D 6.1 “Ship Structure”

Creation Date: 2013-02-15
Revision Date: 2014-04-22
Project: MoVeIT!
WP: WP 6

Responsible: CMT - Timo Wilcke

ABSTRACT

This deliverable 6.1 “Ship Structure” presents the investigations on the lengthening possibilities of two existing inland navigation vessels for dry bulk cargo, MV “Hendrik” (L_{OA} 70.0 m) and MV “Rheinland” (L_{OA} 57.5 m), representing a share of the European fleet in need of retrofitting and modernisation in order to regain competitiveness on the market. Among other retrofitting procedures such as increasing the breadth of the hull or conversion for different types of purposes, lengthening the ship’s hull in the midship area by a prismatic section is the most effective and cost efficient way.

MV “Hendrik”, originally built in 1975, represents CEMT class III to IV (Conférence Européenne des Ministres de Transport) for inland navigation vessels and features a double bottom and single side platings. CEMT class II is represented by MV “Rheinland”, built in 1959, which is equipped with a single hull. Both vessels comprise transversally framed ordinary mild steel structures. Those two vessels serve as basis for exemplary investigation on the lengthening of the ship’s hull and its required strength.

After the determination of current plate thicknesses and stiffener dimensions according to GL (Germanischer Lloyd) rules for MV “Hendrik” and BV (Bureau Veritas) rules for MV “Rheinland” and comparison with the “as built” dimensions from the general arrangement drawings, investigations were made in order to define the maximum possible lengthening sections. Hence, each step was set to 6.0 m. The maximum lengthening sections turned out to be 18.0 m for MV “Hendrik” and 12.0 m for MV “Rheinland” which were limited by the thicknesses of existing plates. Additionally, some stiffeners had to be modified to comply with the current rules.

For economic purposes, initial estimations regarding the cargo benefit and draught reduction per lengthening meter were made as well as an approximate cost calculation for the retrofitting procedures.

The results will serve as input for all other tasks within WP 6 and additionally WP 7.

Document Properties

Document Name:	D 6.1 “Ship Structure”
Document Author(s)	Timo Wilcke (CMT), Ionel Chirica (UGAL), Vasile Giuglea (SDG)
Document Editor(s)	Timo Wilcke (CMT)
Date of delivery	2014-04-30
Nature of Deliverable	☒ Report ☐ Prototype ☐ Demonstrator ☐ Other
Circulation	
Security Status	
Document Status	☐ Draft ☒ Final ☐ Approved by SG Steering (or SP meeting type-D) ☒ Approved by reviewer ☐ Acknowledged by MOVEIT! Steering ☐ Issued to EC
Keywords	Ship Structure Hull --- --- ---
Related MoVeIT! Reports	D 5.1, D 5.2, D 5.3, D 5.4, D 7.1

Partners involved

No.	Organisation Name	Name	Email
4	Technische Universiteit Delft	Dr. Robert G. Hekkenberg	R.G.Hekkenberg@tudelft.nl
5	CENTER OF MARITIME TECHNOLOGIES e.V.	Malte Riesner Dr. Lars Molter Timo Wilcke	via molter@cmt-net.org molter@cmt-net.org wilcke@cmt-net.org
7	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK - TNO	Alex Vredefeldt	lex.vredeveldt@tno.nl
12	UNIVERSITATEA DUNAREA DE JOS DIN GALATI	Prof. Dr. Ionel Chirica	Ionel.chirica@ugal.ro
14	University of Belgrade – Faculty of Mechanical Engineering	Prof. Dr. Dejan Radojcic Prof. Dr. Milorad Motok	radojcic@beotel.rs mmotok@mas.bg.ac.rs
16	SHIP DESIGN GROUP SRL	Vasile Giuglea	vgiuglea@shipdesigngroup.eu

Document history

Version	Date of delivery	Changes	Author(s) Editor(s)	Reviewed by
1	2013-02-15	First version for approval	Timo Wilcke (CMT), Prof. Dr. Ionel Chirica (UGAL), Vasile Giuglea (SDG)	Prof. Dr. Milorad Motok (BU)
2	2014-04-22	Reviewed version for approval	Timo Wilcke (CMT)	Dr. Robert G. Hekkenberg (DUT)

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1. Executive Summary

The subsequent chapter provides an overview of the investigations that have been carried out within task 6.1 “Ship Structure” being part of WP 6 “New Scales & Services” in the MoVe IT! Project (Modernisation of Vessels for Inland Waterway Freight Transport).

1.1. Problem Definition

Modernisation of existing overaged small inland navigation vessels in terms of retrofitting is a central issue for European ships in order to regain economical competitiveness through increasing the ship’s cargo capacity or reducing the draught by lengthening the vessel in the mid ship area.
For this reason, the general objective is to work out maximum feasible lengthening sections and optimum lengthening sections for the selected inland navigation vessels which represent a share of the European fleet in need of modernisation. Moreover, the investigations have to be executed according to existing rules and regulations of classification societies, defining minimum plate thicknesses and stiffener dimensions for the structural members of the hull. A comparison of thicknesses of existing parts with required thicknesses of parts of the lengthened solution reveals the maximum possible length for each particular vessel. Hence, the ultimate solution will include as little changes in the existing steel structure as possible.
The determination of the scantlings of the structural elements involves the use of ordinary mild steel structures, commonly used in the shipbuilding industry. Novel solutions with new materials such as composites and advanced construction techniques refer to WP 5 where such solutions are developed and examined.

1.2. Technical approach

First step was to select two appropriate reference vessels with typical characteristics for their specific CEMT class. Exotic ship types were disregarded in order to easily adopt the procedures and thus the results to a major share of the European inland navigation vessel fleet. This phase turned out to be difficult because very limited information on the reference vessels could be gathered due to the fact that even the ship owners often cannot provide further information regarding their ships.
Beside this challenge, two dry bulk cargo ships were selected:

- MV “Hendrik”: L_{OA} 70.0 m, double bottom, single side, CEMT class III to IV
- MV “Rheinland”: L_{OA} 57.5 m, single hull, CEMT class II

Based on the technical documentation available, current rules and requirements from two classification societies were applicated. GL rules served as basis for the lengthening procedure of MV “Hendrik” and BV rules governed the lengthening of MV “Rheinland” in order to diversify the application cases. For each of the two vessels the lengthening step has been set to intervals of 6.0 m, which corresponds approximately to the length of a TEU. The maximum considerable length for MV “Hendrik” is set to 94.99 m because 95.0 m forms the transition into a higher CEMT class with requirements relating to additional crew.
Regarding the determination of the scantlings of the structural members the procedure is similar for both classification societies. Generally, the sequence is as follows:

I. Determination of the ship’s bending moments based on load cases in hogging and sagging condition

II. Calculation of the ship’s motions and accelerations ant the resulting pressures

III. Determination of the net thicknesses and net section moduli of the structural members

IV. Calculation of the net section modulus of the main frame section and check for compliance with the governing rules

V. Stage III and IV have to be repeated if the required section modulus by the rules is not fulfilled

VI. Identify the corrosion addition for each plating and stiffener and calculate the gross thickness by rounding off to the next half millimetre

VII. Comparison of the values “as built” with the values obtained by the lengthened vessel

Additional FE analyses may provide extra information for the dimensioning of the structural members if applicable.
Furthermore, the cargo benefit at equal draught and the decrease in draught for equal cargo for each lengthening step were investigated. These results and initial cost estimation for the lengthening sections will provide an overview on the benefits and the feasibility of such a retrofitting procedure.

1.3. Results and Achievements

The lengthening analysis on the two overaged inland navigation vessels reveal the maximum feasible lengthening section for each ship by applying conventional steel structure solutions.
The limit turned out to be an additional section of 18.0 m, resulting in a L_{OA} 88.0 m, for MV “Hendrik” accompanied with a few modifications to the existing structural members such as upgrading ordinary side frames and replacing every fourth side frame by a side web girder. The maximum possible length for an additional section for MV “Rheinland” is 12.0 m. However, this procedure can only be executed if additional longitudinal stiffeners are fitted to the bottom plates to reduce the buckling length and if the classification society advisor accepts the direct calculations of the ship’s hull regarding the floors and web frames.
The results for the two different vessels show the general feasibility of retrofitting by lengthening of the ship’s hull at the midship area. Economical benefits can be obtained either by increasing the amount of cargo at equal draught or decreasing the draught at constant amount of cargo in order to enhance the operating time in low water periods.
Furthermore, additional masses of the vessel’s steel structure and retrofitting costs are assessed to serve as basic input for ship owners to decide whether the ship lengthening can be taken in consideration for their current fleet.

1.4. Contribution to MoVeIT! objectives

This deliverable provides input data for the subsequent tasks 6.2 to 6.4 within WP 6, investigating the manoeuvrability and powering of lengthened inland navigation vessels as well as the synthesis and impact assessment of those tasks, and WP 7.

1.5. Exploitation and Implementation

In WP 6, two alternative ways for retrofitting of the existing fleet are investigated:

I. Lengthening of small inland navigation vessels and its consequences to regain economical competitiveness (task 6.1 to 6.4)
II. Adaption of existing vessels to new market situations through conversion (task 6.5 to 6.7)

With respect to the Description of Work, this report concentrates on the impact of the lengthening process of small inland navigation vessels.

2. STRENGTH ANALYSIS AND LENGTHENING OF MV “Hendrik”

2.1. Application Case

The selected inland navigation vessel MV “Hendrik” (currently named “Alk”) was built in 1975 at the Joh. van Duijvendijk shipyard in Krimpen a/d Ijssel, Netherlands, with an original ship length over all of 70.0 m. It has been designed as a general dry bulk cargo ship consisting of 2 separate cargo holds with a length of 20 m each, covered by sliding hatch covers. Within a not further specified time period in between 1975 and 1990, the vessel has been already lengthened once by a division of 10.0 m to a total length over all of 80.0 m in order to improve the economical competitiveness of the vessel. In this application case the initial built vessel, which is depicted in Figure 1, forms the base state for the lengthening process not taken the already lengthened vessel into account.

According to vessel’s field of usage on the European inland waterways, different classes (CEMT I to V) have been introduced depending on their maximum length, breadth and draught. The vessel type as formerly built in 1975 was located between the CEMT waterway classes III and IV.

Figure 1. MV “Hendrik” as initially built [Source: (VERENIGING "DE BINNENVAART", 2012)]

The main particulars of the vessel presented in Table 1 were taken partially from the website “VERENIGING DE BINNENVAART” [source: (VERENIGING "DE BINNENVAART", 2012)] and the general arrangement drawing.

Table 1. Main particulars of MV “Hendrik”

Length over all	[m]	69.98
Breadth over all	[m]	8.60
Draught	[m]	2.95
Depth	[m]	3.00

Displacement	[t]	1360
Main engine	[-]	SKL 660 pk 6 NVD 48-2U

The ship’s structure was built from mild steel in conventional manner incorporating a single hull with transversal framing. Side frames, deck beams and floors are fitted every 0.5 m according to the general frame spacing. Vertical stiffeners at the side coaming are arranged every 2.0 m (four frame spacings).The general arrangement plan is illustrated in Figure 2.
Primary supporting members of the side shell or deck structure are not further specified due to limited information. Additional details such as scantlings of the bulkheads and their supporting structural members are missing as well. Absent information on specific details is assumed and indicated as required in the further lengthening process.

