Annex E

Bureau Veritas report on load and strength assessment

MARINE DIVISION

ATA: 1234A
NT: 3005/DR

MSC NAPOLI - ULTIMATE STRENGTH ANALYSIS

BUREAU VERITAS

Move Forward with Confidence

Issue	0		
Date	28/01/08		
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MARINE DIVISION – GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine Division (the "Society") is the classification ("Classification") of any ship or vessel or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- prepares and publishes Rules for classification, Guidance Notes and other documents ("Rules");
- issues Certificates, Attestations and Reports following its interventions ("Certificates");
- publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as "Certification".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1 2. and 1.3. are referred to as "Services". The party and/or its representative requesting the services is hereinafter referred to as the "Client". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisement given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisement is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisement or cause to modify its scope.

2.4. - The Client is to give to the Society all access and information necessary for the performance of the requested Services.

ARTICLE 3

3.1. - The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are not a code of construction neither a guide for maintenance or a safety handbook.

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.

3.3. - The Services of the Society are carried out by professional Surveyors according to the Code of Ethics of the Members of the International Association of Classification Societies (IACS).

3.4. - The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- conducts surveys at the place of their construction;
- classes Units and enters their class in its Register;
- surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.

5.2. - The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder, respectively.

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - If the Services of the Society cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee.

The Society bears no liability for indirect or consequential loss such as e.g. loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on of were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. hereabove subject to compliance with 2.3. hereabove and Article 8 hereunder.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - Overdue amounts are increased as of right by interest in accordance with the applicable legislation.

8.3. - The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit ;
- copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society Member of the International Association of Classification Societies (IACS) in case of the Unit's transfer of class;
- the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units are passed on to IACS according to the association working rules;
- the certificates, documents and information relative to the Units classed with the Society may be reviewed during IACS audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France.

12.3. - Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.

ARTICLE 13

13.1. **- These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement.**

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.

0. FOREWORD

The present technical note has been drawn-up within the framework of the General Conditions applicable to BUREAU VERITAS interventions.

The technical comments and the conclusions thus expressed may have to be re-considered in light of any modifications or alterations that would invalidate the data shown in the documents which are referred to therein.

These comments and conclusions would become null and void should BUREAU VERITAS not be kept informed of such modifications or alterations with specific reference to the present report.

1. EXECUTIVE SUMMARY

The container vessel “MSC Napoli” was damaged on the starboard side on 17th of January. The aim of this report is to evaluate the maximum loads acting on the vessel at the moment of the damage and to compare them with those obtained from the ultimate strength analysis of the structure.

The wave conditions were obtained from hindcast model provided by METOFFICE, the governmental British organism in charge of the Public Weather Service (PWS) in UK (www.metoffice.gov.uk), and from DNV, the current classification society of the vessel.

The loading condition used in this report was provided by DNV as being the loading condition of the vessel at the moment of the damage.

The following calculation conditions were used and the results are presented in this report:

- Condition A: Water depth of 90m, JONSWAP spectrum with Hs=7.5m, Tp within a range from 12s to 15s and γ from 1.0 to 3.3 and spreading factor s=4 in the spreading function cos2s [$(\theta-\theta_0)/2$]. Ship speed was 11knots (most probable situation according to BV based on data obtained from UK METOFFICE).

- Condition B: Water depth of 90m, JONSWAP spectrum with Hs=9.0m, Tp within a range from 12s to 15s, γ =3.3 and no spreading function. Ship speed was 11knots (most severe condition reported according to DNV)

The following results were obtained from the non-linear hydrodynamic analysis considering the rigid body:

Wave Condition B : Water Depth 90m; Hs = 9.0 ; γ = 3.3; no spreading			
Description	**Value at Frame #88 (kN.m)**		
	VWBM (non-linear)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	1.90E+06	2.27E+06	**4.17E+06**

To note that the above condition leads to equivalent value as per recommended by IACS UR S11 for ship scantling (4.22E+06 kN.m).

From the ultimate structural analysis it has been concluded that the global collapse occurs for a bending moment at frame 88 between 4.6E+06 kN.m and 4.7E+06 kN.m.

This way, we may conclude that the values obtained from the hydrodynamic analysis for the rigid body does not induce to the global collapse of the structure.

Additionally to the analysis for the rigid body, a hydro-elastic analysis has been carried out in order to account for slamming effects on the global loads (whipping). A preliminary calculation has indicated an increase of 30% on the vertical bending moment calculated for the rigid body.

The table below presents the results obtained:

Wave Condition B : Water Depth 90m; Hs = 9.0 ; γ = 3.3; no spreading			
Description	**Value at Frame #88 (kN.m)**		
	VWBM (elastic)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	2.47E+06	2.27E+06	**4.74E+06**

- ► **In the most severe conditions considered (Hs=9m), collapse is possible with the addition of whipping. (These extreme conditions exceed the maximum IACS bending moment).**

2. REFERENCE DOCUMENTS

1- DWG No SB00710 Rev D / SHELL EXPANSION
2- DWG No SB00210 Rev D / MIDSHIP SECTION
3- DWG No SF06110 Rev E / HOLD CONSTRUCTION
4- DWG No SF03110 Rev C / ENGINE ROOM CONSTRUCTION
5- DWG No SF08110 Rev B / DECKHOUSE CONSTRUCTION

3. SHIP'S CHARACTERISTICS AND LOADING CONDITIONS

The main characteristics of the ship and the mechanical properties for the determined loading condition are presented below.

Table 1 - MSC Napoli Characteristics

PARAMETER	SYMBOL	UNIT	VALUE
Length Over All	LOA	m	275.60
Length Between Perpendiculars	LBP	m	261.40
Breadth Moulded	B	m	37.10
Depth	H	m	21.50
Draught at FP	d_{FP}	m	12.01
Draught at AP	d_{AP}	m	13.25
Draught Mean	d_M	m	12.63
Displacement	Δ	t	75323.1
Vertical CoG / BL (Base Line)	VCG	m	14.66
Longitudinal CoG / AP	LCG	m	123.08
Transverse Metacentric Height	GM_0	m	3.056
Trans. Met. Height, Corrected	GM	m	3.001
Roll Radius of Gyration	R_{xx}	m	13.03
Pitch Radius of Gyration	R_{yy}	m	62.85
Yaw Radius of Gyration	R_{zz}	m	63.34

The above loading condition has been provided by DNV and considered by them as the closest condition at the moment of the damage of the vessel. The detailed description of the loading condition is presented in Annex 1.

This loading case is significantly more severe than the one of our first report, especially considering the aft frames (e.g. frame 88), due to the increase of draft and the trim.

4. WAVE CONDITIONS

The wave data observed during the day when the vessel was damaged were used in a short term analysis. The data was provided by METOFFICE (www.metoffice.gov.uk), which is the governmental British organism in charge of the Public Weather Service (PWS) in UK, upon our request.

The wave parameters were provided at grid points at the proximity of the vessel at the moment of the SOS based on hindcast models. The most critical conditions obtained from the hindcast models are summarized below:

Table 2 – Wave conditions from hindcast model

Hour	Day	Month	Year	Latitude	Longitude	Water Depth	Resultant Wave Height	Resultant Wave Period
6	18	1	2007	49.50N	4.86W	81	6.8	9.7
6	18	1	2007	49.50N	4.46W	77	6.6	9.5
6	18	1	2007	49.25N	4.86W	84	6.8	9.7
6	18	1	2007	49.25N	4.46W	78	6.5	9.5
9	18	1	2007	49.50N	4.86W	81	7.3	9.9
9	18	1	2007	49.50N	4.46W	77	7.1	9.8
9	18	1	2007	49.25N	4.86W	84	7.3	9.9
9	18	1	2007	49.25N	4.46W	78	7	9.8
12	18	1	2007	49.50N	4.86W	81	7.4	9.6
12	18	1	2007	49.50N	4.46W	77	7.3	9.7
12	18	1	2007	49.25N	4.86W	84	7.5	9.8
12	18	1	2007	49.25N	4.46W	78	7.3	9.7
15	18	1	2007	49.39N	4.75W	99	7.4	9.3
15	18	1	2007	49.39N	4.58W	94	7.4	9.3
15	18	1	2007	49.39N	4.42W	93	7.4	9.3
15	18	1	2007	49.28N	4.75W	99	7.4	9.3
15	18	1	2007	49.28N	4.58W	96	7.3	9.3
15	18	1	2007	49.28N	4.42W	93	7.3	9.3
15	18	1	2007	49.50N	4.86W	81	7.3	9.4
15	18	1	2007	49.50N	4.46W	77	7.1	9.4
15	18	1	2007	49.25N	4.86W	84	7.3	9.4
15	18	1	2007	49.25N	4.46W	78	7.1	9.4
18	18	1	2007	49.50N	4.86W	81	7.1	9.1
18	18	1	2007	49.50N	4.46W	77	6.8	9.1
18	18	1	2007	49.25N	4.86W	84	7.1	9.1
18	18	1	2007	49.25N	4.46W	78	6.9	9.0

In the above table the resultant wave height refers to significant wave height and the resultant wave period refers to the zero-up-crossing period.

According to the data presented and the position of the vessel at the moment of the SOS, we consider that the most severe significant wave height for the analysis is 7.5m associated with a peak period that can vary from 12s to 15s in order to make sure that the most critical bending moment is obtained within this range. The water depth at the location of the vessel at the moment of the SOS is probably greater than 90m.

According to METOFFICE the spectrum to be considered is JONSWAP with a gamma parameter that can vary between 1, for fully developed sea of a Pierson Moskowitz, and 3.3, for younger sea which is used for limited fetch situations.

A spreading function $\cos^{2s}[(\theta-\theta_0)/2]$, with s=4 was used.

The following picture presents the location of the grid points used in the hindcast model as well as the position of the vessel at the moment of the SOS. It can be noted that the minimum distance between a grid point and the vessel is 5.30km. Also, for the points represented in red (closer to the vessel), the water depth is always greater than 90m.

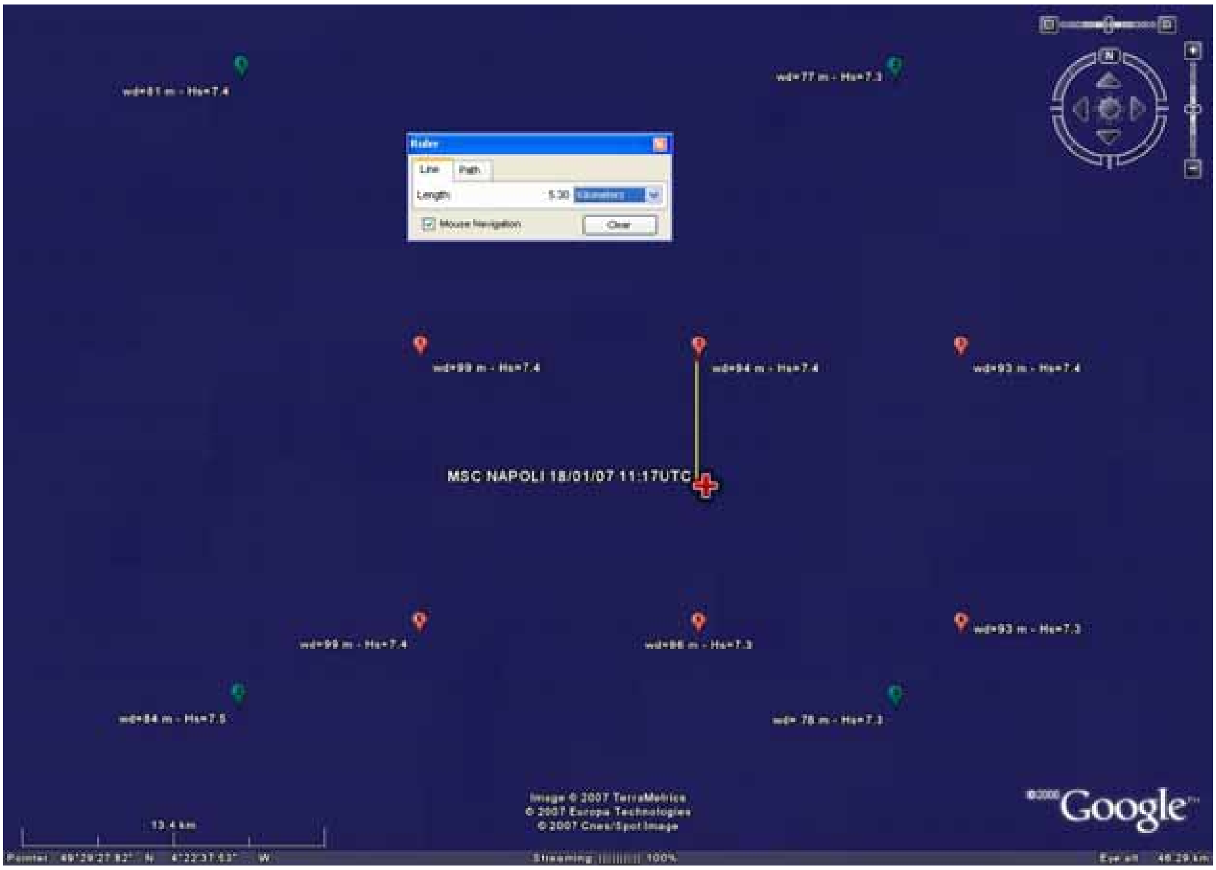


Figure 1 – Position of the grid points and corresponding wave parameters

Additionally to the wave condition derived from the information presented above, the wave condition proposed by DNV has been also taken into account (condition B).

