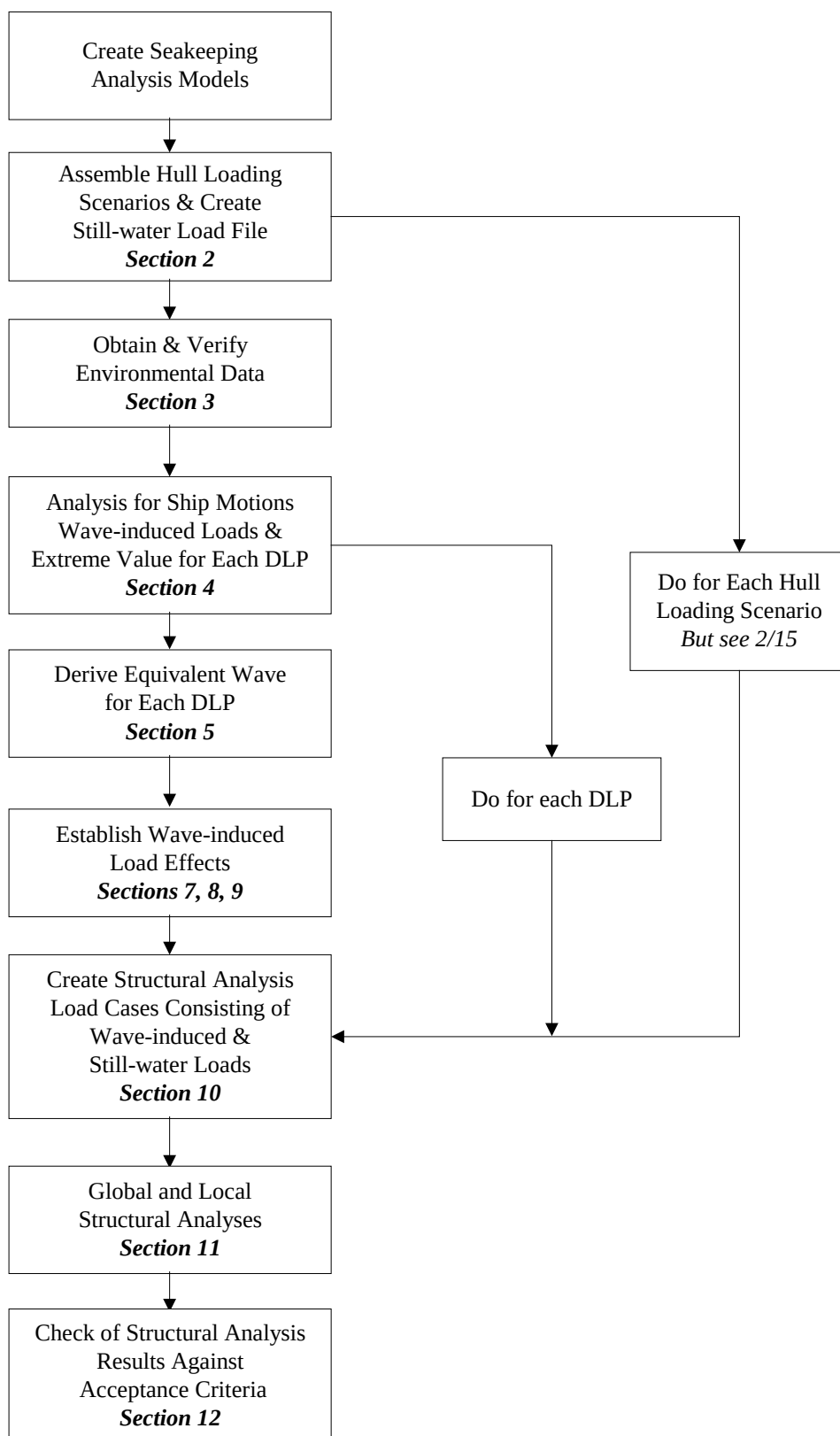
vii) Permissible stresses used in the acceptance criteria.

These topics are presented in the following Sections 2 through 12, and Appendix 1 summarizes the DLA analysis procedure.

Refer to Section 1, Figure 1 for a schematic representation of the DLA analysis procedure.

While the DLA can, in principle, be applied to all types of floating offshore structures, the focus of this Guide is on FPSOs. In the case of other ship types, clients should consult with ABS to establish appropriate analysis procedures. This applies particularly to the choice of loading conditions and Dominant Load Parameters. For trading ship types, designers can refer to the *ABS Guide for SafeHull-Dynamic Loading Approach for Vessels*.