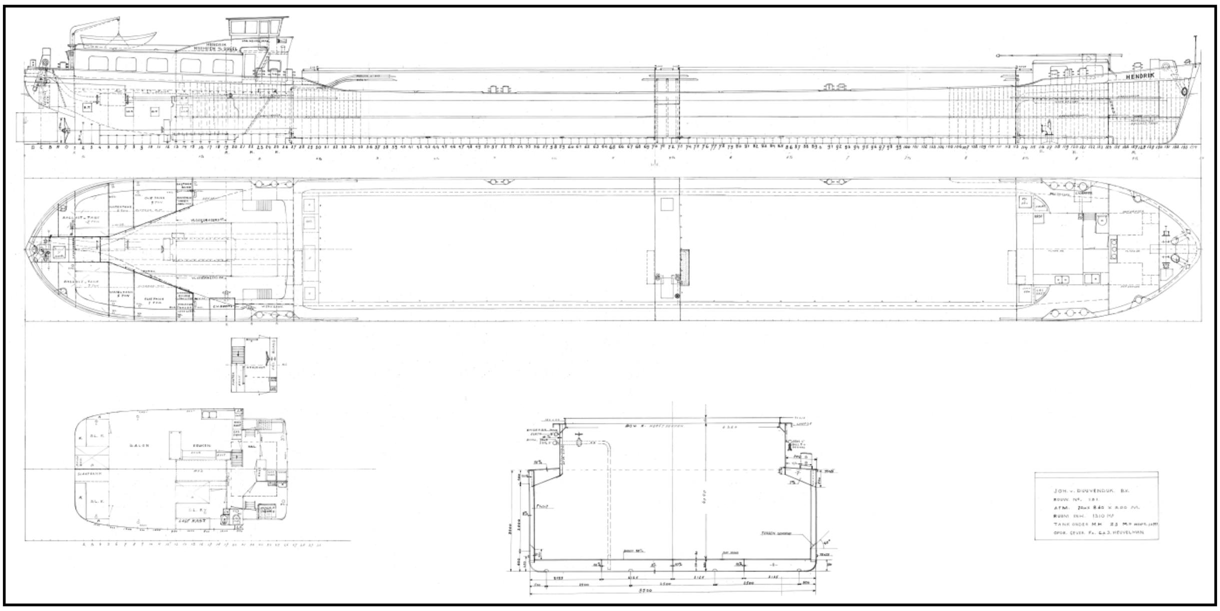

Figure 2. General arrangement drawing of MV “Hendrik”

The vessel’s aft peak ranges from the stern to frame 1 which is the aft engine room bulkhead. Main accommodation, bridge and engine room is positioned between frame 1 and 27. A 0.34 m high double bottom ranges from the engine room front bulkhead at frame 27 to the cargo bulkhead at frame 124. The cargo is transported in two separate holds: the aft hold ranges from frame 30 to frame 70 and the forward hold ranges from frame 73 to frame 113 with a space in between of 3 frame spacings for pumps and piping. Crew is accommodated between frame 113 and frame 124. From frame 124 on to the bow the fore peak is located. Detailed specifications of the main frame are given in Figure 3.

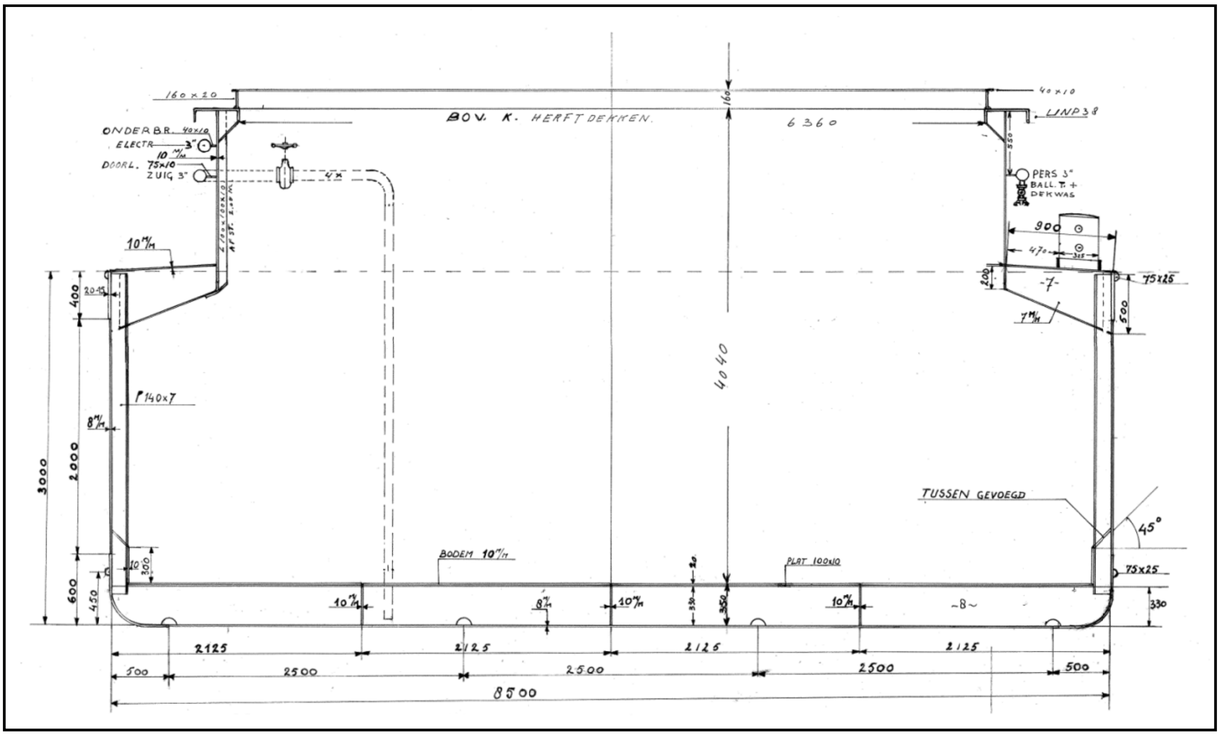

Figure 3. Main frame detail drawing of MV “Hendrik”

2.2. Freeboard Check

For each lengthening step a freeboard check according to the requirements for inland navigation vessels published by the European Union in 2006 has to be carried out [source: (Directive of the European Parliament and of the Council, 2006), pages 48 – 50]. Every vessel has to fulfil minimum freeboard requirements to be taken into account for safe operation in designated waters.

The results are presented in Table 2. In order to opt for a conservative approach, reductions of the allowable freeboard due to superstructures are neglected concerning for instance possible crew changes caused by the lengthening process. Solely the sheer is regarded with its maximum allowable values forward S_v (1000 mm) and aft S_a (500 mm). The abscissa of the sheer located at $0.25xS_v$ and $0.25xS_a$ taken from the forward and respectively aft end of the vessel are 17.5 m for both. The effective sheer is calculated according to the following formulae:

- $Se_v = S_v * 4 * X_v / L$
- $Se_a = S_a * 4 * X_a / L$

The minimum freeboard is derived from the equation below:

- $F = 150 * (Se_v + Se_a) / 15$

In order to calculate the maximum draught of the vessel a deck plating thickness of 10 mm is assumed, which is taken from the general arrangement drawing. The maximum allowable draught of the vessel derives to:

- $T_{max} = D + t - F$

Table 2. Freeboard check of different lengthening steps for MV “Hendrik”

			L_{OA} 70.0	L_{OA} 76.0	L_{OA} 82.0	L_{OA} 88.0	L_{OA} 90.0	L_{OA} 95.0
L	Ship length	[m]	70.000	76.000	82.000	88.000	90.000	95.000
S_v	Forward sheer	[m]	1.000	1.000	1.000	1.000	1.000	1.000
X_v	Abscissa at $0.25xS_v$	[m]	17.500	17.500	17.500	17.500	17.500	17.500
Se_v	Effect. fwd. sheer	[m]	1.000	0.921	0.854	0.795	0.778	0.737
S_a	Aft sheer	[m]	0.500	0.500	0.500	0.500	0.500	0.500
X_a	Abscissa at $0.25xS_a$	[m]	17.500	17.500	17.500	17.500	17.500	17.500
Sa_v	Effect. aft sheer	[m]	0.500	0.461	0.427	0.398	0.389	0.368
F	Min. freeboard	[mm]	50	58	65	70	72	76
t	Deck plating	[mm]	10	10	10	10	10	10
D	Depth	[m]	3.000	3.000	3.000	3.000	3.000	3.000
T_{max}	Max. draught	[m]	2.960	2.952	2.945	2.940	2.938	2.934

As indicated in the table, the maximum allowable draught is decreasing with increasing ship length. However, the initial draught is set to maximum 2.95 m which means that values exceeding 2.95 m are not regarded (accounts for L_{OA} 70.0 m and L_{OA} 76.0 m).

2.3. The Vessel’s Steel Structure “as built”

First step in the lengthening process of an existing inland navigation vessel is the assessment of the current structure regarding their present plate and stiffener thicknesses. This is very important because corrosion takes place on the steel surfaces even though they are protected by multiple layers of paint. Due to very limited information on the entire steel structure of the selected vessel it was impossible to gather actual steel plate and stiffener thicknesses after corrosion exposure. For this reason, the actual state is assumed to be “as built” as illustrated in the general arrangement drawing to simplify the entire process.

The detailed specifications of the platings and the supporting structure are summarised in Table 3.

The double bottom is constructed with ordinary continuous floors on each frame spacing (0.5 m). A 100 mm wide and 10 mm thick flange supports the floor’s top face in order to increase the transversal strength of the vessel and back the inner double bottom platings. Three longitudinal girders divide the double bottom in four equally distributed compartments.

No specific details of primary steel structure at the side shells could be obtained. Therefore, it is assumed that there were no primary supporting members in the side shells during the built of the vessel in 1975. Ordinary stiffeners (bulb flat profiles 140x7) are located at every frame connected to the floors by lap joints and to the deck by brackets. The sheer strake has a width of 400 mm and the thickness is assumed to be 17.5 mm as average value from the given range of 15 mm to 20 mm in the general arrangement drawing.

The deck structure is arranged with a continuous stringer plate reaching from the sheer strake to the longitudinal hatch coaming. Deck beams are substituted by

continuous transversal brackets which connect the side frames and the longitudinal deck girder. The deck girder is a 200 mm downwards extended longitudinal hatch coaming with an equal thickness of 10 mm.
Two longitudinal stiffeners support the longitudinal hatch coaming. The primary stiffener is a U-profile welded onto the top edge of the coaming in order to increase the longitudinal strength of the hull, prevent the coaming from buckling and to serve as a track for the sliding hatch covers. An additional secondary stiffener is located on the outer side of the coaming and acts as support for piping. Every four frame spacings a vertical L-profile stiffens the longitudinal hatch coaming. The profile ranges from the primary longitudinal stiffener to the deck bracket at the bottom.
Unfortunately, no information about the scantlings of the cargo bulkheads could be obtained from the general arrangement drawing. For this reason, the data is missing and cannot be compared with values determined in the lengthening process later on.