In summary, the following calculation conditions were defined in this study, resulting from the analysis above:

- Condition A: Water depth of 90m, JONSWAP spectrum with Hs=7.5m, Tp within a range from 12s to 15s and γ from 1.0 to 3.3 and spreading factor s=4 in the spreading function cos2s [(θ-θ_0)/2]. Ship speed was 11knots (most probable situation according to BV based on data obtained from UK METOFFICE).

- Condition B: Water depth of 90m, JONSWAP spectrum with Hs=9.0m, Tp within a range from 12s to 15s, γ =3.3 and no spreading function. Ship speed was 11knots (most severe condition reported according to DNV)

5. HYDRODYNAMIC MODEL

The following hydrodynamic model was prepared for this study:

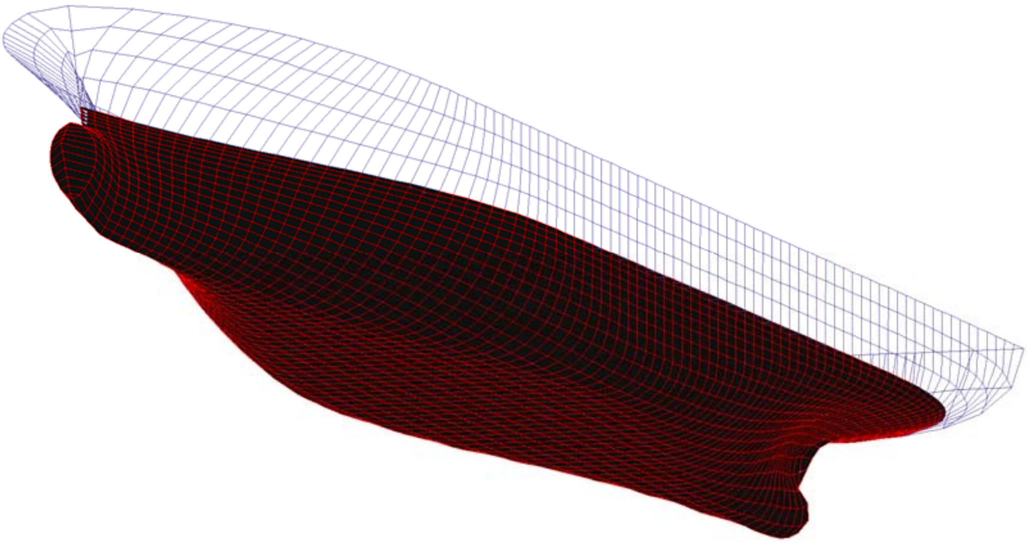


Figure 2 – Hydrodynamic mesh – 1624 panels on the half hull (wetted part)

The following hydrostatic properties were calculated and compared with the values in the Loading Manual:

Table 3 – Hydrostatic Properties

Volume (m^3)	Provided	73486
	Modeled	73118
	Difference	**0.5%**
GMt (m)	Provided	3.00
	Modeled	2.98
	Difference	**0.7%**

The differences presented above were considered negligible.

6. MECHANICAL PROPERTIES

The following mechanical properties were used:

ROLL DAMPING

As no accurate data concerning the roll viscous damping exists, a value corresponding to 3% of the critical damping was used.

CORRECTION FOR FREE SURFACE EFFECTS

Free surface effects in cargo and ballast are taken into account in calculation by reducing the restoring coefficient:

$K44' = g \, \delta GM \, \Delta$

Where,

K44' is the correction on the roll restoring force due to the free surface effects;
G is the gravity acceleration
δGM is the correction on GM due to the free surface on the tanks;
Δ is the displacement (mass) for the loading condition considered.

Considering the data provided, the following values were obtained:

$\delta GM = 0.055$
$g \, \delta GM \, \Delta = -4.064e+7$ N.m

GYRATION RADIUS

The gyration radius of pitch and yaw were directly calculated based on the longitudinal distribution of weight provided for the loading condition.

The values obtained are:

Table 4 – Gyration Radius

	Rxx (m)	Ryy (m)	Rzz (m)
Draft 1	13.03	62.85	63.34

7. REFERENCE SYSTEM

The coordinate system used in motion and geometry definition of the vessel is defined here together with those used for wave headings and vessel's RAOs.

The coordinate system used in the description of vessel's geometry and motion is defined as follows:

Origin O located at the intersection of the baseline on the centreline and the section at frame 0 of the vessel;

- Axis Ox is positive in the forward direction;
- Axis Oy is positive to port side;
- Axis Oz is positive upwards.

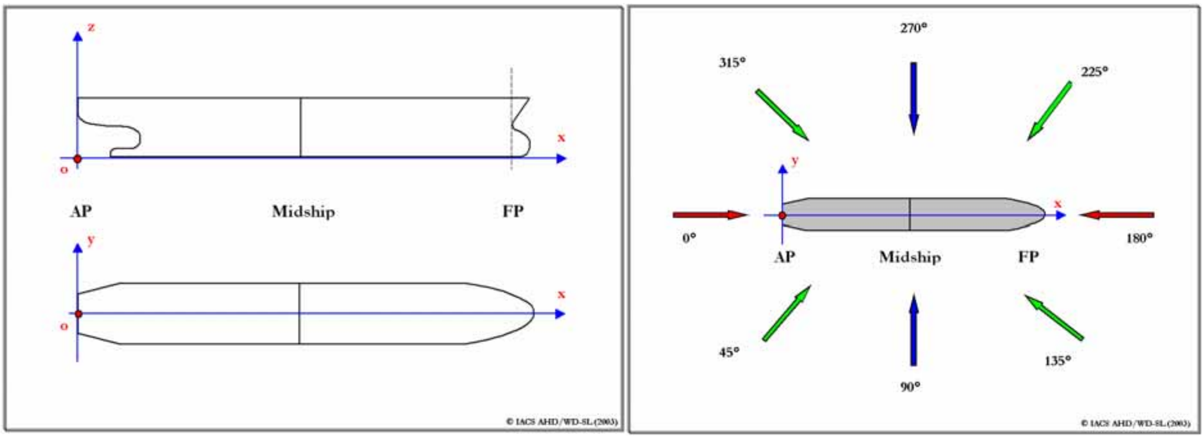


Figure 3 – Reference System

By default the centre of gravity of the vessel (COG) is taken as reference point for all the computations, although the user has the possibility of defining any other point.

The vessels translations surge, sway and yaw are the motions in Ox, Oy and Oz respectively. The vessel's rotations roll, pitch and yaw are defined with respect to COG:

- Roll is the rotation around the axis parallel to Ox through the reference point;
- Pitch is the rotation around the axis parallel to Oy through the reference point;
- Yaw is the rotation around the axis parallel to Oz through the reference point.

Regular incoming waves are described by their amplitude (a), frequency (ω) in rad/s and heading (β). The wave heading is defined by the angle between the propagation direction and the positive direction of the axis *Ox*.

8. MAXIMUM LOADS

The maximum vertical bending moment was evaluated by means of direct calculations. The calculation according to IACS UR S11 was also performed for reference reasons.

8.1. Maximum Bending Moment according to IACS URS11

The IACS URS11 is applicable to steel ships of length 90m and greater in unrestricted navigation.

According to those Unified Requirements, the wave bending moment in hogging at each section along the ship length is given by the following formula:

$$M_w = 190\, M\, C\, L^2\, B C_b \times 10^{-3} \text{ (kN.m)}$$

where,

M is a distributuion factor depending on the section position

$$C = 10.75 - \left[\frac{300 - L}{100} \right]^{1\ 5}$$

L is the length of the ship in meters, defined by the UR S2
B is the breadth of the ship in meters
C_b is the block coefficient

The following total bending moment was obtained according to IACS:

Table 5 – IACS URS11 Bending Moment

Description	**Value at Frame #88 (kN.m)**		
	VWBM	**SWBM**	**Total (VWBM+SWBM)**
Vertical Bending Moment – IACS UR S11	1.95E+06	2.27E+06	**4.22E+06**

8.2. Hydrodynamic Analysis for the Rigid Body

In order to evaluate the maximum vertical wave bending moment at frame #88 at the moment of the damage, a short term analysis was carried out considering the wave conditions described above. Both, the linear and non-linear hydrodynamic analysis were performed in order to obtain the transfer functions of motions for the spectral analysis.

The non-linear analysis was executed for two regular waves of amplitude 16.74m and 13.02m. For those waves the ratios between the non linear and linear results are **0.72** and **0.78**, respectively, for the hogging condition. Thus we have applied a reduction of **20%** on the values presented above.

The following tables present the Vertical Wave Bending Moment when accounting for the non-linear effects and the Total Vertical Bending Moment when adding the Still Water component for the two wave conditions considered.

Table 6 – Maximum Wave Bending Moment – Wave Condition A

Wave Condition A : Water Depth 90m; Hs = 7.5 ; γ = 3.3 ; spreading s=4			
Description	**Value at Frame #88 (kN.m)**		
	VWBM (non-linear)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	1.39E+06	2.27E+06	**3.65E+06**

Table 7– Maximum Wave Bending Moment – Wave Condition B

Wave Condition B : Water Depth 90m; Hs = 9.0 ; γ = 3.3; no spreading			
Description	**Value at Frame #88 (kN.m)**		
	VWBM (non-linear)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	1.90E+06	2.27E+06	**4.17E+06**

Remarks

It can be noticed from the tables presented above that the Maximum Bending Moment was achieved for the wave condition B and it’s equivalent to the value recommended by IACS for the structure scantling.

8.3. Hydro-Elastic Analysis – Whipping Loads consideration

Whipping is defined as the transitory global ship vibrations due to slamming. During the slamming, not only very high localized pressures will appear, but also the corresponding overall forces are very high. This means that not only the local ship structure will be affected, but whole ship will feel the slamming loading.

The slamming loads are calculated by means of a 2D model given the impact conditions obtained through a time domain simulation.