FIGURE 1
Schematic Representation of the DLA Analysis Procedure





SECTION 2 Load Cases

1 Basic Considerations

The DLA Analysis requires the development of Load Cases to be investigated using the Finite Element Method (FEM) of structural analysis. The Load Cases are derived mainly based on the operational loading conditions (see Subsection 2/5), Dominant Load Parameters (see Subsection 2/7) and environmental conditions (see Section 3).

For each Load Case, the applied loads to be used for structural FE analysis 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 acting simultaneously on the hull structure including external wave pressures, 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 sea conditions and headings, which produce the considered critical responses of the hull 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 Vessel Speed

For the DLA analysis of an FPSO, the vessel speed is set to be zero for site-specific design wave conditions after installation and average transit speed for transit condition from the building or outfitting site (or the shipyard where the conversion modifications are made) to the project site.

5 Operational Loading Conditions

The design of an FPSO should consider the production rate, storage capacity and produced fluid's offloading capability. Hence, loading on the hull structure relates to the liquid cargo and ballast patterns, the vessel's draft and trim ranges, the deck loading from processing equipment and the loads resulting from the mooring system.

About five (5) to seven (7) tank loading pattern and hull draft conditions, typically found in the FPSO's Loading Manual, are to be selected as representative conditions in the DLA analysis. Also loading condition(s) representing major transportation phase(s) for the FPSO should be included in the DLA analysis. For example:

i) *On-site Operations:*

- Ballast or minimum draft condition after offloading (all cargo tanks empty)
- 2nd intermediate loading (33% filled)
- 3rd intermediate loading (tanks 50% filled)
- 4th intermediate loading (67% filled)
- Full-load condition at scantling draft or before offloading (tanks full)
- Inspection and repair conditions
- Tank testing conditions – during conversion and after construction (periodic survey)

Other cargo loading conditions that may be deemed critical can also be considered in the DLA analysis. The need to consider the other loading conditions or additional loading conditions is to be determined in consultation with ABS.

ii) *Transit:*

- Vessel Loading Pattern and Draft for the voyage from outfitting yard to the installation site.

Additionally, load conditions representative of other transit conditions, which are anticipated during the life of the FPSO, will need to be included in the scope of the DLA analysis.

7 Dominant Load Parameters

The term, Dominant Load Parameter (DLP) refers to a global load or motion effect of the hull (e.g., hull girder bending or vessel motion) that may yield the maximum structural response for critical structural members. The instantaneous response of the vessel can be judged by one of the several Dominant Load Parameters. These parameters are to be maximized to establish Load Cases for the FE analysis.

Ocean waves produce external dynamic pressures on the hull surface. These waves also induce vessel motions that produce load components in translational and rotational motion modes, and generate inertial forces through the acceleration of the structural, equipment and the internal fluid masses including ballast and cargo. Vessel motion responses in waves are calculated for the hull operational loading conditions. The important range of vessel response can be obtained by the use of a series of Dominant Load Parameters. For the DLA analysis of an FPSO, five Dominant Load Parameters have been identified as necessary to develop the Load Cases for the hull structure. These five DLP's are as follows:

- i) Vertical Bending Moment, (VBM)
- ii) Vertical Shear Force, (VSF)
- iii) Horizontal Bending Moment
- iv) Horizontal Shear Force
- v) Vertical acceleration (V_{acc})
- vi) Lateral acceleration (L_{acc})
- vii) Roll angle (Φ)

The vertical bending moment is to be assessed for both hogging and sagging conditions. Vertical bending moment and shear force are especially to be evaluated in way of an internally mounted mooring turret. Accelerations are to be determined at a sufficient number of process equipment locations to represent accurately the load effects arising from their motion. As appropriate, roll angle calculations may include simultaneous effects of waves and winds.

Other DLPs that may be deemed critical can also be considered in the DLA analysis. The need to consider other DLPs or additional DLPs is to be determined in consultation with ABS.

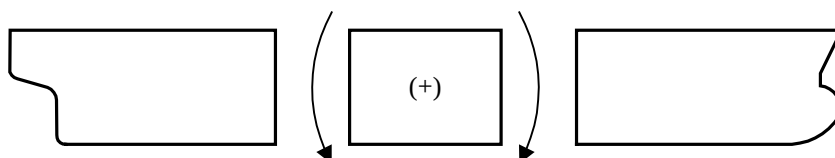
7.1 Maximum VBM

- i) Vertical bending moment amidships, (+) hogging (see Section 2, Figure 1)
- ii) Vertical bending moment amidships, (–) sagging

This DLP refers to the maximum wave-induced vertical bending moment amidships. For structural analysis load cases including this DLP, it is to be combined with the appropriate still-water VBM.