Table 3. Scantlings of MV “Hendrik” as built in 1975

Item	Gross thickness or type of profile
	[mm]
Bottom plate	8.00
Inner bottom	10.00
Longitudinal girder	10.00
Floor	8.00
Floor face	Flat bar 100x10
Bulkhead cargo	n/a
Bulkhead cargo vertical stiffener	n/a
Bulkhead cargo horizontal stiffener	n/a
Chine radius	9.50
Side plating	8.00
Side frame trans.	Bulb flat 140x7
Side web girder	n/a
Sheer strake	17.50
Deck	10.00
Deck beam	7.00
Deck girder (longitudinal)	Flat bar 200x10
Hatch coaming	10.00
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	75x10
Hatch coaming vertical stiffener (stay)	L-profile 100x100x10

2.4. The Vessel’s Steel Structure According to GL Rules

After the investigation of the scantlings of the “as built” steel structure, next step is to determine the scantlings of the platings and stiffeners according to the current rules and regulations published by the classification society GL. The rules for inland navigation vessels have been updated and amended by GL in 2011. All calculations

made in this section are according to the 2011 rules [source: (Germanischer Lloyd, 2011)].
Key sections, used for the calculation, are summarised in the following:

- GL Part 2, Chapter 2, Section 2 “Materials and Structure Design Principles”
- GL Part 2, Chapter 2, Section 3 “Design Load Principles”
- GL Part 2, Chapter 2, Section 4 “Hull Girder Strength”
- GL Part 2, Chapter 2, Section 5 “Hull Scantlings”

The general method to determine the scantlings of the ship’s steel structure is to calculate net plate thicknesses or section moduli of stiffeners based on different load cases which affect the structural part. The maximum value has to be regarded as the governing dimension in most cases. The net thickness represents the minimum required dimension or section modulus without taken corrosion and special treatments such as grab loading into account. The gross thickness depends on different values for corrosion addition defined by GL regarding environmental exposure influences in a range from 0.5 mm to 2.0 mm for each face of the plate or stiffener. In this specific case, an additional increase of the inner bottom, the cargo bulkhead and the side shell stiffeners due to grab loading for dry bulk carriers are taken into account [source: (Germanischer Lloyd, 2011), Chapter 4, Section 4 B, 4] because the thickness of the “as built” inner bottom indicate that a grab loading addition has been applied. A buckling check according to the GL rules for plate fields and stiffeners has to be carried out for the outer bottom, inner bottom, floors, side shell, bulkheads and deck [source: (Germanischer Lloyd, 2011), Chapter 2, Section 2 C].
For the lengthening process mild steel (grade A: E = 2.06 N/mm², ReH = 235 N/mm², k = 1) is selected as material for the structural parts. Loading and unloading procedures are considered to be carried out in two runs. Moreover, homogenous cargo is assumed for the loading conditions. The range of navigation is IN(0.6) resulting in a significant wave height of 0.6 m which directly affects the bending moments of the hull in hogging and sagging conditions. For the calculation of the scantlings the severest bending moments according to GL rules (cargo, light ship, loading, unloading) are taken into account.

2.4.1. Corrosion Addition According to GL Rules

The scantlings of the structural steel parts of the ship’s hull are defined as gross thicknesses including a corrosion addition for each of the two faces of the part. The net thicknesses are calculated according to the GL rules and a corrosion addition, depending on the location of the structural member, for each side is added. Afterwards, the obtained value is rounded off to the nearest half millimetre [source: (Germanischer Lloyd, 2011), Chapter 2, Section 2 B, 2.2].
An exemplary summary of the corrosion additions for the structural members for a L_{OA} 70.0 m is presented in Table 4. The inner bottom thickness is increased by 2.0 mm and the cargo bulkhead by 1.5 mm due to assumed grab loading procedures in the hold.

Table 4. Corrosion additions of structural members for L_{OA} 70.0 m

Item	Corrosion addition			Remark
	Inner face	Outer face	Total	
	[mm]	[mm]	[mm]	
Bottom plate	0.80	0.80	1.60	
Inner bottom	3.00	1.00	4.00	Incl. 2.0 mm (grab loading)
Longitudinal girder	0.50	0.50	1.00	
Floor	0.50	0.50	1.00	
Floor face	1.00	1.00	2.00	
Bulkhead cargo	2.15	0.65	2.80	Incl. 1.5 mm (grab loading)
Bulkhead cargo vertical stiffener	0.50	0.50	1.00	
Bulkhead cargo horizontal stiffener	0.50	0.50	1.00	
Chine radius	1.00	1.00	2.00	
Side plating	0.75	0.75	1.50	
Side frame trans.	0.50	0.50	1.00	
Side web girder	0.50	0.50	1.00	
Sheer strake	1.00	1.75	2.75	
Deck	1.00	1.00	2.00	
Deck beam	0.50	0.50	1.00	
Deck girder (longitudinal)	0.50	0.50	1.00	
Hatch coaming	1.00	1.00	2.00	
Hatch coaming top stiffener	0.50	0.50	1.00	
Hatch coaming sec. stiffener	0.50	0.50	1.00	
Hatch coaming vertical stiffener (stay)	0.50	0.50	1.00	

2.4.2. Required Structure at LOA 70.0 m

A first investigation if the built steel structure is still sufficient according to 2011 GL rules for the base length of L_{OA} 70.0 m has to be carried out. These considerations serve as indicator for a feasible lengthening process of the vessel. The calculations

according to the current GL rules lead to the plate thicknesses and profile types presented in Table 5.
It has to be noted that each individual structural part, i.e. plating or stiffener, is below or equal to the limit “as built” except the side frames, the side web girder and the bulkhead scantlings. The cargo bulkhead has to be fitted with vertical primary stiffeners with a spacing of 1.5 m and horizontal secondary bulb flat profiles 120x7 with a spacing of 0.5 m. A corrugated bulkhead instead of the conventional construction method is not taken into account due to inferior retrofitting possibilities.

Table 5. Scantlings of MV “Hendrik” as required by GL for L_{OA} 70.0 m

Item	Gross thickness or type of profile [mm]
Bottom plate	7.50
Inner bottom	8.50
Longitudinal girder	10.00
Floor	5.50
Floor face	Flat bar 100x10
Bulkhead cargo	7.50
Bulkhead cargo vertical stiffener	Web: 250x11, Flange: 150x14
Bulkhead cargo horizontal stiffener	Bulb flat 120x7
Chine radius	9.00
Side plating	6.50
Side frame trans.	Bulb flat 160x9
Side web girder	Bulb flat 300x13
Sheer strake	15.50
Deck	9.00
Deck beam	6.00
Deck girder (longitudinal)	Flat bar 90x10
Hatch coaming	9.00
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	Flat bar 160x15
Hatch coaming vertical stiffener (stay)	L-profile 80x80x8

In the present configuration every fourth ordinary side frame, in total 36 items (18 each side), have to be replaced in the hold area by a side web girder, in this case a bulb flat profile 300x13. Moreover, the section modulus of the ordinary side frames in the cargo hold is insufficient and does not pass the present rules. Therefore, the section modulus has to be increased by either replacing the complete stiffeners or welding additional profile sections onto the existing stiffener for 124 items (62 each side). Replacing an existing stiffener is a time-consuming process and should be avoided if possible. Retrofitting of existing stiffeners can be executed according to the “Classification Notes No. 8: Conversion of Ships” published by DNV in 2004 [source: (Det Norske Veritas, 2004)]. This publication gives advice how to deal with the conversion of ships in particular lengthening and widening of the hull. Upgrading existing profiles is easier to manufacture than replacing platings which are undersized. Thus, as indicated, the side frames have to be upgraded from a bulb flat profile 140x7 to a section modulus equal to a bulb flat profile 160x9 according to Figure 4. Solution (c) is selected resulting in an additional welded-on flat bar of 40x9. Moreover, the secondary hatch coaming stiffener (flat bar 75x10) has to be replaced by a flat bar 160x15.

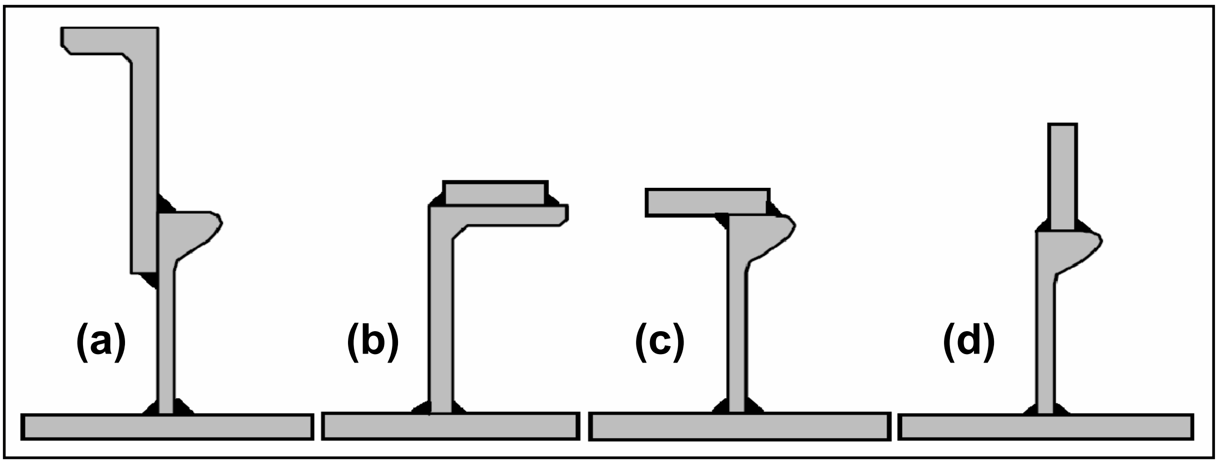

Figure 4. Increasing sections of stiffeners [source: (Det Norske Veritas, 2004) page 18]

2.4.3. Lengthening Step to LOA 76.0 m

The retrofitting procedures, described in the previous section, show the feasibility of a lengthening of the vessel. The first lengthening step from 70.0 m to 76.0 m results in an additional section of 6.0 m. One of the two holds can be enlarged by 6.0 m to 26.0 m in total in the main frame area. The maximum allowable hold length given by GL rules is 30.0 m. For this reason, no additional bulkheads have to be fitted to the hull but if necessary, existing ones have to be upgraded to the required scantlings. Table 6 summarises the determined scantlings for the section of 6.0 m length. The replaced and upgraded stiffeners as described in the previous section remain the same because the transversal strength is not seriously affected by the lengthening procedure.

Table 6. Scantlings of MV “Hendrik” as required by GL for L_{OA} 76.0 m

Item	Gross thickness or type of profile [mm]
Bottom plate	7.50
Inner bottom	9.00
Longitudinal girder	10.00
Floor	5.50

Floor face	Flat bar 100x10
Bulkhead cargo	7.50
Bulkhead cargo vertical stiffener	Web: 250x11, Flange: 150x14
Bulkhead cargo horizontal stiffener	Bulb flat 120x7
Chine radius	9.00
Side plating	6.50
Side frame trans.	Bulb flat 160x9
Side web girder	Bulb flat 300x13
Sheer strake	16.00
Deck	9.00
Deck beam	6.00
Deck girder (longitudinal)	Flat bar 100x9
Hatch coaming	9.00
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	Flat bar 160x15
Hatch coaming vertical stiffener (stay)	L-profile 80x80x8

2.4.4. Lengthening Step to LOA 82.0 m

For the second lengthening step a new separate hold with a length of 10.5 m has to be built. This procedure results in a hold configuration comprising two holds at 20.0 m length and one hold at 12.0 m length which requires two additional cargo bulkheads with corresponding primary and secondary stiffeners. The layout is equal to that at the main frame in the general arrangement drawing of MV “Hendrik” (Figure 2). The bulkhead arrangement comprises three additional frame spacings for pumps and piping and to separate the cargo holds (1.5 m in total).
Another hold configuration would be possible: extending each of the two existing holds by 6.0 m resulting in two separate holds at 26.0 m length. This procedure would save the additional bulkheads but requires two separate cuts, one at each hold, to lengthen the vessel. Separating and aligning the hull compartments would be time intensive. The weight benefit is located at around 6.0 t.
In this second lengthening step, again, the determined scantlings of the steel structure, shown in Table 7, do not exceed the scantlings of the vessel “as built” making this solution feasible. The retrofitting of the primary and secondary stiffeners in the side shell and the hatch coaming secondary stiffener remain the same as presented in section 2.4.2.