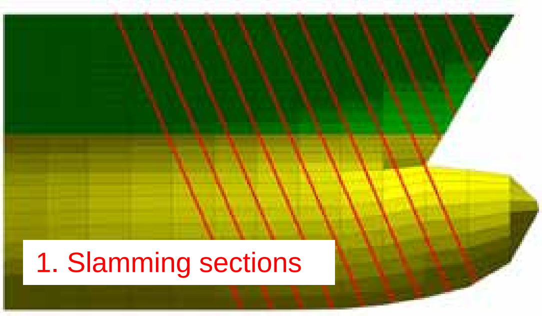
The motion equation in time domain can be written as:

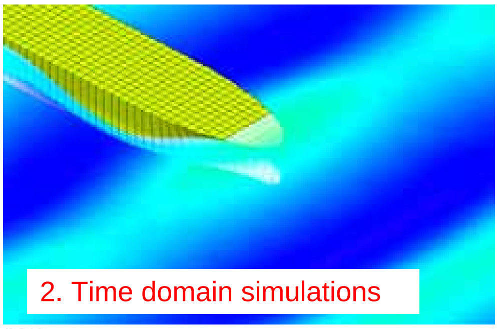
$$([\,\mathbf{m}\,]+[\,\mathbf{A}^{\infty}\,])\{\ddot{\boldsymbol{\xi}}(t)\}+([\,\mathbf{k}\,]+[\,\mathbf{C}\,])\{\boldsymbol{\xi}(t)\}+\int_0^t[\,\mathbf{K}(t-\tau)\,]\{\dot{\boldsymbol{\xi}}(\tau)\}d\tau=\{\boldsymbol{F}(t)\}+\{\boldsymbol{Q}(t)\}$$

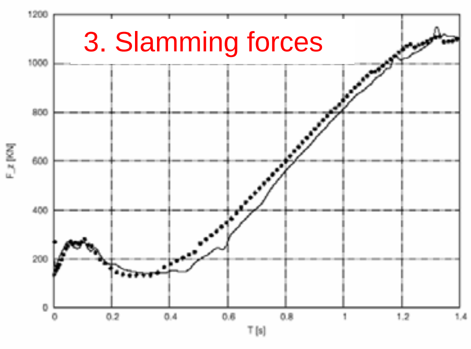
where *Q(t)* represents the excitation force due to slamming.

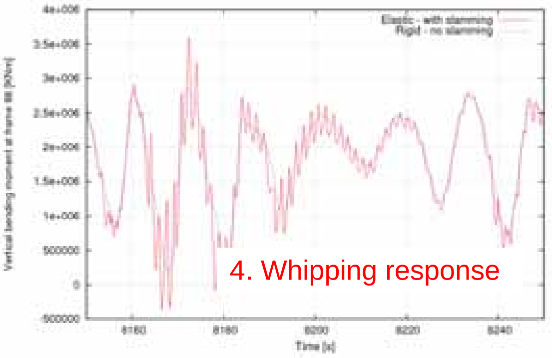
For the hydro-elastic model the number of degrees of freedom is increased considering the modes of vibration of the ship structure.

The general computation scheme is presented in the figure below.


1. Slamming sections

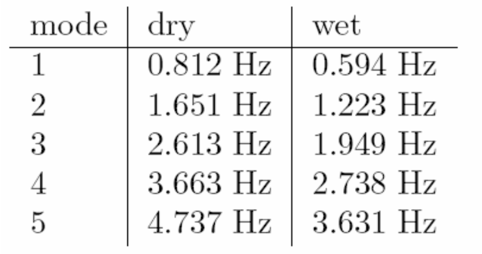

2. Time domain simulations


3. Slamming forces

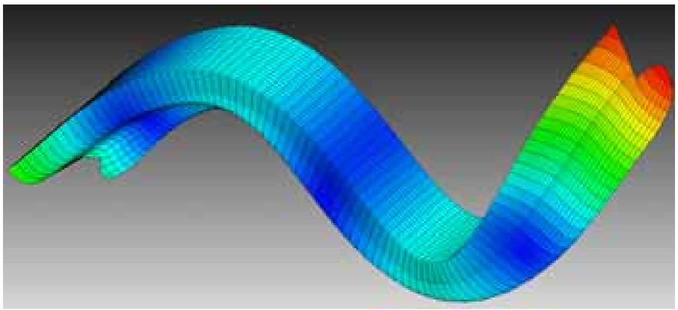

4. Whipping response

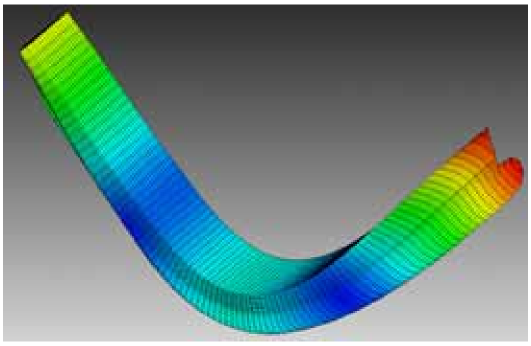
MODAL ANALYSIS (Timoshenko beam model)

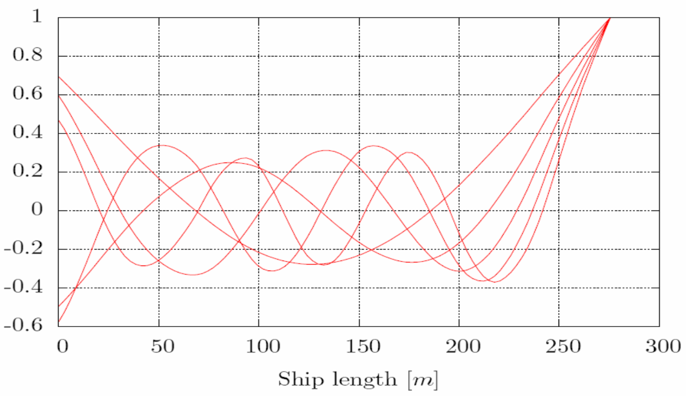
The following vibration modes were obtained and used in the time domain motion equation computation:



mode	dry	wet
1	0.812 Hz	0.594 Hz
2	1.651 Hz	1.223 Hz
3	2.613 Hz	1.949 Hz
4	3.663 Hz	2.738 Hz
5	4.737 Hz	3.631 Hz







The following figure represent the total vertical bending moment (wave + still water) at frame #88 with and without the consideration of slamming for a typical whipping event.

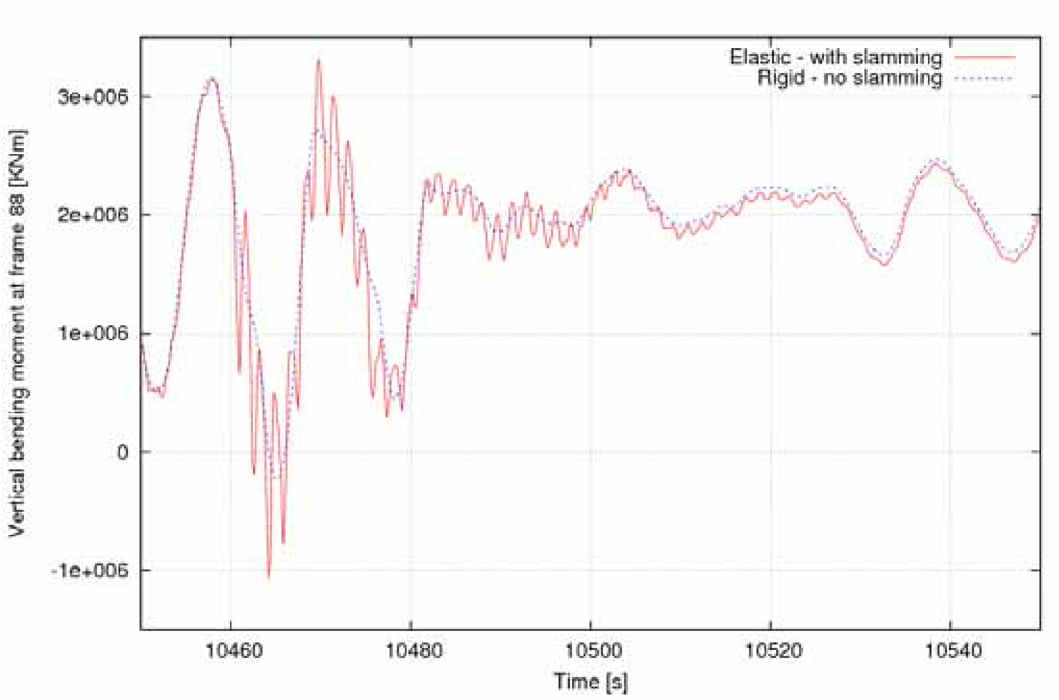


Figure 4 – Influence of the whipping on the total bending moment

The simulation duration was 10800 seconds – 3 hours sea state.

The following picture presents the difference between the rigid model and the hydro-elastic model analysis, where the slamming loads are neglected in the first one. It can be noticed that for a probability of exceedance of 0.001, the vertical bending moment is increased of approximately 30% when considering the slamming loads.

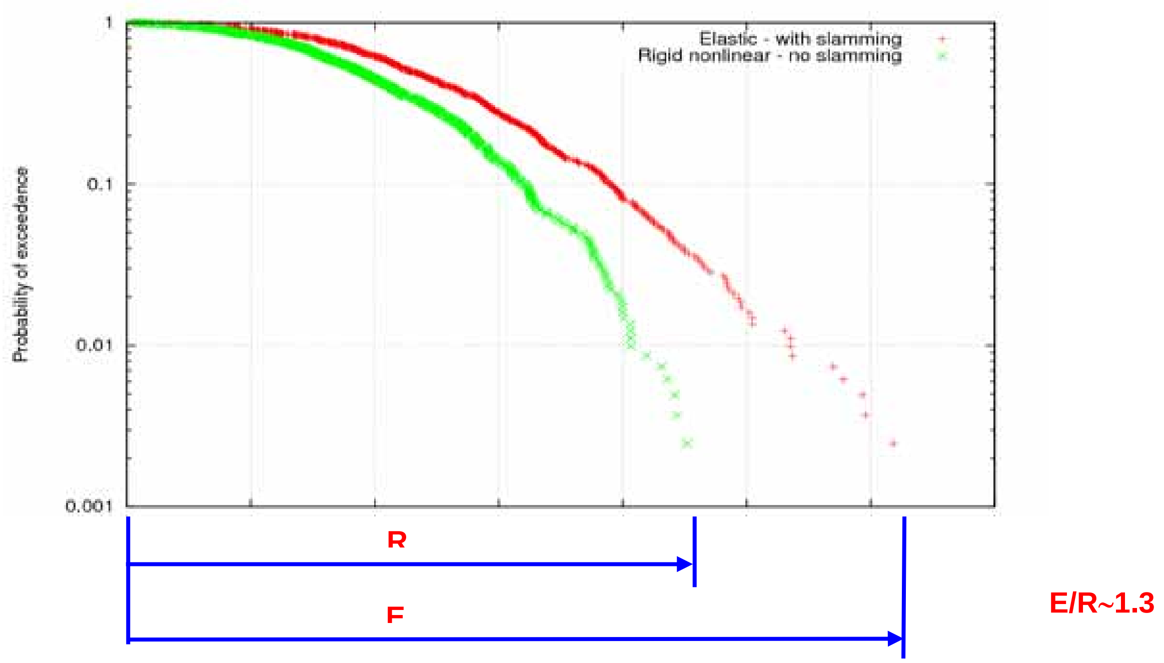


Figure 5 – Statistical Results – influence of the whipping phenomena

Thus the total vertical bending moment obtained for wave condition B when accounting for the whipping loads is:

Table 8 – Vertical Bending Moment – Elastic Model

Wave Condition B : Water Depth 90m; Hs = 9.0 ; γ = 3.3; no spreading			
Description	**Value at Frame #88 (kN.m)**		
	VWBM (elastic)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	2.47E+06	2.27E+06	**4.74E+06**

Remarks

The study gives a good order of magnitude of whipping effects, although further investigation should be carried out in order to evaluate the sensitivity of the results to the following parameters:

- Structural damping;
- Speed;
- Heading;
- Wave spectrum;
- Mass distribution

The values obtained from the analysis are significantly above the IACS recommended values. It shows that due to the important bow and stern slamming, the whipping has a non-negligible contribution to the ship global loads.

9. ULTIMATE STRENGTH ANALYSIS

The ultimate strength analysis was performed using finite element method taking into account non linear effects (large displacements and elasto-plasticity).

9.1. Hypothesis and Modelling

General

Modelling was performed using IDEAS 12 NX (as pre processor). Calculations were performed using finite element software ABAQUS/Standard 6.7. Post-processing was performed using ABAQUS/Viewer 6.7.

Elastic system

The considered elastic system is constituted by hull structure of the ship between frames 79 and 92 and from base line up to first deck of accommodation.

Finite element model

A 3D finite element model of the previously described elastic system was built up using information on the ship drawings (see 'REFERENCE DOCUMENTS'').

Size of the model:

- 60 842 elements (linear thin shell and linear beam elements);
- 56 147 nodes;
- 330 498 degrees of freedom.

Only port side half between frames 79 and 92 was considered (geometry and loads were assumed to be symmetric with respect to centre line).