Note: Due account is to be given to the minimum design wave-induced VBM amidships as specified in Section 5A-1-2 of the *FPI Rules*.

FIGURE 1
Positive Vertical Bending Moment

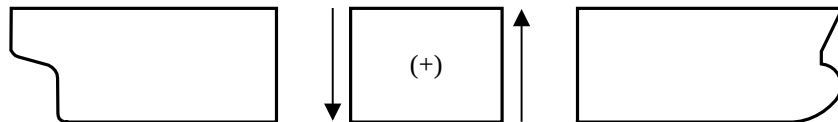


7.3 Maximum VSF

- i) Vertical shear force, (+) upward shear force on a positive face (see Section 2, Figure 2)
- ii) Vertical shear force, (–) downward shear force on a positive face

The shear force location is selected based on the still-water maximum shear force location for the loading condition considered.

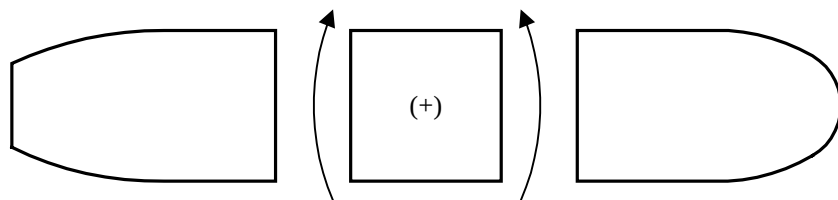
FIGURE 2
Positive Vertical Shear Force

**7.5 Maximum HBM**

- i) Horizontal bending moment amidships, (+) tension on the starboard side (see Section 2, Figure 3)
- ii) Horizontal bending moment amidships, (–) tension on the port side

This DLP refers to the maximum wave-induced horizontal bending moment amidships

FIGURE 3
Positive Horizontal Bending Moment

**7.7 Maximum HSF**

- i) Horizontal shear force, (+) toward port forward
- ii) Horizontal shear force, (–) toward starboard aft

This DLP refers to the maximum wave-induced horizontal shear force at two locations ($1/4$ and $3/4$ of the vessel length).

7.9 Maximum V_{acc}

- i) Vertical acceleration at Forward Perpendicular (FP) or turret center, (+) pitching up
- ii) Vertical acceleration at Forward Perpendicular (FP) or turret center, (–) pitching down

This DLP refers to the maximum vertical acceleration at bow. Unless otherwise specified, the reference point may be taken at intersection of FP or turret center, centerline and waterline.

7.11 Maximum L_{acc}

- i) Lateral acceleration at bow, in way of turret structure or at least to the main deck level, (+) port side;
- ii) Lateral acceleration at bow, in way of turret structure or at least to the main deck level, (–) starboard side;

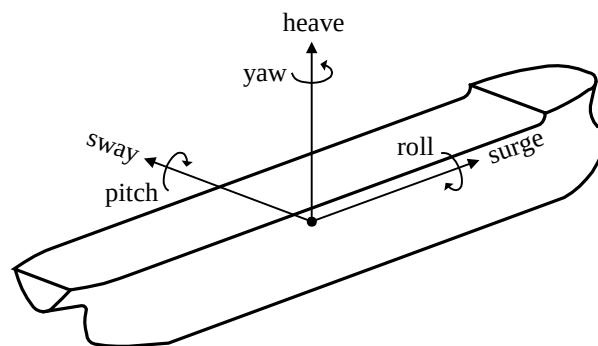
This DLP refers to the maximum lateral acceleration at bow. The lateral acceleration may be taken at the same reference point for vertical acceleration. Additional reference points for accelerations may need to be introduced depending on the configuration of the deck-mounted equipment.

7.13 Maximum Roll Angle

- i) Roll angle, (+) starboard down (see Section 2, Figure 4)
- ii) Roll angle, (–) starboard up

The DLP refers to the maximum roll angle calculated with respect to the vessel center of gravity. 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. This may be significant when ‘steady’ heel angles are considered (say due to persistent winds).

FIGURE 4
Definition of Vessel Motions

**9 Other Accompanying Instantaneous Load Components**

The other accompanying instantaneous load components are the load components that are considered to be simultaneously acting on the vessel at the instant time when the Dominant Load Parameter reaches its maximum considering the equivalent design wave determined for each Load Case. The method to determine the equivalent 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 7 – external hydrodynamic pressures on hull,
- Section 8 – internal pressures at cargo and ballast tank wetted boundaries, and
- Section 9 – loads on lightship weight and equipment.

Mooring loads are another significant accompanying instantaneous load component to be included in the DLA Analysis.