Table 7. Scantlings of MV “Hendrik” as required by GL for L_{OA} 82.0 m

Item	Gross thickness or type of profile [mm]
Bottom plate	8.00
Inner bottom	9.00
Longitudinal girder	10.00
Floor	6.00
Floor face	Flat bar 100x10
Bulkhead cargo	7.50
Bulkhead cargo vertical stiffener	Web: 250x11, Flange: 150x14
Bulkhead cargo horizontal stiffener	Bulb flat 120x7
Chine radius	9.50
Side plating	7.00
Side frame trans.	Bulb flat 160x9
Side web girder	Bulb flat 300x13
Sheer strake	16.50
Deck	9.50
Deck beam	6.00
Deck girder (longitudinal)	Flat bar 100x9
Hatch coaming	9.50
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	Flat bar 160x15
Hatch coaming vertical stiffener (stay)	L-profile 85x85x8.5

2.4.5. Lengthening Step to LOA 88.0 m

Lengthening the vessel from L_{OA} 70.0 m to 88.0 m as third step results in an additional hold with a length of 16.5 m and 1.5 m bulkhead spacing. This procedure requires two additional bulkheads with stiffening, equal to the lengthening step to L_{OA} 82.0 m. The calculations according to the GL rules result in the scantlings presented in Table 8. The “as built” values are again not exceeded. However, some plate thicknesses are close to the maximum allowable value such as the bottom plate, the chine radius and the longitudinal hatch coaming.

Table 8. Scantlings of MV “Hendrik” as required by GL for L_{OA} 88.0 m

Item	Gross thickness or type of profile [mm]
Bottom plate	8.00
Inner bottom	9.00
Longitudinal girder	10.00
Floor	6.00
Floor face	Flat bar 100x10
Bulkhead cargo	7.50
Bulkhead cargo vertical stiffener	Web: 250x11, Flange: 150x14
Bulkhead cargo horizontal stiffener	Bulb flat 120x7
Chine radius	9.50
Side plating	7.00
Side frame trans.	Bulb flat 160x9
Side web girder	Bulb flat 300x13
Sheer strake	17.50
Deck	10.00
Deck beam	6.00
Deck girder (longitudinal)	Flat bar 110x9
Hatch coaming	10.00
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	Flat bar 160x15
Hatch coaming vertical stiffener (stay)	L-profile 85x85x8.5

2.4.6. *Lengthening Step to LOA 90.0 m*

In order to reveal the maximum possible lengthening compartment for the vessel, a step of 20.0 m is considered, leading to an additional hold length of 18.5 m. As indicated in Table 9 (highlighted in red colour) three steel platings exceed the “as built” limit: the bottom plate, the chine radius and the hatch coaming. The thicknesses are required to satisfy the longitudinal strength of the hull and hence, the section modulus of the main frame. The GL buckling requirements are also fulfilled. For this reason, the maximum reasonable lengthening step is to a L_{OA} 88.0 m without including too much additional changes in the steel structure.
Keeping in mind that a conversion of a ship is treated by GL as a new building [source: (Germanischer Lloyd, 2011), Chapter 1, Section 1 C, 6.4.3], all existing undersized platings and stiffeners have to be replaced or upgraded to satisfy the requirements of the lengthened vessel. Changing the plates of a major area of a hull section is a complex and time-consuming process.

Fitting doubling plates instead is only allowed by GL rules in the sheer strake area but not for ordinary platings. Hence, this solution is not applicable for the lengthening due to required additional works leading to too high retrofitting costs.

Table 9. Scantlings of MV “Hendrik” as required by GL for L_{OA} 90.0 m

Item	Gross thickness or type of profile [mm]
Bottom plate	8.50
Inner bottom	9.50
Longitudinal girder	10.00
Floor	6.00
Floor face	Flat bar 100x10
Bulkhead cargo	7.50
Bulkhead cargo vertical stiffener	Web: 250x11, Flange: 150x14
Bulkhead cargo horizontal stiffener	Bulb flat 120x7
Chine radius	9.50
Side plating	7.00
Side frame trans.	Bulb flat 160x9
Side web girder	Bulb flat 300x13
Sheer strake	17.50
Deck	10.00
Deck beam	6.00
Deck girder (longitudinal)	Flat bar 110x10
Hatch coaming	10.50
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	Flat bar 160x15
Hatch coaming vertical stiffener (stay)	L-profile 85x85x8.5

2.4.7. Lengthening Step to L_{OA} 95.0 m

The last lengthening step is set to 25.0 m which is limited by the circumstance that the lengthened vessel would change its CEMT class to V above a L_{OA} 95.0 m. A class change is going to be avoided because that would comprise also a change in requirements for the vessel relating to additinal crew. This step is for comparison purposes only.
As indicated in Table 10, multiple scantlings of various plates (bottom plate, chine radius, sheer strake, hatch coaming) exceeded the “as built” values in this lengthening step caused by the required longitudinal strength of the hull at the main frame section. The initial side plating (gross thickness 7.50 mm) fails due to buckling.

Table 10. Scantlings of MV “Hendrik” as required by GL for L_{OA} 95.0 m

Item	Gross thickness or type of profile [mm]
Bottom plate	8.50
Inner bottom	9.50
Longitudinal girder	10.00
Floor	6.00
Floor face	Flat bar 100x10
Bulkhead cargo	8.00
Bulkhead cargo vertical stiffener	Web: 250x11, Flange: 150x14
Bulkhead cargo horizontal stiffener	Bulb flat 120x7
Chine radius	10.00
Side plating	7.50 / 8.50
Side frame trans.	Bulb flat 160x9
Side web girder	Bulb flat 300x13
Sheer strake	18.00
Deck	10.00
Deck beam	6.00
Deck girder (longitudinal)	Flat bar 110x10
Hatch coaming	11.00
Hatch coaming top stiffener	U-profile 370x90x15
Hatch coaming sec. stiffener	Flat bar 160x15
Hatch coaming vertical stiffener (stay)	L-profile 85x85x8.5

The initial net thickness of the side plating has to be increased from 6.10 mm to 7.00 mm in order to pass the GL buckling check (Variant A, Table 11). Taking the required corrosion addition into account, the gross thickness exceeds the “as built” value as well. Another possibility is to fit an additional longitudinal frame with a larger size than the ordinary side frames at a location half the height of the side frames (z = 1675 mm), presented as variant B in Table 11. With this modification, the base net thickness of 6.10 mm can remain the same and the side shell plate field passes the buckling check.

Table 11. Buckling check of side shell for L_{OA} 95.0 m

			Base variant	Variant A	Variant B
Length of single or partial plate field	[mm]	a	500	500	500
Breadth of single plate field	[mm]	b	2650	2650	1325
Aspect ratio of single plate field	[-]	α	0.189	0.189	0.377
Nominal plate thickness	[mm]	t	6.1	7.0	6.1
Buckling check (≤ 1.0)	[-]		1.109	0.977	0.543

Of course, existing plate fields can be replaced by thicker plates but will result in an extraordinary increase in production costs and labour efforts. Simple structural parts, such as the hatch coaming, might be in the scope to be replaced by a thicker plate or stiffened by an additional stiffener, but that solution is not covered by the rules and therefore needs negotiation with a classification society advisor. The thickness of the bottom platings and the chine radius, for instance, can be reduced by introducing additional longitudinal stiffeners to meet the longitudinal strength requirements. However, a mixture between transversal and longitudinal framing is not defined in the GL rules for inland navigation vessels and has to be also regarded as a special solution. It has to be kept in mind, that fitting stiffeners in the existing hull sections lead to difficulties at their endings or links to the new built hull section. The transition would result in a sudden change in stiffness in the structure, for this reason, special steel parts have to be developed in order to form a smooth and reliable transition.

2.5. Lengthening Summary

The investigation of possible lengthening steps at 6.0 m for the inland navigation vessel MV “Hendrik” reveals that 18.0 m is the maximum possible section length to be retrofitted to the existing hull in conventional building manner. Exceeding that length leads to conversion processes of the existing structures which are not governed by standard GL rules and regulations and require individual solutions. Figure 5 to Figure 8 illustrate the platings of interest which are limiting the lengthening of the hull at L_{OA} 88.0 m. Additional graphs can be found in Annex 7.1.
Limited information on steel structure details of MV “Hendrik” complicate the investigation of the lengthening of the hull. Typically, the analysis of the ship’s existing steel structure has to be based on thickness measurements of the actual steel components in order to assess the remaining strength of the components appropriately. This option could not be chosen because the data was unavailable. Therefore, the lengthening analysis of the vessel serves as general feasibility study for inland navigation vessels of the type of MV “Hendrik” in general and not as a special solution for the vessel.