Deckhouse has been modelled up to the first deck. It is assumed that the structure above first deck do not contribute to hull girder strength.

All primary and secondary stiffeners were modelled using shell elements except in deckhouse where some secondary stiffeners were modelled using beam elements.

Typical mesh size was based on two or three thin shell elements between two frames (in areas between frame 79 and 81 and between frames 86 and 92). However, area between frames 81 and 86 and from the base line up to deck 4 (9620 from baseline) was defined by typical mesh size based on six thin shell elements between two frames.

Whole model is shown on Figure 6.

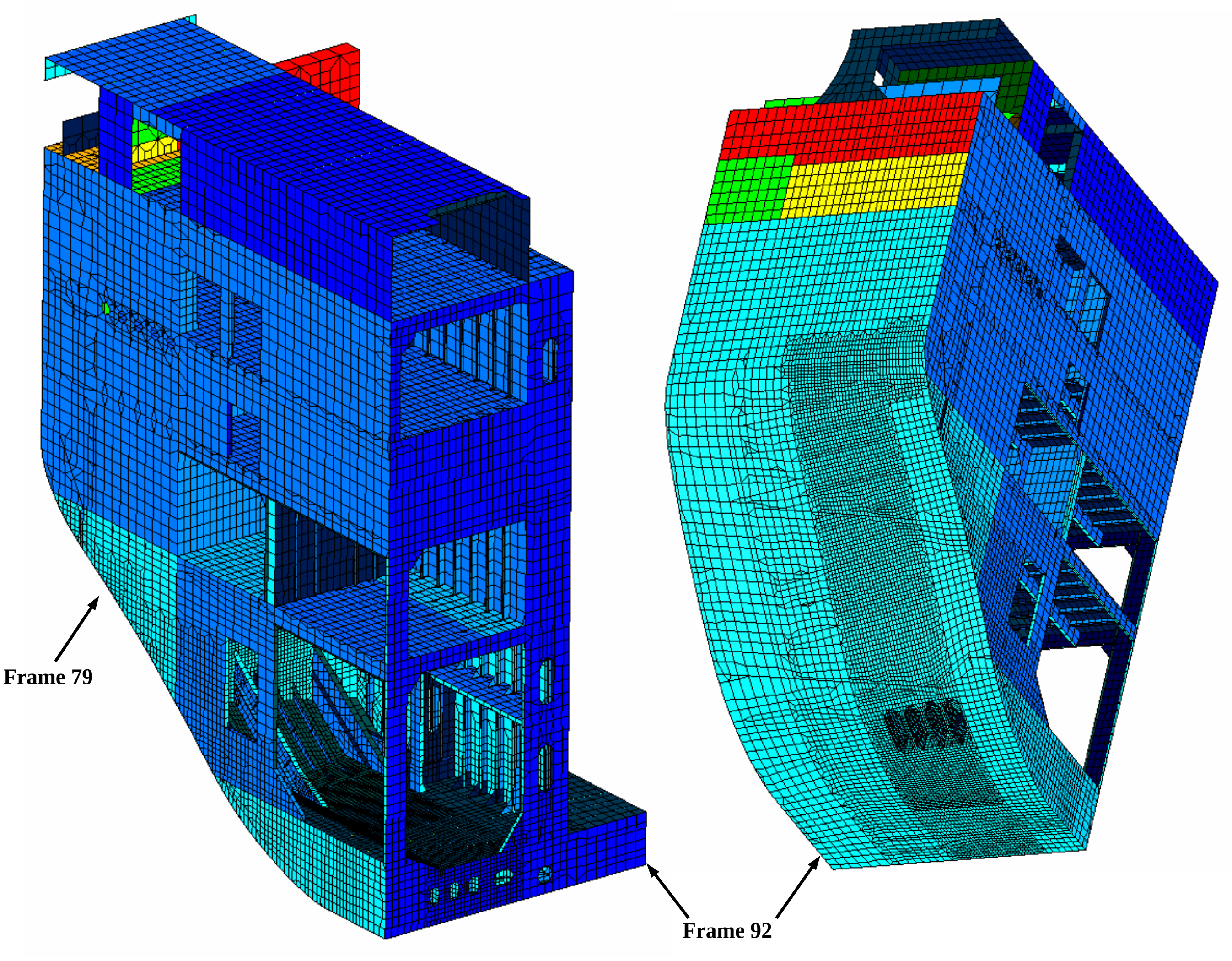


Figure 6 : Finite element model

Coordinate system:

- X: longitudinal direction positive forward
- Y: transversal direction positive port side
- Z: vertical direction positive upwards.

Figure 7 show bottom part up to stringer (6020 from baseline) and particularly the refined area. Double bottom, frame 79 and frame 88 have been removed from this figure.

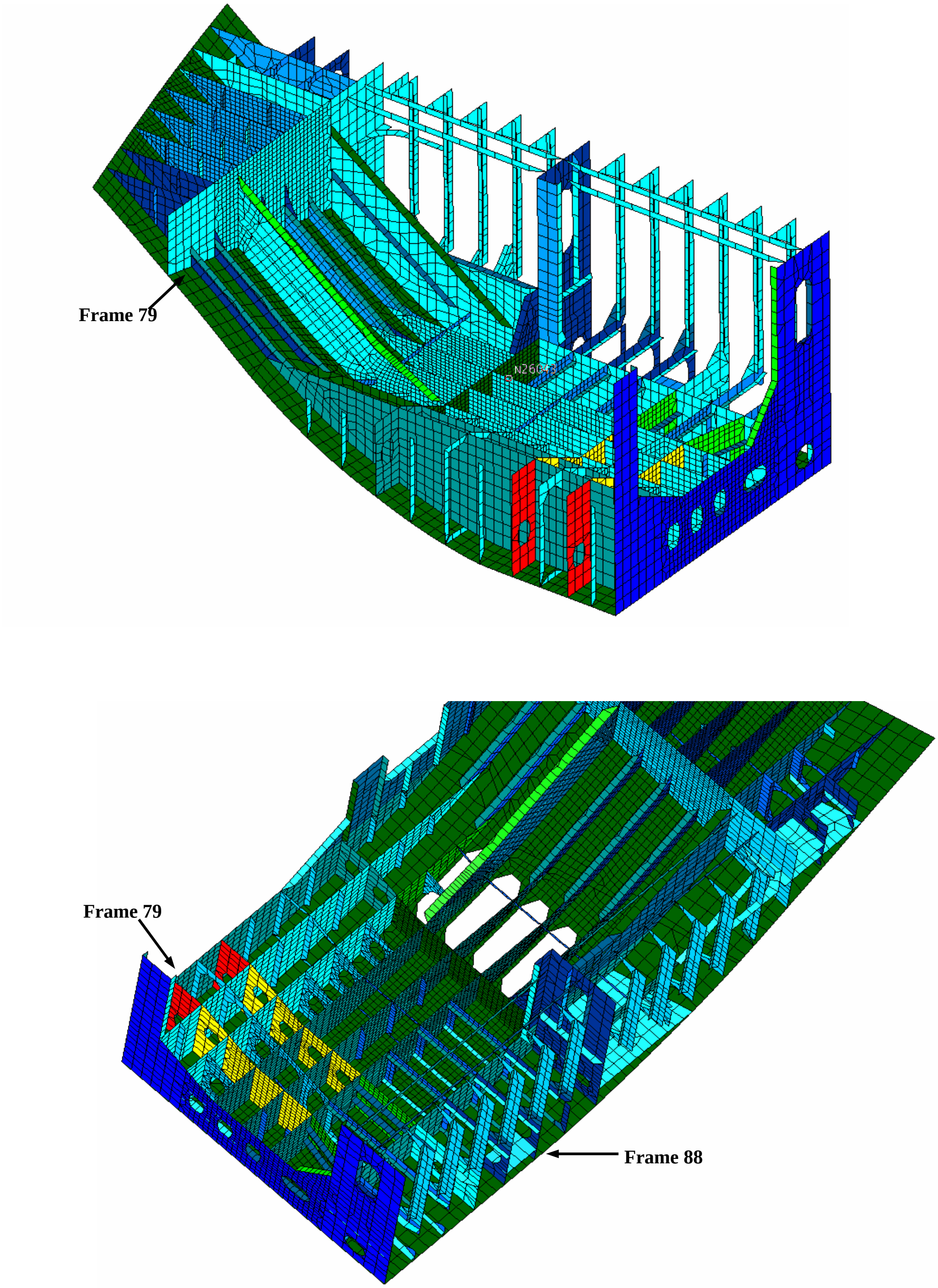


Figure 7 : Local finite element model

Material properties

Stress – strain curves corresponding to each material have to be introduced in the model. Corresponding areas are indicated on reference documents.

According to reference documents, three different steels were used. Corresponding characteristics are indicated in the following table.

Table 9 – Material Properties

Steel	Young's modulus (MPa)	Poisson's ration	Density (kg/m3)	Yield stress (MPa)	Ultimate Tensile Strength (MPa)
Grade A	207000	0,29	17465	235	400
Grade AH / DH				315	440
Grade AH36 / EH36				355	490

Density value has been adjusted to take into account the mass of the non modelled equipments and to reach structural mass equal to about 842 t.

Areas concerned by AH36/EH36 are very limited. For this reason, only two steel grades have been considered (A and AH/DH).

Values of yield stresses are given by reference documents. Values of Ultimate Tensile Strength (UTS) are issued from Bureau Veritas Rules (ref. NR 216 DNC R02 F).

For each stress-strain curve, plastic domains have been defined by the Ramberg-Osgood theory and are shown on Figure 8.

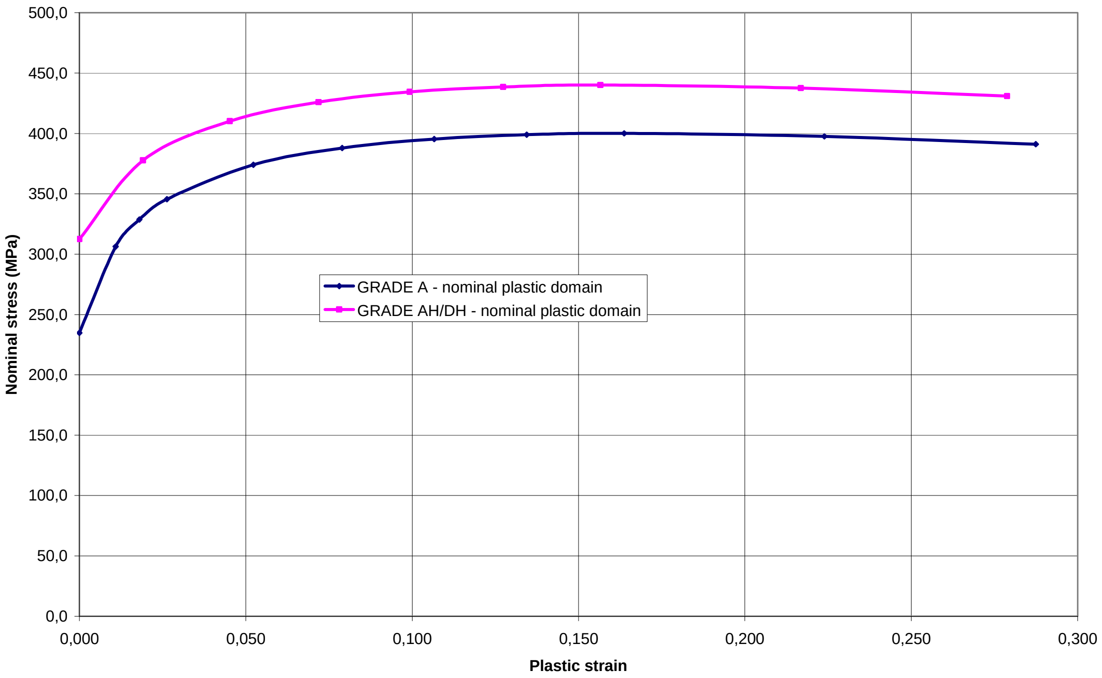


Figure 8 : plastic stress - strain curve

Boundary conditions

All nodes located on frame 92 are restrained in displacements and rotations.

Symmetric conditions are applied on all nodes located on centre line (Y displacements, X and Z rotations are restrained).