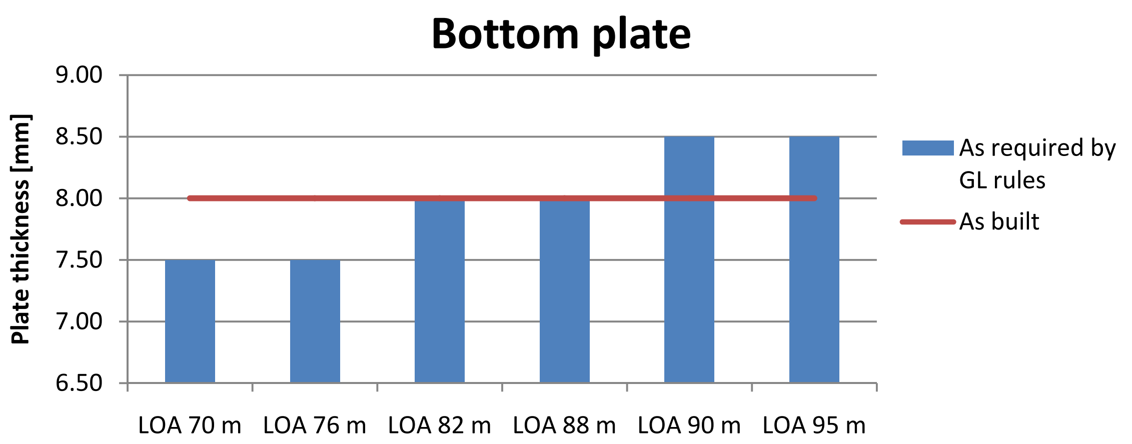

Figure 5. Bottom plate thicknesses for different lengthening steps

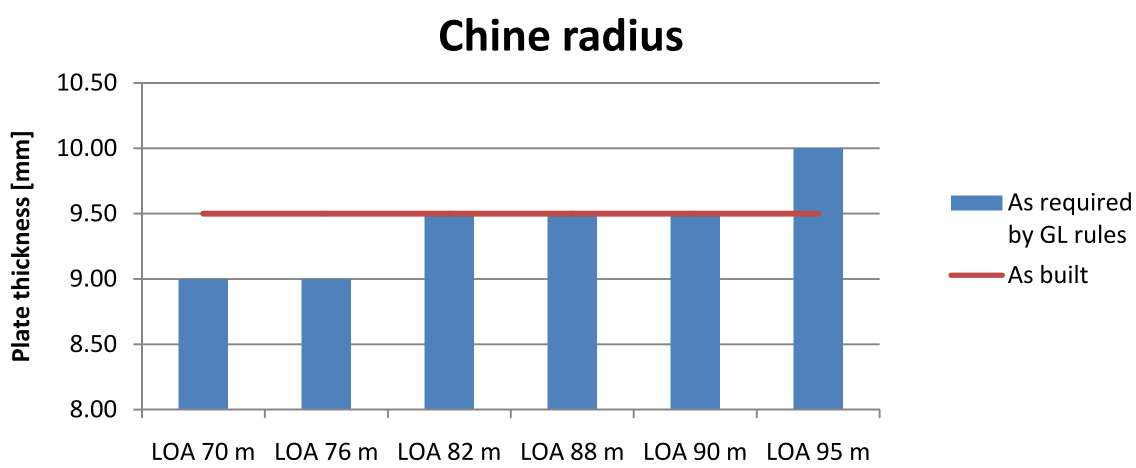

Figure 6. Chine radius thicknesses for different lengthening steps

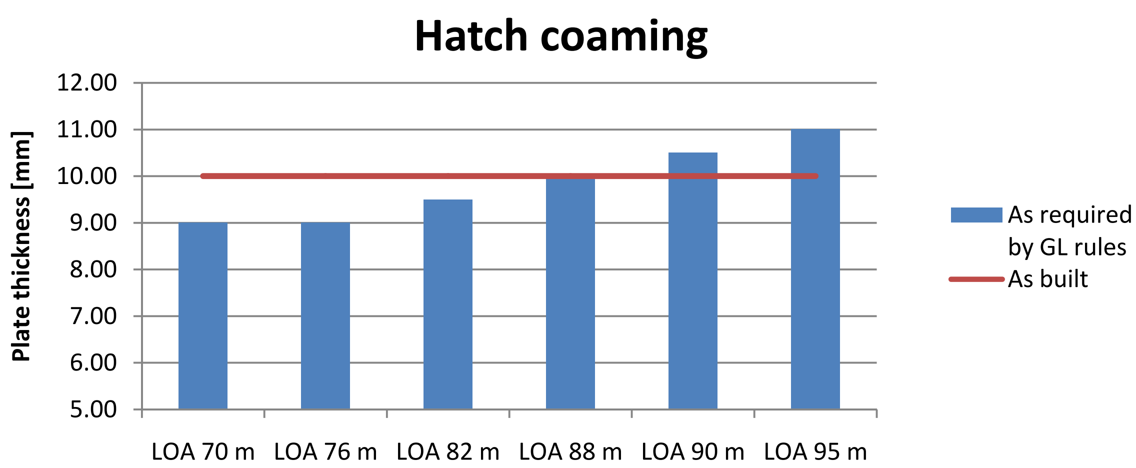

Figure 7. Hatch coaming thicknesses for different lengthening steps

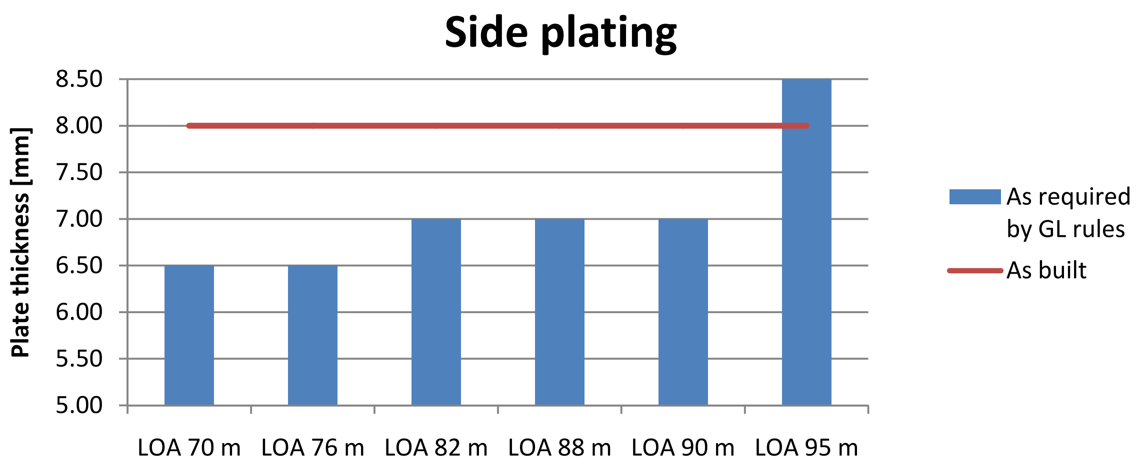

Figure 8. Side plating thicknesses for different lengthening steps

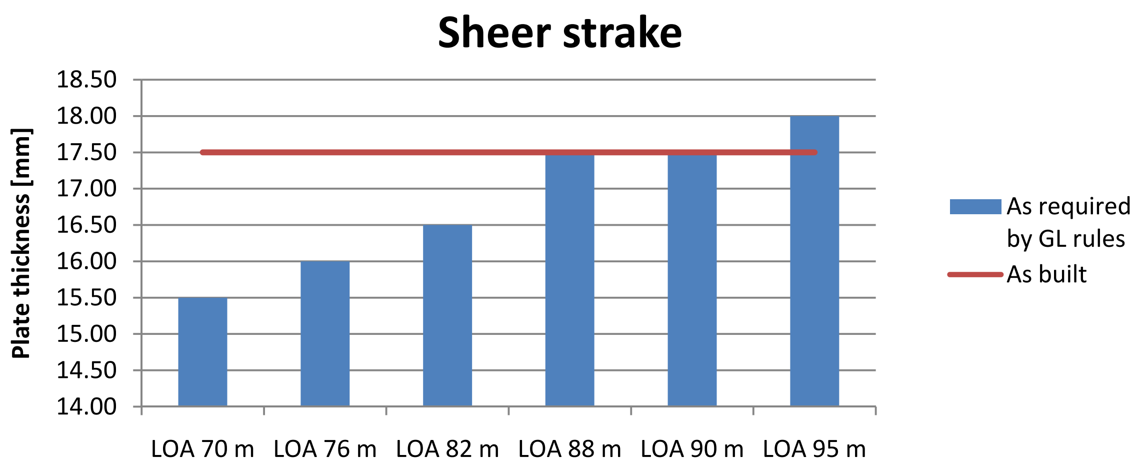

Figure 9. Sheer strake thicknesses for different lengthening steps

2.6. Mass Estimation

The additional mass for each lengthening step of the vessel is calculated for the vessel’s steel structure including hatch covers without taking outfitting such as piping or mooring equipment into account. The mass is composed of the mass of the new hull section, which is going to be fitted, and the modifications to the existing hull. Those modifications include the side frame stiffener upgrade in section modulus and the fitting of side web girders instead of ordinary side frames in the existing hold area as first approach. Detailed masses, calculated with the density of steel (7.850 t/m³), for each lengthening step are presented in Table 12. Every item category consists of the summarised mass of the required stiffeners or plates to build the entire hull section. The hatch covers are assumed to weigh 1.0 t for a length equal to the lengthening steps (6.0 m).

The masses regarding the lengthening steps L_{OA} 90.0 m and L_{OA} 95.0 m are preliminary estimations because not all of the required structural modifications could be taken into account as described in section 2.4.6 and 2.4.7. However, they provide an approximate evaluation of the masses.

Table 12. Additional masses of different lengthening steps for MV “Hendrik”

Item	L_{OA} 76 m [t]	L_{OA} 82 m [t]	L_{OA} 88 m [t]	L_{OA} 90 m [t]	L_{OA} 95 m [t]
Bottom plate	2.77	5.91	8.86	10.46	13.08
Inner Bottom	3.60	7.21	10.81	12.68	15.85
Longitudinal girders	0.48	0.96	1.44	1.60	2.00
Floor	1.45	3.17	4.76	5.28	6.61
Floor face	0.80	1.60	2.40	2.67	3.34
Bulkhead cargo		3.66	3.66	3.66	3.66
Bulkhead cargo vertical stiffeners		1.54	1.54	1.54	1.54
Bulkhead cargo horizontal stiffener		0.98	0.98	0.98	0.98
Chine radius	0.44	0.93	1.39	1.55	2.03
Side plating	1.39	2.99	4.49	4.99	7.57
Side frame trans.	0.52	0.97	1.42	1.57	1.94
Side web girder	0.44	1.11	1.77	1.99	2.54
Sheer strake	0.60	1.24	1.98	2.20	2.83
Deck	0.76	1.61	2.54	2.83	3.53
Deck beam	0.41	0.81	1.22	1.36	1.70
Deck girder (longitudinal)	0.09	0.17	0.28	0.35	0.43
Hatch coaming	1.12	2.37	3.74	4.37	5.72
Hatch coaming top stiffener	0.78	1.55	2.33	2.59	3.24
Hatch coaming sec. Stiffener	0.23	0.45	0.68	0.75	0.94
Hatch coaming vertical stiffener (stay)	0.06	0.17	0.28	0.31	0.40
Side web frame replacement	3.05	3.05	3.05	3.05	3.05
Side frame upgrade	0.94	0.94	0.94	0.94	0.94
Hatch cover	1.00	2.00	3.00	3.33	4.17
Total Σ [t]	**20.94**	**45.40**	**63.56**	**71.04**	**88.08**
VCG [m]	**1.71**	**1.66**	**1.61**	**1.57**	**1.55**

Remark: The mass estimations for L_{OA} 90.0 m and L_{OA} 95.0 m do not include masses for additional modifications, described in section 2.4.7, in comparison to L_{OA} 88.0 m.

Comparing the different lengthening steps of the vessel, it is obvious that the lengthening to L_{OA} 76.0 m results in the lowest relative increase in masses because of the missing additional bulkheads and their stiffening. Figure 10 graphs the additional masses for the five considered lengthening steps of MV “Hendrik”. The values for the first three equal lengthening steps show a virtually linear slope.

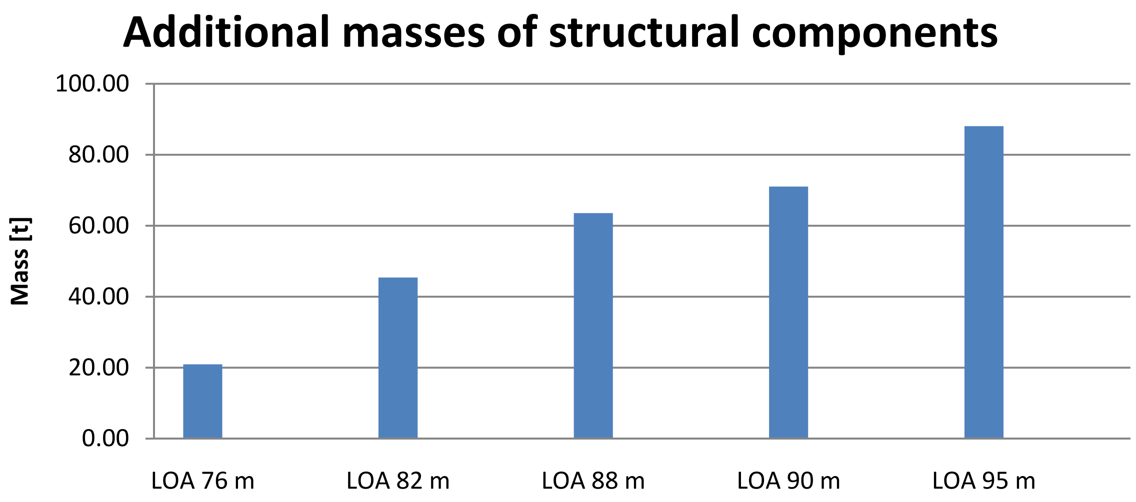

Figure 10. Additional masses of structural components according to GL rules 2011

Not only the additional masses but also the increased cargo capacity of the vessel is of importance. The figures relating to that task are shown in Table 13 where the total cargo in the holds is calculated according to the GL rules 2011 for inland navigation vessels. The increment of growth is nearly linear at approximately 11.5 % per 6.0 m section, as expected. The directly calculated light ship weight is in the range of the light ship weight according to the GL rules 2011. Basis in both cases is the light ship weight according to GL rules for L_{OA} 70.0 m.