Applied loads

Four types of loads are considered:

- Gravity loads;
- Hydrostatic pressure on outside shell (scantling draft value: 13.5 m);
- Bending moment at frame 79 – Collapse load will be calculated on the basis of initial value of bending moment applied at frame 79. This initial value, considered as a reference load, has been calculated using following formula: $M_{f79} = 0.9xM_{CH}+1.6xM_{HV} = 3\,638\,136$ kN.m;
  This formula is taken from Bureau Veritas Rules 1987. Although using this formula in the Rules is restricted to midship area, it has been used in this study to calculate a realistic initial value of bending moment at frame 79. Calculated collapse load is the product of initial load by calculated load factor at collapse.
- Vertical force at frame 79 – $F_{z79} = 73\,550$ kN calculated to reach bending moment value at frame 92: $M_{f92} = 0.9xM_{CH}+1.6xM_{HV} = 4\,314\,154$ kN.m.

Calculations

Calculations are performed using Riks method. This method is efficient for simulating buckling or collapse behaviour, where the load-displacement response shows a negative stiffness and the structure must release strain energy to remain in equilibrium.

A load proportionality factor (λ) applied to a set of loads characterize the load corresponding to collapse.

Calculation is performed in 2 steps:

- Step 1: application of ‘dead loads’ (P_0) – these loads are considered as constant during calculation process.
- Step 2: application of ‘reference loads’ (P_{ref}) – loads are increased step by step up to collapse.

In our case, ‘dead loads’ are gravity loads and hydrostatic pressure and ‘reference loads’ are bending moment and shear force in frame 79.

If load proportionality factor (λ) is found to be equal to 1, it means that collapse occurs for the given ‘reference loads’. In the present calculations, reference loads correspond to above mentioned values.

Collapse load (P_c) is equal to $P_c = P_0 + \lambda\, P_{ref}$.

Collapse is detected when a very small increment of load proportionality factor (λ) corresponds to a very large displacement increment.

Relative rotation between frame 79 and frame 92 as a function of load proportionality factor has to be studied to characterize the collapse behaviour.

9.2. Results

The following figure shows the relative rotation between frame 79 and frame 92.

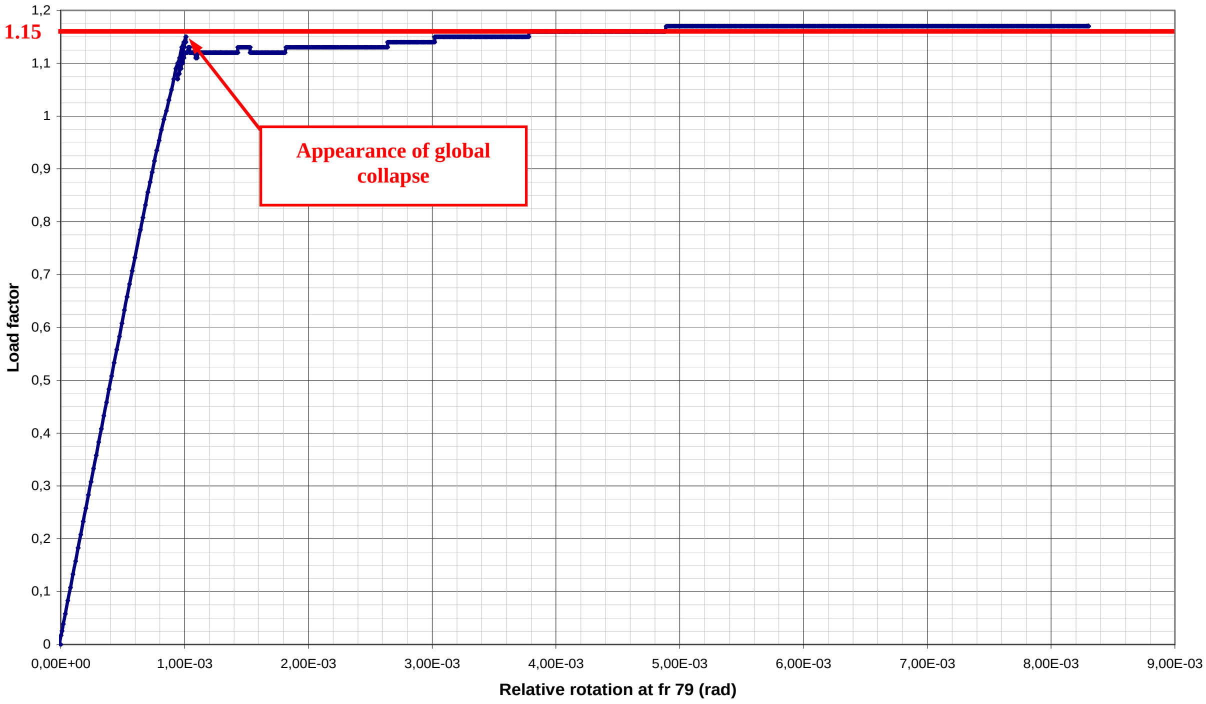


Figure 9 : Load factor – Relative rotation

The curve on Figure 9 shows large variation of rotation for a small variation of load factor. Global collapse is identified for λ = 1.15.

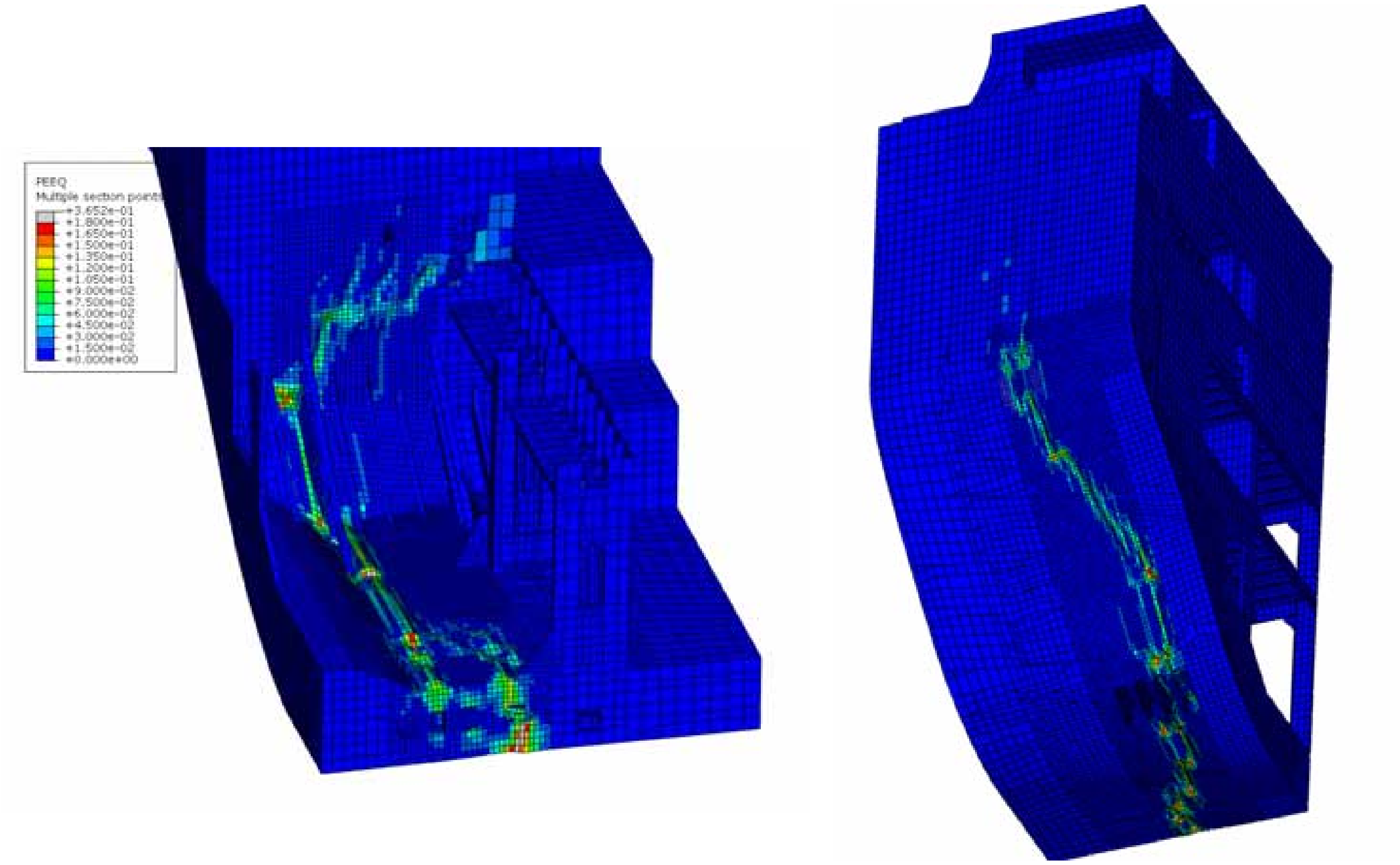


Figure 10 : Distribution of equivalent plastic strains at collapse

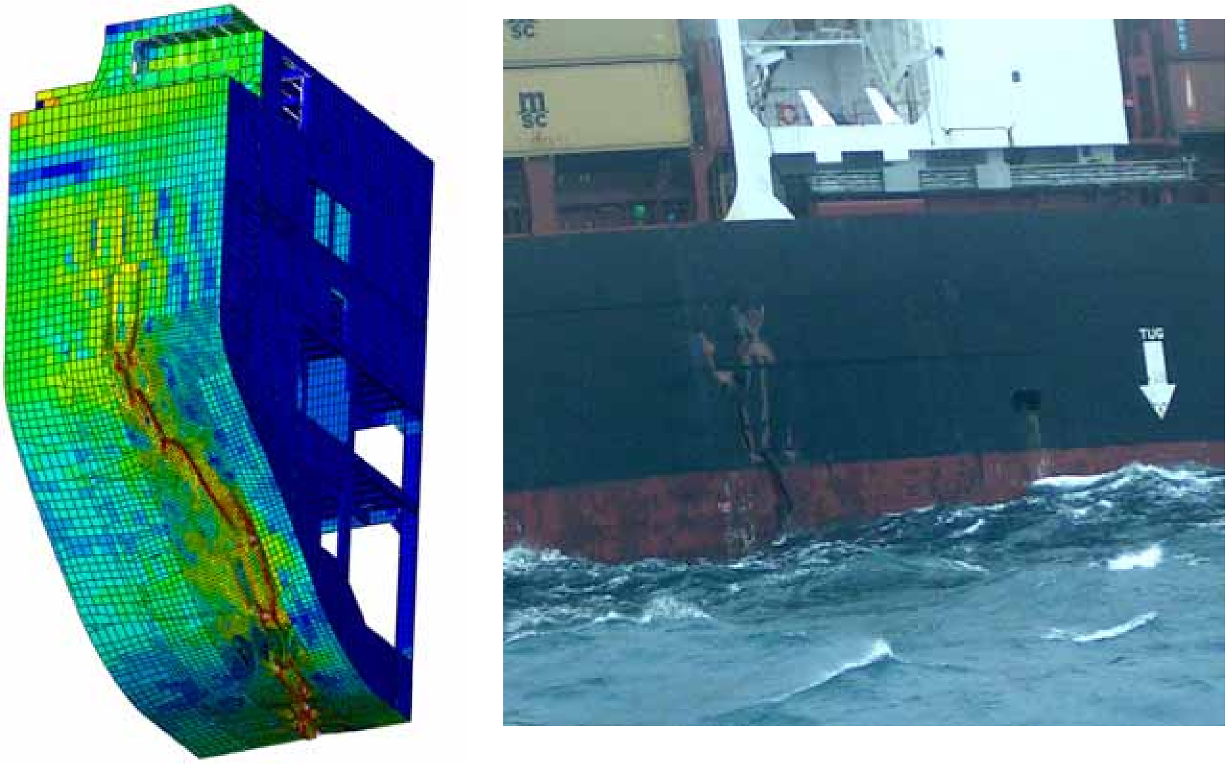


Figure 11 : Comparison between calculated deformed shape at the collapse and observed damage

Figure 11 shows the calculated deformed shape which can be compared to the picture of real damage, showing a good correlation.