Table 13. Additional cargo and light ship weight for different lengthening steps

		L_{OA} 70 m	L_{OA} 76 m	L_{OA} 82 m	L_{OA} 88 m	L_{OA} 90 m	L_{OA} 95 m
Total cargo in holds	[t]	1114	1241	1372	1502	1545	1653
Additional cargo in holds	[t]	0	128	259	388	432	539
	[%]	0.0	11.5	23.3	34.9	38.8	48.4
Light ship weight	[t]	207.8	228.7	253.2	271.3	278.8	295.9
Additional light ship weight	[t]	0	20.9	45.4	63.6	71.0	88.1
Additional cargo /ship weight ratio	[-]	0	6.11	5.70	6.11	6.07	6.12

In order to evaluate the current lengthening steps and to identify the most beneficial ones, the ratio of additional cargo to additional light ship weight is utilised as indicating value. The ratio trend is presented in Figure 11. The first lengthening step to L_{OA} 76.0 m exhibits a high ratio exceeding 6.0, followed by a decreasing ratio for L_{OA} 82.0 m due to additional masses of bulkheads and stiffeners. Further lengthening steps exhibit an increasing ratio, more than 6.0, resulting in a peak value of 6.12 for the maximum considered lengthening step of 25.0 m. Hence, the step to L_{OA} 82.0 m involves the lowest figures in terms of cargo benefit versus additional light ship weight.

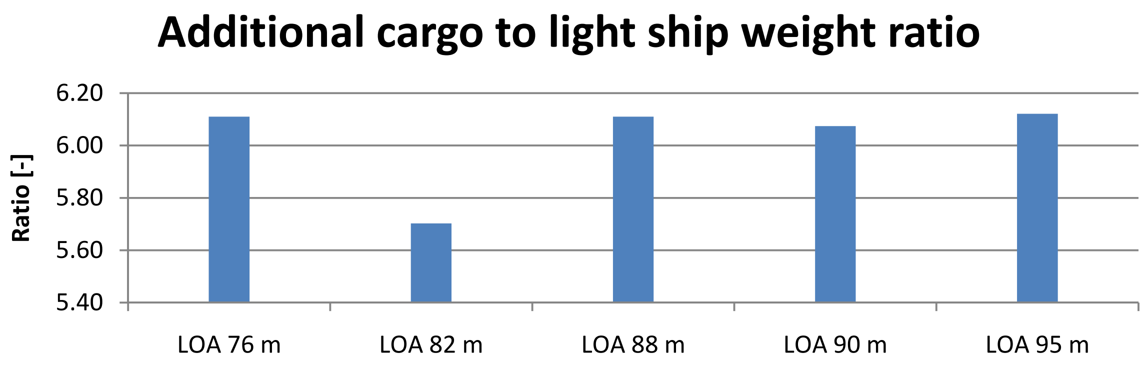

Figure 11. Additional cargo to light ship weight ratio

From the ship owners point of view two different variants arise relating to the lengthening of a vessel. On one hand, variant “A”, with increased cargo capacity and constant draught and on the other hand, variant “B”, with constant cargo capacity and reduced draft. Of course, mixed variants in between those extremes are possible as well. Variant “A” results in an average cargo benefit of 21.6 t/m (tons per lengthening meter of the vessel) which corresponds to +1.9 %/m (percentage per lengthening meter of the vessel). Figure 12 presents the achievable cargo benefit.

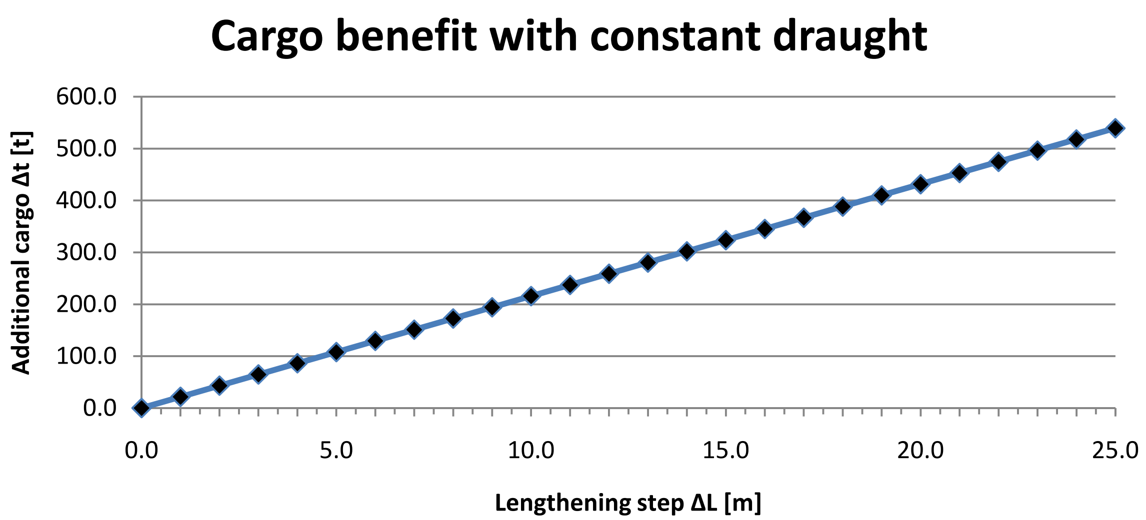

Figure 12. Cargo benefit for each lengthening step with constant draught

The considerations of variant “B” lead to a draught reduction per lengthening meter of the ship of -3.4 cm/m, corresponding to -1.2 %/m. Hence, the maximum obtainable margin of draught reduction is -0.66 m at a lengthening step of 18.0 m, resulting in a draught of 2.283 m. The corresponding graph is presented in Figure 13.

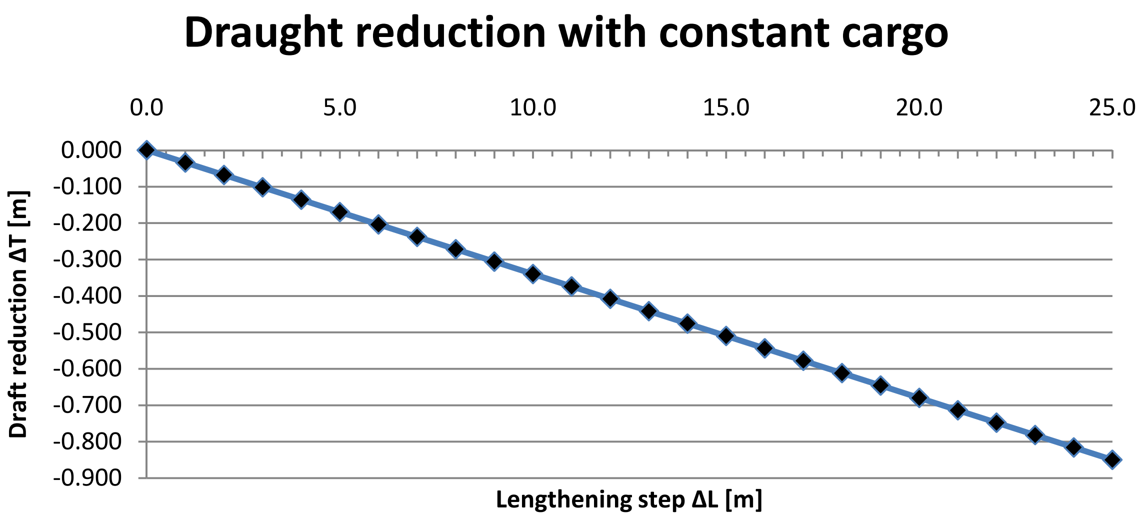

Figure 13. Draught reduction for each lengthening step with constant cargo

2.7. Cost Assessment

Keeping in mind that retrofitting procedures for inland navigation vessels are only in the scope of interest for ship owners if the return on invested capital is in the expected range and time frame, each ship owner has to evaluate possible retrofitting procedures and decide for their own fleet.

This cost estimation provides an initial impression on the lengthening costs for the previously selected lengthening steps (6.0 m, 12.0 m, 18.0 m) and serves as a basis on which ship owners can draw conclusions from for their particular fleet.

To assess the costs for the lengthening, base input and information from the EU funded project CREATE3S is utilised [source: (CREATE3S Consortium, 2008)]. The project developed innovative concepts to improve the efficiency in short sea shipping with focus on manufacturing strategies and key performance indicators. In this particular case, the calculation methods are modified and adopted to the present application case for inland navigation vessels.

The total costs comprise four main aspects:

1) Building the new hull section (material and labour costs)
2) Upgrade parts of the existing hull (material and labour costs)
3) Hatch cover procurement
4) Docking of the vessel

General outfitting, piping, painting and electrical equipment are neglected in this initial considerations in order to keep the cost estimation simple. Table 14 gives an overview and summarises the costs per lengthening meter for each particular lengthening step. Base is a steel price of 620 €/t [source: (World Steel Prices, 2013)]. Moreover, the production cost for the new hull structure is assumed to be 1600 €/t. Small steel works, relating to the removal, replacement and upgrade of existing parts, account for 1960 €/t (material costs) and 3450 €/t (production costs) [source: (CREATE3S Consortium, 2008)]. A required sliding aluminium hatch cover including outfitting, mechanics and sliding rails for an area of 6.0 m in length and 6.8 m in width costs approximately 10000 €, composed of 5500 € for the hatch cover itself and 4500 € for the rails and mechanics. Information on the hatch covers were provided by the Belgian manufacturer Blommaert Scheepsluiken [source: (Blommaert

Scheepsluiken, 2013)]. The docking procedure is assumed to be calculated for one week (5 days) in the dry dock for 16.00 € per ship length meter a day plus 1000 € for crane works [source: (Northlake Shipyard, 2013)]. As presented, the costs per meter of the new hull section decrease with increasing lengthening steps from 11700 € for L_{OA} 76.0 m to 10100 € for L_{OA} 88.0 m.

Table 14. Summary of costs per lengthening meter for MV “Hendrik”

		L_{OA} 76	L_{OA} 82	L_{OA} 88	L_{OA} 90	L_{OA} 95
Lengthening step ΔL	[m]	6.0	12.0	18.0	20.0	25.0
New hull section	[€]	35'000	88'000	126'000	142'000	178'000
Upgrade of existing parts	[€]	18'000	18'000	18'000	18'000	18'000
Hatch cover	[€]	10'000	20'000	30'000	33'300	41'700
Total Σ	[€]	64'000	126'000	175'000	193'300	237'700
Costs per meter of the new section (steel parts)	[€/m]	**10500**	**10500**	**9700**	**9700**	**9500**
Cost for additional modifications on steel parts	[€/m]				1000 (+10%)	1900 (+20%)
Costs per meter of the new section (dry dock per week)	[€/m]	1200	600	400	400	300
Total costs per meter Σ	[€/m]	**11700**	**11100**	**10100**	**11100**	**11700**
Remark: The cost estimations for L_{OA} 90.0 m and L_{OA} 95.0 m include costs for additional modifications, described in section 2.4.7, in comparison to L_{OA} 88.0 m. For L_{OA} 90.0 m an increase of 10% per lengthening meter and for L_{OA} 95.0 m 20% respectively are assumed as additional costs.						

On the basis of the initial figures (see Table 14 and Figure 14) the ship owners are able to estimate the needs and benefits for similar ships of their current fleet.