Remarks

Considering the results presented above, it can be noticed that the global collapse of the structure occurs for a load proportionality factor equal to 1.15 with respect to considered reference loads. This corresponds to a value of bending moment at frame 88 between 4.6E+06 kN.m and 4.7E+06 kN.m.

10. CONCLUSIONS

The vertical bending moment has been calculated by means of linear and non-linear analysis. The maximum results obtained are presented here below:

Wave Condition B : Water Depth 90m; Hs = 9.0 ; γ = 3.3; no spreading			
Description	**Value at Frame #88 (KN.m)**		
	VWBM (non-linear)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	1.90E+06	2.27E+06	**4.17E+06**

To note that the above condition leads to equivalent value as per recommended by IACS UR S11 for ship scantling (4.22E+06 kN.m).

From the ultimate structural analysis it has been concluded that the global collapse occurs for a bending moment at frame 88 between 4.6E+06 kN.m and 4.7E+06 kN.m

This way, we may conclude that the values obtained from the hydrodynamic analysis for the rigid ship does not induce to the global collapse of the structure.

Additionally to the analysis for the rigid body, a hydro-elastic analysis has been carried out in order to account for slamming effects on the global loads (whipping). A preliminary calculation has indicated an increase of 30% on the vertical bending moment calculated for the rigid body. The study gives a good estimation of magnitude of whipping effects although further investigation should be carried out.

The table below presents the results obtained:

Wave Condition B : Water Depth 90m; Hs = 9.0 ; γ = 3.3; no spreading			
Description	**Value at Frame #88 (kN.m)**		
	VWBM (elastic)	**SWBM**	**Total (VWBM+SWBM)**
Most expected value of extreme distribution	2.47E+06	2.27E+06	**4.74E+06**

- ► **In the most severe conditions considered (Hs=9m), collapse is possible with the addition of whipping. (These extreme conditions exceed the maximum IACS bending moment).**

ANNEX 1
LOADING CONDITION

```
ARGOS 8.2.s    : 38V475                          38V475 "CGM NORMANDIE" PAGE   1
 LOADING CONDITIONS                            Client: 000 - Unregistered 04/12/07




                              ITEMS OF LOADING

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  No                      (m)     (m)      (t)     (m)     (m)     (m)      (t.m)

   1 HEAVY FUEL 4S     140.720 177.280    14.80  4.530 161.820  15.219    197.13
   2 HEAVY FUEL 4P     140.720 177.280     5.10  4.465 161.820 -15.207    192.01
   3 HEAVY FUEL 5S     104.160 140.720  1036.00  9.477 122.440  17.090     74.25
   4 HEAVY FUEL 5P     104.160 140.720  1055.20  9.570 122.440 -17.090     74.25
   5 HEAVY FUEL STOR.T  82.000 104.160   582.60 10.712  93.360   0.000      0.00
   6 HEAVY FUEL STOR.T  82.000 104.160   587.70 10.712  93.350   0.000      0.00
   7 HEAVY FUEL SETTL.  61.800  69.200   158.00 13.080  65.500   0.000      0.00
   8 HEAVY FUEL SERV.T  56.200  61.800   217.90 13.156  59.000   0.000      0.00
   9 L.O M/E STOR.TK P  67.400  69.200    68.30 13.513  68.300   0.000      0.00
  13 L.O CYL.O.STOR.TK  43.200  51.400    73.20 15.675  47.300   0.000      0.00

  15 L.O M/E SUMP TK C  36.800  57.800    38.50  1.418  47.170   0.000      0.00
  20 D.O STOR.TK (P)    69.200  82.000    23.50  7.638  75.090   0.000      0.00
  21 D.O STOR.TK (S)    69.200  82.000    95.40  7.638  75.120   0.000      0.00
  22 D.O SETT.TK (P)    53.800  55.400    22.00 13.798  54.600   0.000      0.00
  23 D.O SERV.TK (P)    51.400  53.800    16.60 13.679  52.610   0.000      0.00
  24 FRESH WATER TK P   70.000  81.200   166.00 14.810  75.600   0.000      0.00
  25 POTABLE WATER TK   69.200  81.200   158.00 14.794  75.600   0.000      0.00
  26 FEED W.STOR.TK  P  36.800  49.600    18.00  1.280  44.920   0.000      0.00
  27 W.B N.1 DEEP TK C 234.480 242.480   502.60  6.966 238.243   0.000      0.00
  28 W.B D.B. TK 2 (C) 205.880 234.480     7.20  2.689 217.570   0.000      0.00

  29 W.B D.B. TK 3 (P) 177.280 205.880   500.90  2.298 190.380  -6.227      0.00
  30 W.B D.B. TK 3 (S) 177.280 205.880   500.90  2.298 190.380   6.227      0.00
  31 W.B D.B. TK 4 (P) 140.720 177.280  1051.30  1.715 158.040  -9.402    875.28
  32 W.B D.B. TK 4 (S) 140.720 177.280  1051.30  1.715 158.040   9.402    875.28
  33 W.B DBTS INSIDE 5 104.160 140.720     7.60  0.010 122.440   6.957   3319.92
  34 W.B DBTP INSIDE 5 104.160 140.720     7.60  0.010 122.440  -6.957   3319.92
  35 W.B DBTS OUTER  5 104.160 140.720     6.60  0.055 125.400  13.729      9.29
  36 W.B DBTP OUTER  5 104.160 140.720     6.60  0.055 125.400 -13.729      9.29
  37 W.B D.B. TK 6 (P)  69.200 104.160  1003.30  1.848  88.010   0.000      0.00
  38 W.B D.B. TK 6 (S)  69.200 104.160  1003.30  1.848  88.010   0.000      0.00

  39 W.B SIDE TANK 3 P 177.280 205.880   435.80  6.834 191.730 -10.295    408.97
  40 W.B SIDE TANK 3 S 177.280 205.880   598.80  7.762 191.760  10.841    505.69
  41 W.B SIDE TANK 7 P  30.560  36.800     5.10 10.340  34.720   0.000      0.00
  42 W.B SIDE TANK 7 S  30.560  36.800     5.10 10.340  34.720   0.000      0.00
  44 CREW,EFFECTS (C)   51.400  67.400     5.00 40.600  59.500   0.000      0.00
  45 STOR.& PROV. (C)   51.400  67.400    10.00 31.400  59.500   0.000      0.00
  46 STORES             -7.000 249.580    35.00 16.000  91.757   0.000      0.00
  47 SPARE PROPSHAFT    14.800  46.400    40.00  3.150  30.200   0.000      0.00
  48 CONT.FITT.AFT      -4.900  50.500    40.00 22.100  21.900   0.000      0.00
  49 CONT.FITT.FORE     69.200 256.580   110.00 22.100 141.518   0.000      0.00
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ARGOS 8.2.s    : 38V475                        38V475 "CGM NORMANDIE" PAGE   2
LOADING CONDITIONS                         Client: 000 - Unregistered 04/12/07



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 No                      (m)     (m)     (t)      (m)    (m)      (m)     (t.m)
------------------------------------------------------------------------------
 50 BILGE HOLDING TK  205.880 213.880    40.00  1.042 209.680   0.000      0.00
 51 COOLING W.TK (C)    7.000  14.800    42.90  3.814  11.790   0.000      0.00
 54 SLUDGE TK          50.500  60.200    18.00  0.680  56.090   0.000      0.00
 55 DECANT.PURI.SLU.T  61.800  67.400    58.00  6.410  64.900   0.000      0.00
 56 F.O OVERFLOW TK    55.030  65.800     7.80  0.140  62.210   0.000      0.00
 57 F.O DRAIN TK (P)   63.400  65.800    12.00  0.600  64.620   0.000      0.00
 58 SEP.BIL.HOLD.TK    60.290  62.600    20.00  0.620  61.830   0.000      0.00
 65 BAY 00            250.280 256.580   104.90 26.960 253.426   0.000      0.00
 66 BAY 01            242.480 248.880   267.50 22.930 245.910   0.000      0.00
 67 BAY 03            235.280 242.480   486.10 21.930 239.409   0.000      0.00

 70 BAY 09            213.880 220.280   544.30 13.930 216.950   0.000      0.00
 71 BAY 11            207.480 213.880   752.30 13.070 210.810   0.000      0.00
 72 BAY 13            199.480 205.880   880.00 12.330 202.546   0.000      0.00
 73 BAY 15            194.890 199.480  1042.20 12.010 197.950   0.000      0.00
 74 BAY 17            185.280 191.680  1004.60 11.910 188.350   0.000      0.00
 75 BAY 19            180.690 185.280  1149.70 11.160 183.750   0.000      0.00
 76 BAY 21            170.880 177.280  1355.90 10.580 173.950   0.000      0.00
 77 BAY 23            166.290 170.880  1424.60 10.430 169.350   0.000      0.00
 78 BAY 25            156.520 163.080   803.10 11.260 159.800   0.000      0.00
 79 BAY 27            148.720 155.120  1339.00 10.930 151.790   0.000      0.00

 80 BAY 29            144.130 148.720  1372.40 10.800 147.190   0.000      0.00
 81 BAY 31            134.320 140.720  1336.30 10.270 137.390   0.000      0.00
 82 BAY 33            127.920 134.320  1349.70 10.230 131.250   0.000      0.00
 83 BAY 35            119.960 126.520  2122.10 12.070 123.240   0.000      0.00
 84 BAY 37            112.160 118.560  1532.60 10.590 115.230   0.000      0.00
 85 BAY 39            105.760 112.160  1536.30 10.540 109.090   0.000      0.00
 86 BAY 41             97.760 104.160  1662.70 10.880 100.830   0.000      0.00
 87 BAY 43             93.170  97.760  1659.80 10.940  96.230   0.000      0.00
 88 BAY 45             83.400  89.960   758.50 11.610  86.680   0.000      0.00
 89 BAY 47             75.600  82.000  1100.10  9.530  78.250   0.000      0.00

 90 BAY 49             69.200  75.600  1011.70 10.010  72.000   0.000      0.00
 91 BAY 51             43.200  49.600   139.40 19.900  46.577   0.000      0.00
 92 BAY 53             38.610  43.200   327.70 16.900  41.670   0.000      0.00
 93 BAY 55             29.000  35.400   324.20 15.940  32.431   0.000      0.00
 94 BAY 57             22.600  29.000   324.20 17.409  25.623   0.000      0.00
 95 BAY 59             14.800  21.200   421.30 17.520  17.870   0.000      0.00
 96 BAY 61              8.400  14.800   355.60 18.383  11.425   0.000      0.00
112 bay 01 deck       242.480 248.880   201.10 31.540 245.550   0.000      0.00
113 bay 03 deck       235.280 242.480   201.10 31.540 239.409   0.000      0.00
116 bay 09 deck       213.880 220.280   451.00 28.670 217.260   0.000      0.00

117 bay 11 deck       208.690 213.880   464.00 28.640 212.150   0.000      0.00
118 bay 13 deck       199.480 205.880   494.00 26.840 202.910   0.000      0.00
119 bay 15 deck       194.470 199.480   470.50 26.890 197.810   0.000      0.00
120 bay 17 deck       185.280 191.680   505.60 28.260 188.660   0.000      0.00
121 bay 19 deck       180.090 185.280   491.60 28.420 183.550   0.000      0.00
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ARGOS 8.2.s    : 38V475                        38V475 "CGM NORMANDIE" PAGE   3
LOADING CONDITIONS                        Client: 000 - Unregistered 04/12/07



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122 bay 21 deck       170.880 177.280   441.00 28.460 174.310   0.000     0.00
123 bay 23 deck       165.870 170.880   486.40 28.180 169.210   0.000     0.00
124 bay 25 deck       156.520 163.080   133.80 27.180 159.800   0.000     0.00
125 bay 27 deck       148.720 155.120   472.10 28.950 152.100   0.000     0.00
126 bay 29 deck       142.320 148.720   472.10 28.950 145.990   0.000     0.00

127 bay 31 deck       134.320 140.720   353.10 27.900 137.750   0.000     0.00
128 bay 33 deck       129.310 134.320   353.10 27.900 132.650   0.000     0.00
129 bay 35 deck       119.960 126.520   758.40 27.830 123.240   0.000     0.00
130 bay 37 deck       112.160 118.560   332.30 28.200 115.540   0.000     0.00
131 bay 39 deck       106.970 112.160   383.90 28.190 110.430   0.000     0.00
132 bay 41 deck        97.760 104.160   499.50 28.490 101.190   0.000     0.00
133 bay 43 deck        92.750  97.760   464.00 28.650  96.090   0.000     0.00
134 bay 45 deck        83.400  89.960    42.90 26.540  86.687   0.000     0.00
135 bay 47 deck        75.600  82.000   359.50 27.820  78.250   0.000     0.00
136 bay 49 deck        69.200  75.600   337.40 27.910  72.000   0.000     0.00

137 bay 51 deck        43.200  49.600   466.50 28.950  46.577   0.000     0.00
138 bay 53 deck        38.010  43.200   466.50 28.950  41.470   0.000     0.00
139 bay 55 deck        29.000  35.400   558.80 28.590  32.431   0.000     0.00
140 bay 57 deck        23.990  29.000   554.80 28.630  27.330   0.000     0.00
141 bay 59 deck        14.800  21.200   580.60 29.160  18.230   0.000     0.00
142 bay 61 deck         9.790  14.800   580.60  2.160  13.130   0.000     0.00
157 bay 64 deck        -4.900   7.000   874.70 29.970   0.928   0.000     0.00
    UNKNOWN             0.000 239.280  2550.00 14.470 109.010   0.000     0.00
-------------------------------------------------------------------------------
DEADWEIGHT                            55759.21 14.501 127.975   0.033  9861.29


                             SUMMARY OF LOADING

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                                         (t)     (m)     (m)     (m)     (t.m)
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       DEADWEIGHT                     55759.21 14.501 127.975   0.033  9861.29
       LIGHT SHIP                     19564.07 14.467 109.012   0.000     0.00
-------------------------------------------------------------------------------
       TOTAL WEIGHT                   75323.28 14.493 123.050   0.024  9861.29
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Executive summary of the University of Southampton's whipping calculations on the *MSC Napoli* 2D hydroelasticity calculations

SUMMARY

This report contains results for calculated bending moments and shear forces that arise due to the motions of the ship in head seas, including the effects of bottom slamming.

The dynamic response of the ship was calculated based on various simplifying assumptions that are detailed in full in the report. These included: treating the structure as a single beam; calculating the hydrodynamic properties in strips up to the datum waterline; and modelling the waves as long crested.

Relevant structural, hydrostatic and operational data were provided by Det Norske Veritas (DNV). Calculations were performed in various seas, which it is understood represented conditions in which the MSC Napoli was likely to have encountered at the time of its failure.

Checks were made on the sensitivity of the results to variations in effective shear area and structural damping. The sensitivity was found to be small, within reasonable limits for the associated assumptions.

Calculations were made for steady state motions in both regular and irregular seas. Additional calculations were made for the effects of bottom slamming following emergence of the forefoot up to 20% of the ship's length (0.2L).

Springing is a problem associated with resonant structural response in waves but the calculations indicated this was not significant for the MSC Napoli. This was due to the resonant peak in the 2-node bending response of the wet hull of the ship occurring at higher frequency than the wave spectral peak.

The calculated motions in regular waves produced bottom slamming over the 0.2L region in wave heights between 6.4m and 9.8m, depending on their length. A few bottom slams occurred over the 0.2L region during the 30 minute simulations from the irregular wave calculations for sea states with significant wave heights between 7m and 9m.

Whipping is a transient structural response associated with slamming. The slam occurs due to re-entry of the hull into the sea following forefoot emergence. This produces impulsive hydrodynamic forces of short duration but with high peak values compared to the steady state wave loadings. The impulsive nature of the slam force excites the natural beam responses.

The slam forces were calculated from the impact velocities acting on the bottom sections of the ship. Forces due to the change of the momentum as the ship immerses, following impact, were also included. They could also arise from the bow flare impacting with waves, although this could not be simulated by the 2D method used in these calculations.