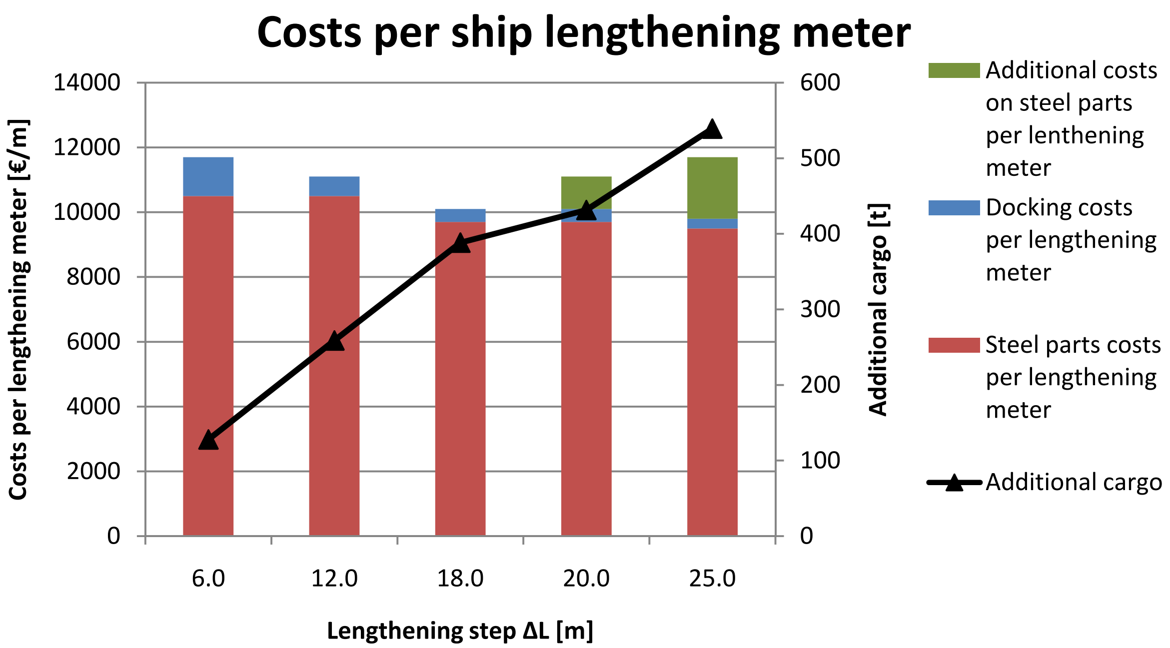

Figure 14. Costs per ship lengthening meter and cargo benefit

3. STRENGTH ANALYSIS AND LENGTHENING OF MV “Rheinland”

3.1. General

Introduction

The scope of the present study is to analyse the possibility of improving the cargo capacity for the inland cargo-ship MV “Rheinland” by increasing its length.

This study is based on the structural verification of the ship’s hull according to BV classification society rules and by means of supplementary FEM calculations of the base vessel. The FE analyses will show problem areas and reveal possible discrepancies in comparison to the design according to the calculation rules. The objective is to maximise the cargo capacity and eventually to decrease the draught by lengthening the vessel so that the requirements regarding the hull strength are fulfilled.

Problem statement

Starting from the existing ship, the work aims to find applicable dimensional and structural modifications and to establish the methodology for their implementation in way of improving the ship’s operating efficiency.

Main objectives

- Increasing cargo capacity
- Increasing operational flexibility in conditions of variable water levels

Under these circumstances, the existing ship is chosen, in such way that modifications would achieve the following:

- Transport a larger quantity of cargo, when water levels allow it
- Operate in low water conditions and in these conditions to be able to transport a reasonable amount of cargo as for the operation to remain economically

Systematic approach

In terms of approach and the strategy adopted, the direction that needs to be followed is to determine the maximum cargo amount that the ship can carry with minimal structural modifications.

This implies:

- Analysis of the current rules in terms of vessel type, navigation area, scantling and checking methods
- Freeboard and scantling checking, and if applicable intact and damage stability
- Identification of the design reserves regarding the freeboard, hull structure and vessel stability (if applicable)
- Increasing the amount of cargo – including draught to the limit of the reserves
- Structural analysis by systematic changing of the length. This can be done easily by inserting a cylindrical part. The other main dimensions (width and height) are not reasonable to be modified due to cost and structural complications.

After finishing the tests mentioned above, the following tasks will be performed:

- Determining the optimal length according to the objectives
- Design and detailed checking for the modified vessel

Working tools
A range of tools are required to execute the approach described above. Of these the most significant are:
Rules and regulations

- DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 December 2006 laying down technical requirements for inland waterway vessels and repealing Council Directive 82/714/EEC (2006/87/EC)
- Recommendations on Technical Requirements for Inland Navigation Vessels- UNITED NATION, New York and Geneva, 1997
- BUREAU VERITAS – NR217- Rules for the Classification of Inland Navigation Vessels Nov. 2011
- Regulamentul de Navigatie pe Dunare (Rules for Danube navigation, in Romanian)

Calculation software

- COSMOS – FEM analysis software
- 3D-Beam – DNV FEM analysis software
- MARS INLAND – BV scantling software
- CARENA – Hydrostatic and stability software
- MICROSOFT OFFICE EXCEL 2007

Reference drawings

- Rheinland 1676-851-0-GA.pdf – General arrangement
- Rheinland 1676-200-1.pdf – Construction plan aft part
- Rheinland 1676-200-3.pdf – Construction plan fore part
- Rheinland 1676-309-3.pdf – Hatchway arrangement
- EP-2000-202 – Midship section

3.2. *Application Case*

The inland navigation vessel MV “Rheinland” is presented in the reference drawings described in the previous section.

Table 15. Main particulars of MV “Rheinland”

Length over all	[m]	57.50
Length scantling	[m]	57.00
Breadth over all	[m]	6.34
Draught	[m]	2.43

Depth	[m]	2.50
Cargo hold capacity	[t]	537

Compartments

From Aft to frame 7 - aft peak, where the rudder and steering device are located;
From frame 7 to frame 23 - engine compartment, on top of which are located the superstructure and wheelhouse;
From frame 23 to frame 59 - aft cargo hold (watertight). This is divided into three non-tight compartments, separated through light wooden bulkheads as follows:

- Hold VI: frame 23 – frame 35;
- Hold V: frame 35 – frame 46;
- Hold IV: frame 46 – frame 59.

From frame 59 to frame 98 - fore cargo hold (watertight). This is divided into three non-tight compartments, separated through light wooden bulkheads as follows:

- Hold III: frame 59 – frame 71;
- Hold II: frame 71 – frame 83;
- Hold I: frame 83 – frame 98;

From frame 98 to frame 106 - fore accommodation including a roof;
From frame 106 to stem - fore peak with chain locker and mooring system.

Hull structure:

- Transversely framing along the whole ship
- Frame spacing: 500 mm along the whole ship
- Web frames at each 6 frames (3.0 m in between)
- Material used for the hull: steel Grade A, with E=2.06 105 N/mm^2; ReH=235 N/mm^2; k=1.

The detailed description of the ship structure in cargo area can be seen in Figure 15. The Lines plan of the ship can be seen in Annex 7.7. The midship sections of the ship can be seen in Annex 7.8.

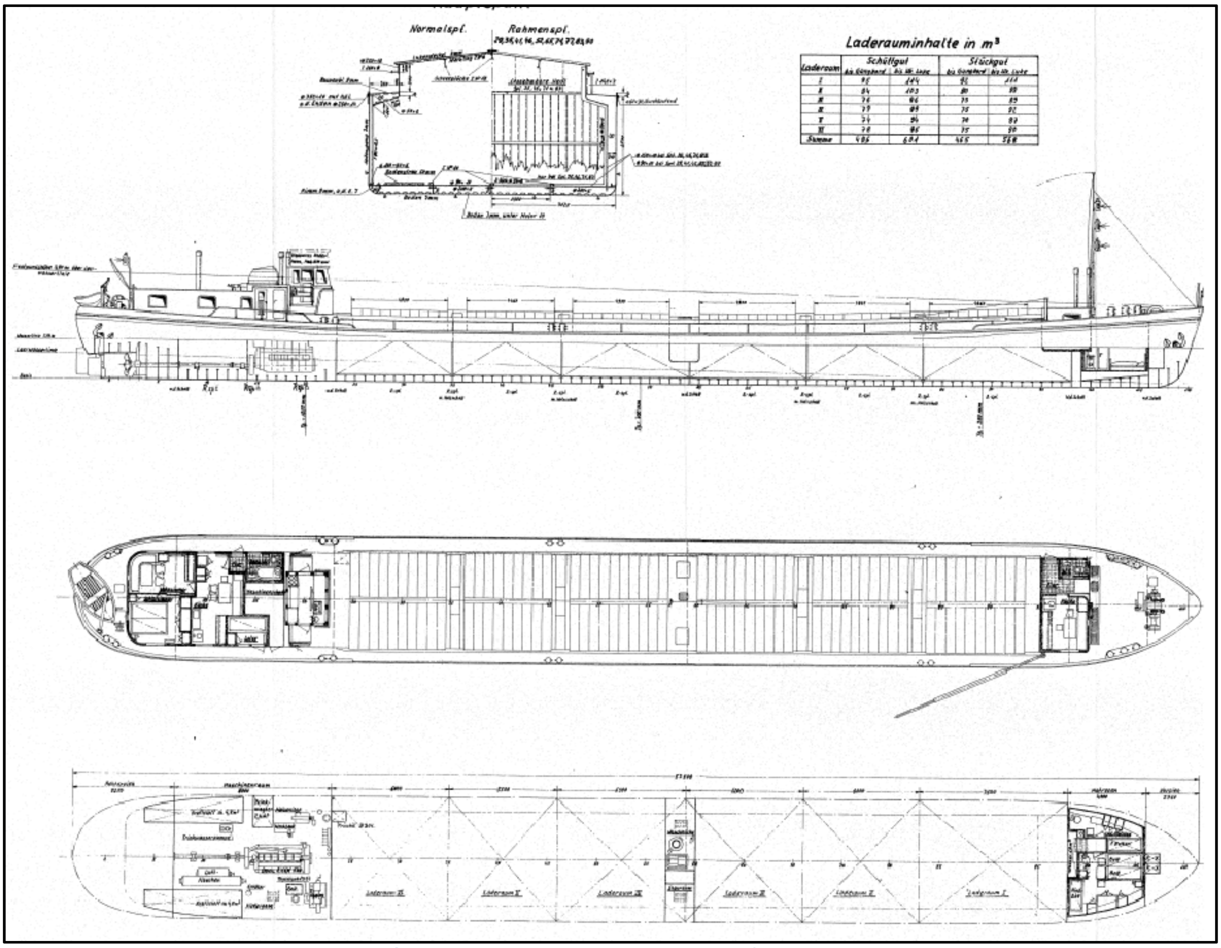

Figure 15. General arrangement drawing of MV "Rheinland"

3.3. Rules and Regulations

3.3.1. Range of Navigation

According to the Rules

- Ships that sail on inland waters are classified as Zone 3 of navigation. According to source (United Nations, 1997), for Zone 3, the significant wave height is 0.6 m.
- Type of the vessel: bulk cargo vessel, self-propelled, with crew onboard
- Character of Classification (optional characters between brackets)

  ✠ I 5 IN(0.6) Z, Cargo vessel, , Self-Propelled, 2R
  ✠ MC

3.3.2. Freeboard Check

<u>Rules</u>
DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 12 December 2006 laying down technical requirements for inland waterway vessels and repealing Council Directive 82/714/EEC (2006/87/EC), CHAPTER 4
Minimum freeboard: $F = \min(50\text{ mm}, 150-(S_{ev}+S_{ea})/15)$
where:
$S_{ev} = S_v \times 4X_v/L$
$S_{ea} = S_a \times 4X_a/L$
$S_{v(a)}$ = the actual forward (aft) sheer, in mm, not more than 1000 (500) mm

X = the abscissa, measured from the extremity of the point where the sheer is 0,25 S_v or 0,25 S_a
L = ship’s length
S_v = 1040 mm; will be taken 1000 mm
S_a = 760 mm; will be taken 500 mm
X_a = 11350 mm
X_v = 10560 mm
Deck plate thickness t= 9 mm
Maximum draught Tmax= D+t-F = 2500+9-F

Table 16. Freeboard and maximum draught for 3 ship’s length values

L	S_{ev}	S_{ea}	F	Tmax
55.3	821	382	70	2.439
61.3	740	345	78	2.431
67.3	675	314	84	2.425