Fluctuations in the bending moment due to steady state motions and with additional slam induced whipping were simulated in the irregular wave calculations. An illustration is given below in Figure A10.5 taken from the main body of this report and it can be seen that the total bending moment due to slamming contains more of the higher frequency oscillations, which represent whipping, than in the steady state bending.

The simulations showed that whipping effects following a slam increased the maximum bending moment for a particular wave encounter. The random nature of the motions had, however, to be taken into account when assessing any increase in the maximum bending

moment during a series of wave encounters in irregular seas so whipping could not simply be added to the steady state maximum.

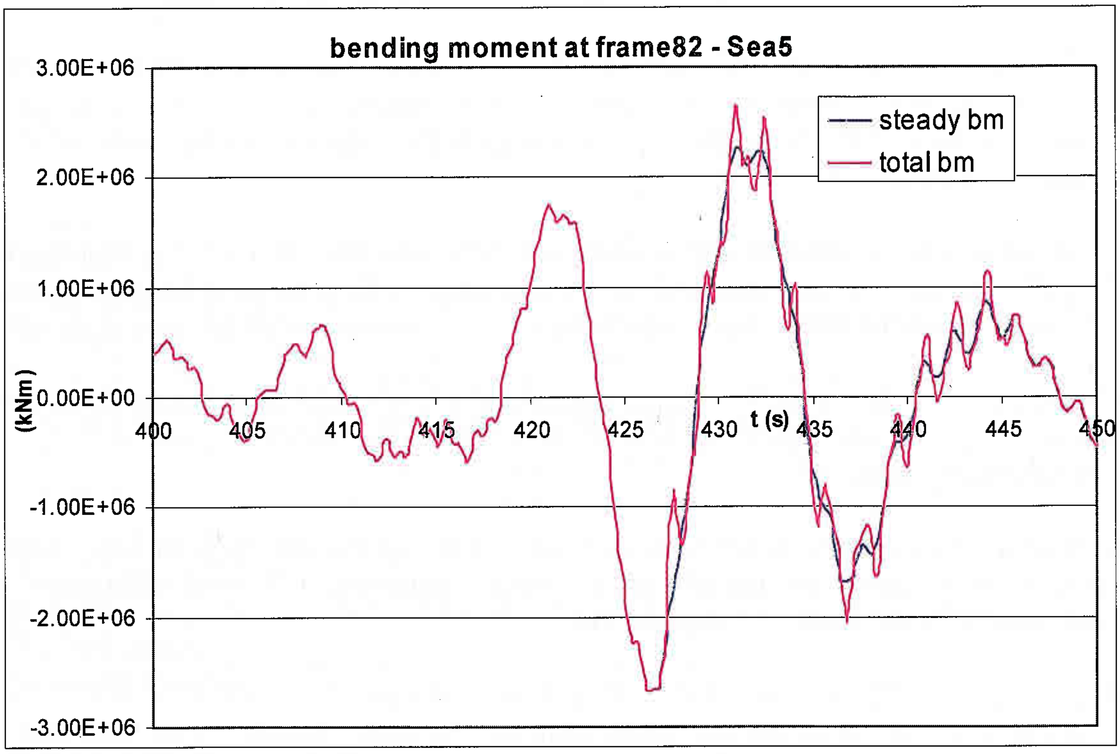

Fig. A10.5: Part of (a) Bending moment and (b) Shear force time histories in the vicinity of the aft quarter, e.g. at frame 82 – Sea5; the part of time history corresponds to the occurrence of a slam with 0.2L forefoot emergence.

Although bottom slamming occurs in both of the JONSWAP sea spectra used; it is neither severe nor intense enough for whipping to have any effects in the vicinity of the aft quarter, namely frames 82 and 88.

More severe, yet realistic, two-parameter seas were used to increase slamming severity as well as intensity, in an attempt to simulate impulsive forces on the forebody commensurate with severe flare slamming, and these produced an increase of up to 17% in the maximum bending moment due to whipping.

Whipping will continue to increase with the severity of the seas but this may not correspond to realistic conditions. It is, therefore, important to simulate flare slamming but extensive revision of existing 2D hydroelasticity analysis is required to turn it into a flare slamming methodology

Within the limitations of the 2D investigation carried out, the bending moment, shear force and stresses due to whipping are not considered significant enough to influence the structural failure in way of frames 82 and 88. However, during the investigations it was observed, with or without the inclusion of slamming, that the keel stresses in the vicinity of the aft quarter, namely frames 82 and 88, can be as large as the keel stresses at amidships. This is an issue of concern to us, irrespective of the effects of whipping.

The report identified areas where the global 2D analysis may be insufficient in allowing for the details of the structure around the aft quarter, e.g. influence of effective shear area. Thus, 3D modelling of the structure for global dynamic analysis in waves is recommended, to allow an improved qualitative, as well as quantitative, understanding of the wave-induced stress distribution in the vicinity of the aft quarter

MSC Napoli - Buckling Checks - Frame 82
BMT SeaTech Ltd

MSC Napoli - Buckling Checks - Frame 82

This calculation assess the buckling strength of the bottom structure of MSC Napoli in way of Frame 82.

The calculations are performed using:

a) "Rules & Regulations for the Classification of Steel Ships of more than 65m in length"
Bureau Veritas, November 1987
Part II, Chapter 3, Section 3-7 Buckling Criteria

b) "Unified Requirement S11 - Longitudinal Strength Standard", IACS req.1989/Rev.5 2006

Main Particulars

Scantling Length (97% of loaded waterline length) $L := 258.31$ m

Moulded Breadth $B := 37.10$ m

Scantling Draught $T := 13.5$ m

Moulded Depth $C := 21.5$ m hence $\frac{C}{\sqrt{L}} = 1.338$

Block Coefficient $C_b := 0.609$

Buckling Checks using BV Rules (1987)

Fr88 Still Water Bending Moments

(Ref: 4,400 TEU Post-Panamax Container Vessel - Trim & Stability Calculation (Incl. Longl. Strength Calc.) - m/v "CGM Normandie")

Maximum design still water bending moment (hogging) $M_{CHmax} := 2258000$

Minimum still water bending moment (hogging) $M_{CHmin} := 1585000$

$$0.9 \cdot M_{CHmax} + 0.1 \cdot M_{CHmin} = 2.191 \cdot 10^6$$

Vertical Wave Bending Moments (Section 3-34)

Coefficient, F

$$F := \begin{cases} \left[109.5 - \left(\frac{L}{3}\right)\right]\cdot\frac{L}{1000} & \text{if } L \le 120 \\ \left[10.75 - \left(\frac{300 - L}{100}\right)^{\left(\frac{3}{2}\right)}\right] & \text{if } 120 < L \le 300 \\ 10.75 & \text{if } 300 < L \le 350 \\ \left[10.75 - \left(\frac{L - 350}{150}\right)^{\left(\frac{3}{2}\right)}\right] & \text{if } 350 < L \le 350 \end{cases}$$

$F = 10.481$

Coefficient, Cv In sagging condition $C_{Vsag} := 65$

Coefficient, Cv In hogging condition $C_{Vhog} := 58.5$

Rule Vertical Wave Bending Moment Amidships (Probability Level 10^{-5})

$M_{HVsag} := -C_{Vsag}\cdot F\cdot L^2\cdot B\cdot\left(C_b + 0.7\right)\cdot 10^{-3}$ $M_{HVsag} = -2.208\cdot 10^6$ kNm

$M_{HVhog} := C_{Vhog}\cdot F\cdot L^2\cdot B\cdot\left(C_b + 0.7\right)\cdot 10^{-3}$ $M_{HVhog} = 1.987\cdot 10^6$ kNm

Maximum Vertical Wave Bending Moment Amidships (Probability Level 10^{-8})

$M_{HVsagmax} := M_{HVsag}\cdot 1.6$ $M_{HVsagmax} = -3.532\cdot 10^6$ kNm

$M_{HVhogmax} := M_{HVhog}\cdot 1.6$ $M_{HVhogmax} = 3.179\cdot 10^6$ kNm

Longitudinal Distribution of Vertical Wave Bending Moment

$$\mathrm{Data} := \mathrm{READPRN}(\mathrm{frame})$$

$$\mathrm{Frame} := \mathrm{Data}^{\langle 0 \rangle} \qquad \mathrm{Xpos} := \mathrm{Data}^{\langle 1 \rangle}$$

$$\mathrm{XFit} := \frac{\mathrm{linterp}(\mathrm{Frame}, \mathrm{Xpos}, 82)}{1000}$$

$\mathrm{XFit} = 64.2$ m at frame 82

$$\mathrm{FactX} := \begin{bmatrix} 0 \\ 0.4 \cdot L \\ 0.5 \cdot L \\ 0.6 \cdot L \\ L \end{bmatrix} \qquad \mathrm{FactX} = \begin{bmatrix} 0 \\ 103.324 \\ 129.155 \\ 154.986 \\ 258.31 \end{bmatrix}$$

$$\mathrm{FactY} := \begin{bmatrix} 0 \\ M_{HVhog} \\ M_{HVhog} \\ M_{HVhog} \\ 0 \end{bmatrix} \qquad \mathrm{FactY} = \begin{bmatrix} 0 \\ 1986767 \\ 1986767 \\ 1986767 \\ 0 \end{bmatrix}$$

$$M_{HV82} := \mathrm{linterp}(\mathrm{FactX}, \mathrm{FactY}, \mathrm{XFit})$$

Vertical Wave Bending Moment (hogging) at Frame 82 (Probability Level 10^{-5}) $M_{HV82} = 1234471$ kNm

Buckling Criteria (Section 3-7)

Reduction Coefficients (Table 3-1-I) $r_0 := 1$ $r_1 := 1$ $r_2 := 1$ $r_3 := 16.5$

Usage factor for steel $s := 1.15$

Panel Data

$$\text{Panel} := \begin{array}{cccccc|l} a & b & e & Wf & Re & \varepsilon & \text{Location} \\ 800 & 1210 & 18 & 20.02 & 315 & 1.25 & \text{Bottom shell between CL girder and girder 1210 off CL} \\ 800 & \frac{1395}{2} & 18 & 20.02 & 315 & 1.25 & \text{Bottom shell between girders 1210 and 2605 off CL} \\ 800 & \frac{3445}{2} & 18 & 21.6 & 315 & 1.25 & \text{Bottom shell between girders 2605 and 6050 off CL} \\ 800 & 2871 & 18 & 24.69 & 315 & 1.25 & \text{Bottom shell between girder 6050 off CL and tank top} \\ 800 & 3281 & 18 & 32.08 & 315 & 1.25 & \text{Side shell between tank top and bhd 11270 off CL} \\ 800 & 1210 & 15 & 24.69 & 235 & 1.25 & \text{Tank top between CL girder and girder 1210 off CL} \\ 800 & \frac{1395}{2} & 15 & 24.69 & 235 & 1.25 & \text{Tank top between girders 1210 and 2605 off CL} \\ 800 & \frac{3445}{2} & 15 & 24.69 & 235 & 1.25 & \text{Tank top between girders 2605 and 6050 off CL} \\ 800 & 1600 & 19 & 24.69 & 235 & 1.25 & \text{Tank top between girder 6050 off CL and tank top} \end{array}$$

Dimension of unloaded side of panel $a := \text{Panel}^{\langle 0 \rangle}$ $a^T = \begin{pmatrix} 800 & 800 & 800 & 800 & 800 & 800 & 800 & 800 & 800 \end{pmatrix}$

Dimension of loaded side of panel $b := \text{Panel}^{\langle 1 \rangle}$ $b^T = (1210 \quad 698 \quad 1723 \quad 2871 \quad 3281 \quad 1210 \quad 698 \quad 1723 \quad 1600$

Thickness of plating $e := \text{Panel}^{\langle 2 \rangle}$ $e^T = \begin{pmatrix} 18 & 18 & 18 & 18 & 18 & 15 & 15 & 15 & 19 \end{pmatrix}$

Section modulus at bottom $W_f := \text{Panel}^{\langle 3 \rangle}$ ${W_f}^T = \begin{pmatrix} 20 & 20 & 21.6 & 24.7 & 32.1 & 24.7 & 24.7 & 24.7 & 24.7 \end{pmatrix}$

Yield point of steel $R_e := \text{Panel}^{\langle 4 \rangle}$ ${R_e}^T = \begin{pmatrix} 315 & 315 & 315 & 315 & 315 & 235 & 235 & 235 & 235 \end{pmatrix}$

Coefficient ε $\varepsilon := \text{Panel}^{\langle 5 \rangle}$ $\varepsilon^T = \begin{pmatrix} 1.25 & 1.25 & 1.25 & 1.25 & 1.25 & 1.25 & 1.25 & 1.25 & 1.25 \end{pmatrix}$

Aspect ratio $\alpha_i := \frac{a_i}{b_i}$ $\alpha^T = \begin{pmatrix} 0.7 & 1.1 & 0.5 & 0.3 & 0.2 & 0.7 & 1.1 & 0.5 & 0.5 \end{pmatrix}$

Assuming uniform compressive stress (taking lowest stress acting on panel):

Coefficient, K

$$K_i := \begin{cases} \left[1 + \left(\alpha_i\right)^2\right]^2 & \text{if } \alpha_i < 1 \\ 4 & \text{otherwise} \end{cases}$$

$$K^T = \begin{pmatrix} 2.1 & 4 & 1.5 & 1.2 & 1.1 & 2.1 & 4 & 1.5 & 1.6 \end{pmatrix}$$

Smaller dimension of plate panel

$$E_i := \begin{cases} a_i & \text{if } a_i < b_i \\ b_i & \text{otherwise} \end{cases}$$

$$E^T = \begin{pmatrix} 800 & 697.5 & 800 & 800 & 800 & 800 & 697.5 & 800 & 800 \end{pmatrix}$$

Euler Stress

$$\sigma_{E_i} := 186000 \cdot \left(\frac{e_i}{E_i}\right)^2 \cdot K_i \cdot \varepsilon_i$$

$$\sigma_E{}^T = \begin{pmatrix} 243 & 619 & 174 & 137 & 132 & 169 & 430 & 121 & 205 \end{pmatrix}$$

Scantling Criteria of Plates

Allowable stress considering uniaxial compression

$$\sigma_{\text{allowable}_i} := \begin{cases} \dfrac{\sigma_{E_i}}{s^{\frac{3}{2}}} & \text{if } \sigma_{E_i} < \dfrac{s \cdot R_{e_i}}{2} \\ \left[\dfrac{R_{e_i}}{\sqrt{s}} \cdot \left(1 - \dfrac{s \cdot R_{e_i}}{4 \cdot \sigma_{E_i}}\right)\right] & \text{otherwise} \end{cases}$$

$$\sigma_{\text{allowable}}{}^T = \begin{pmatrix} 184 & 251 & 141 & 111 & 107 & 131 & 185 & 98 & 147 \end{pmatrix}$$

Compressive Stress on Panels

$$\sigma_{f_i} := \frac{1.6 \cdot r_0 \cdot 1 \cdot M_{HV82} + 0.9 \cdot M_{CHmax} + 0.1 \cdot M_{CHmin}}{W_{f_i}} \cdot 10^{-3}$$

$$\sigma_f{}^T = \begin{pmatrix} 208.1 & 208.1 & 192.9 & 168.7 & 129.9 & 168.7 & 168.7 & 168.7 & 168.7 \end{pmatrix}$$

Utilisation

$$UF_i := \frac{\sigma_{f_i}}{\sigma_{\text{allowable}_i}}$$

$$UF^T = \begin{pmatrix} 1.1 & 0.8 & 1.4 & 1.5 & 1.2 & 1.3 & 0.9 & 1.7 & 1.1 \end{pmatrix}$$

Buckling Checks to IACS UR S11 rev.5

Wave Loads

Position of Frame 82 $XFit = 64.2$

Distribution Factor at midships $M_{mid} := 1$

at Fr 82 $M_{82} := \frac{XFit}{0.4 \cdot L}$

$M_{82} = 0.621$

For 90 < L < 300 $C := 10.75 - \left(\frac{300 - L}{100}\right)^{1.5}$

BM midships $M_{Whog} := 190 \cdot M_{mid} \cdot C \cdot L^2 \cdot B \cdot C_b \cdot 10^{-3}$

$M_{Whog} = 3.002 \cdot 10^6$

$M_{Wsag} := 110 \cdot M_{mid} \cdot C \cdot L^2 \cdot B \cdot \left(C_b + 0.7\right) \cdot 10^{-3}$

$M_{Wsag} = 3.736 \cdot 10^6$

BM at Frame 82 $M_{Whog82} := 190 \cdot M_{82} \cdot C \cdot L^2 \cdot B \cdot C_b \cdot 10^{-3}$

$M_{Whog82} = 1.865 \cdot 10^6$

$M_{Wsag82} := 110 \cdot M_{82} \cdot C \cdot L^2 \cdot B \cdot \left(C_b + 0.7\right) \cdot 10^{-3}$

$M_{Wsag82} = 2.321 \cdot 10^6$

Hogging wave bending moment at Fr82 $M_W := M_{Whog82}$

Working Stress

Still water bending moment at Fr82 $M_S := M_{CHmax}$

$M_S = 2.258 \cdot 10^6$

Hull section modulus at frame 82 (cm^3) $z := W_f\, 100^3$

Longitudinal compressive stress (N/mm^2) $\sigma_{a_i} := \dfrac{M_S + M_W}{z_i} \cdot 10^3$

$$\sigma_a{}^T = (\,206 \quad 206 \quad 191 \quad 167 \quad 129 \quad 167 \quad 167 \quad 167 \quad 167\,)$$

Buckling Strength Parameters

Standard deduction
$$\text{deduction}_i := \left|\begin{array}{l} 0.5 \ \text{ if } \ 0.05 \cdot e_i < 0.5 \\ 1 \ \text{ if } \ 0.05 \cdot e_i > 1 \\ 0.05 \cdot e_i \ \text{ otherwise} \end{array}\right.$$

Thickness of plating $t_b := e - \text{deduction}$

Shorter side of plate panel, in m
$$s_i := \left|\begin{array}{l} \dfrac{a_i}{1000} \ \text{ if } \ a_i < b_i \\ \dfrac{b_i}{1000} \ \text{ otherwise} \end{array}\right.$$

Longer side of plate panel, in m
$$l_i := \left|\begin{array}{l} \dfrac{b_i}{1000} \ \text{ if } \ a_i < b_i \\ \dfrac{a_i}{1000} \ \text{ otherwise} \end{array}\right.$$

Modulus of elasticity of material $E := 2.06 \cdot 10^5$

Yield stress of material $\sigma_F := R_e$

For plating stiffened by floors or deep girders $c := 1.3$

Ratio between smallest and largest compressive stress $\psi := 1$

For plating with transverse stiffeners
$$m_i := c \cdot \left[1 + \left(\frac{s_i}{l_i}\right)^2\right]^2 \cdot \frac{2.1}{\psi + 1.1}$$

Critical Buckling Stress

Ideal elastic buckling stress

$$\sigma_{E_i} := 0.9 \cdot m_i \cdot E \cdot \left(\frac{t_{b_i}}{1000 \cdot s_i} \right)^2$$

$$\sigma_E^T = (227 \quad 449 \quad 163 \quad 128 \quad 124 \quad 158 \quad 312 \quad 113 \quad 192)$$

Critical buckling stress in compression

$$\sigma_{C_i} := \left\| \begin{array}{l} \sigma_{E_i} \ \text{ if } \ \sigma_{E_i} < \dfrac{\sigma_{F_i}}{2} \\ \left[\sigma_{F_i} \cdot \left(1 - \dfrac{\sigma_{F_i}}{4 \cdot \sigma_{E_i}} \right) \right] \ \text{ otherwise} \end{array} \right.$$

$$\sigma_C^T = (206 \quad 260 \quad 163 \quad 128 \quad 124 \quad 148 \quad 191 \quad 113 \quad 163)$$

Longitudinal compressive stress (from above) $$\sigma_a^T = (206 \quad 206 \quad 191 \quad 167 \quad 129 \quad 167 \quad 167 \quad 167 \quad 167)$$

The design buckling stress σ_C of plate panels is not to be less than the longitudinal compressive stress σ_a i.e. the utilisation σ_a/σ_C must be less than 1.

Plate panel utilisation

$$\text{Utilisation}_i := \frac{\sigma_{a_i}}{\sigma_{C_i}}$$

$$\text{Utilisation}^T = (1 \quad 0.8 \quad 1.2 \quad 1.3 \quad 1 \quad 1.1 \quad 0.9 \quad 1.5 \quad 1)$$