Actual draught: T = 2.43 m

<u>Conclusions</u>

- For the length of 55.3 m (actual) and 61.3 m, the actual draught 2.43 comply with the freeboard requirements
- For the length of 67.3 m the maximum draught is considered to be 2.42 m

3.3.3. Scantling Calculation

Checking calculation has been performed according to the BV rules NR 217 [source: (Bureau Veritas, 2011)]. In Annex 7.3 the basic relations used for calculations are presented. Microsoft Excel 2007 has been utilised to derive a calculation model from the rules.
Following this procedure, several calculation versions have been obtained as well as information for comparison purposes later on. The obtained results have been compared to those obtained by MARS INLAND software (BV scantling software) where applicable.
The sequence of the used calculation is:

a) Calculation of the ship’s bending moments: Based on this calculation it can be determined the hogging and sagging bending moments M_H and M_S during navigation and harbour conditions.
b) Vessel motions and accelerations: For the calculation only vertical acceleration a_{Z1} determined by MARS INLAND software has been used.
c) Corrosion addition and net thickness: All the performed calculation is related to the net thicknesses after the diminution of the corrosion addition required by BV rules.
d) Hull girder section modulus: For the net section in the middle part, it has been calculated the moment of inertia I_Y and the neutral axis N. Also, have been calculated the stresses σ_{X1} in major structural elements due to bending moments.

e) Bottom scantlings
f) Side scantlings
g) Deck scantlings
h) Cargo bulkhead scantlings
i) Allowable value for scantling

For the items e) to h) the following steps have been considered:

- Design lateral pressure calculation
- Hull girder normal stress calculation
- Plating scantling:
  - t_1 - minimum net thickness;
  - t_2 – thickness corresponding to lateral pressure
  - t_3 – thickness corresponding to buckling check
- Ordinary stiffeners (where applicable)
  - t_1 - minimum net thickness;
  - w_N – net section modulus
- Primary supporting members
  - t_1 - minimum net thickness

The calculated values have been compared to the allowable values from i).
It has to be be noted that the values of the thicknesses t_1 are in relation to the scantling length L and the frame spacing s. If the net thicknesses of the structural member is t_N then $t_1 \leq t_N$. As a result, the maximum length L must be in accordance with this condition for each of the structural members.
For the original vessel, a direct calculation of the structural strength has been performed by using COSMOS FEM analysis software. This calculation can be seen in Annex 7.6.

3.3.4. FEM Calculation of the Ship Structure

For a detailed checking of the strength of the ship structure, a model (half of vessel's breadth) has been made to be used for FEM analysis. In the process of generating the FEM ship model, BV rules (with regard to direct calculation of the structure) have been fulfilled, as follows: BV Inland Navigation Rules Pt.B, Ch.5, Sec.1.
In the assessment of the FEM analysis, the following stages have been established:

- Analysis criteria
  - Structural modelling
  - Boundary condition
  - Load modelling
  - Stress calculation
- Checking criteria
  - Yielding check

The software used for the FEM calculation the COSMOS/M software package. In Annex 7.6 the detailed process of the generating and calculation of the FEM model is presented.

3.4. The Vessel’s Steel Structure

3.4.1. Initial Considerations

The following lengthening operations have been considered for the ship:

- Initial L_{OA}: 57.5 m
- 2 subsequent extensions by 12 frame spacings, i.e. 6.0 m each

The subsequent extension of 6.0 m has been considered as a condition to keep the frame spacing (12 frame spacings) and to keep the existing structural members for extension length. It has been considered that the extensions will be made symmetrically for the two watertight holds (aft/fore).
For each extension the following figures have been calculated:

- Hydrostatic values
- Lightweight value and distribution
- Maximum amount of cargo in homogenous condition
- Longitudinal strength in calm water, in navigation and in loading/unloading operation
- Scantlings of the hull structure for the load cases presented above
- FEM calculation of ship structure (only for original length L_{OA}=57.5m)
- Calculation of the maximum cargo amount that can be carried with no alteration of the ship structure.

Loading operation

- Homogenous cargo where the amount of cargo depends on trim, as consequence it is lesser due to the restriction of minimum freeboard in any point on ship’s length.

Loading sequence

- 6 stacks on ship’s length corresponding with hold capacity indicated in the general arrangement drawing
- Loading in two runs (2R)
- First run from aft to fore
- Second run from fore to aft

The calculation results are presented in Annex 7.5.

Notation

T - ship draught [m]
M_{THN} - for navigation: total vertical bending moment / hogging [kNm]
M_{TSN} - for navigation: total vertical bending moment / sagging [kNm]
M_{TSH} - harbour: maximum vertical bending moment / hogging [kNm]
M_{TSH} - harbour: maximum vertical bending moment / sagging [kNm]
σ_{X1} - the hull girder normal stresses induced by vertical bending moments [N/mm^2]
$w_{N\text{-}BV}$ - net section modulus of structural elements imposed by rules [cm^3]

3.4.2. Original Vessel with LOA 57.5 m

3.4.2.1. Scantlings

The results of the strength calculation are shown in Annex 7.5 and summarisation of the data is presented in the following tables.

Table 17. Maximum value for total bending moments and hull girder stresses

Load	Draught	Cargo	Navigation		Harbour		σ_{X1}
	T	weight	M_{THN}	M_{TSN}	M_{THH}	M_{TSH}	Max
	[m]	[t]	[kNm]	[kNm]	[kNm]	[kNm]	[N/mm^2]
Ship without cargo	1.425	0	5932	777	0	0	66.5
Ship with full cargo	2.429	537.6	912	4050	0	0	45.4
Ship in harbour	0.846	42.5	0	0	4952	0	55.5

Table 18. Net thickness of plate elements and net section modulus for frames and wall

Draught	thk.	thk.	thk.	thk.	thk.	thk.	thk.	w_{N-BV}
T	bottom	bilge	side	sheer strake	deck	hatch	tr.wall	frames
[m]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[cm^3]
1.425	6.40	7.36	4.91	11.67	4.94	5.68	3.28	15.32
2.429	5.36	6.16	4.91	11.67	4.94	5.68	3.28	28.98
0.846	5.85	6.73	4.91	11.67	4.94	5.68	3.28	8.81
Allow. thk.	6.24	8.24	6.24	15.24	8.24	7.24	4.24	33.90

3.4.2.2. Remarks

It can be seen that all elements are within allowable limits except the following parts:

- Bottom plates which exceed the allowable limit from buckling condition for light ship (t_3) (highlighted in
- Table 18);
- Webs of main supporting structure (floors, web frames) do not comply with the minimum thickness condition (t_1).

The first issue regarding buckling, can be solved by reducing the corrosion addition to zero or by adding longitudinal stiffeners on the bottom plates at mid span between the bottom longitudinal girders.

In Annex 7.5 are presented: the analysis of the variation of the thicknesses for different types of structural elements based on three Rules criteria (t_1, t_2, t_3) as well as for section modulus of the structural elements of the transverse and longitudinal bulkheads of the cargo hatch (w_N).

As noted above, for the vessel with L_{OA} = 57.5 m a FEM analysis has been performed. This calculation is described in detail in Annex 7.6. For this analysis, two load cases (presented in Annex 7.5) have been considered:

1) LC51 – Lightship (without wave component)
2) LC52 – Homogenous cargo 538 t, draught 2.429 m (without wave component)

In Table 19 and
Table 20 the stress values, determined by BV rules and by FEM calculation for which the wave component have been added, are presented. As it can be seen, all the stress values are comparable with the values determined with BV rules.
To be noted: the value σ_{X1} is obtained from the hull girder loads (the stress due to local loads is not included).
It has been noticed that stress values obtained in the bottom plates are higher which, regarding the issue generated by buckling condition, concludes that the bottom plates need to be longitudinally stiffened, at least in the aft watertight hold where the hogging maximum value occurs.

Table 19. LC51 - The stresses in plates elements obtained in BV Rules and FEM analysis

LC51 - Ship without cargo				
Element	σ_{BVmax}	$\sigma_{BVcompression}$	σ_{FEMmax}	$\sigma_{FEMcompression}$
	[N/mm^2]	[N/mm^2]	[N/mm^2]	[N/mm^2]
Bottom plate	43.83	-43.83	51.51	-51.51
Bilge plate	43.83	-43.83	46.01	-46.01
Side plate	36.14	-36.14	34.19	-26.03
Shear strake doubling plate	41.45	-5.43	45.23	-5.93
Deck plate	42.67	-5.59	49.19	-11.29
Hatch coaming	66.50	-8.71	69.31	-8.81

Table 20. LC52 - The stresses in plates elements obtained in BV Rules and FEM analysis

LC52 - Ship with full cargo				
Element	σ_{BVmax}	$\sigma_{BVcompression}$	σ_{FEMmax}	$\sigma_{FEMcompression}$
	[N/mm^2]	[N/mm^2]	[N/mm^2]	[N/mm^2]
Bottom plate	29.92	-6.74	25.11	-25.11
Bilge plate	29.92	-6.74	24.71	-18.51
Side plate	24.67	-21.33	17.99	-17.99
Shear strake doubling plate	28.30	-28.30	26.23	-26.23
Deck plate	29.13	-29.13	26.49	-26.39

Hatch coaming	45.40	-45.40	27.75	-27.75

3.4.3. Lengthening Step to LOA 63.5 m

3.4.3.1. Scantlings

The results of the strength calculation are shown in Annex 7.5 and a summarisation of the data is presented in the following tables.

Table 21. Maximum value for total bending moments and hull girder stresses

Load	Draught	Cargo	Navigation		Harbour		σ_{X1}
	T	weight	M_{THN}	M_{TSN}	M_{THH}	M_{TSH}	Max
	[m]	[t]	[kNm]	[kNm]	[kNm]	[kNm]	[N/mm^2]
Ship without cargo	1.308	0	6841	949	0	0	76.7
Ship with full cargo	2.429	615.1	1075	4374	0	0	49.0

Table 22. Net thicknesses of plates and net section moduli for frames and bulkheads

Draught	thk.	thk.	thk.	thk.	thk.	thk.	thk.	w_{N-BV}
T	bottom	bilge	side	sheer strake	deck	hatch	tr.wall	frames
[m]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[cm^3]
1.308	6.87	7.91	5.06	12.33	5.06	5.92	3.44	13.90
2.429	5.54	6.37	5.06	12.33	5.06	5.92	3.44	28.98
Allow. thk.	6.24	8.24	6.24	15.24	8.24	7.24	4.24	33.90

3.4.3.2. Remarks

It can be seen that all elements are within allowable limits except the following parts:

- Bottom plates which exceed the allowable limit from buckling condition for light ship (t3) (highlighted in
- Table 22);
- Webs of main supporting structure (floors, web frames) do not comply with the minimum thickness condition (t_1).

In Annex 7.5, the analysis of the variation of the thicknesses for different types of structural elements based on three Rules criteria (t_1, t_2, t_3) as well as for section modulus of the structural elements of the transverse and longitudinal bulkhead of the cargo hatch (w_N) is presented.

3.4.4. Lengthening Step to LOA 69.5 m

3.4.4.1. Scantlings

The results of the strength calculation are shown in Annex 7.5 and a summarisation of the data is presented in the following tables.

Table 23. Maximum value for total bending moments and hull girder stress

Load	Draught	Cargo	Navigation		Harbour		σ_{X1}
	T	weight	M_{THN}	M_{TSN}	M_{THH}	M_{TSH}	Max
	[m]	[t]	[kNm]	[kNm]	[kNm]	[kNm]	[N/mm^2]
Ship without cargo	1.212	0	7803	1138	0	0	87.5
Ship with full cargo	2.420	690	1264	4885	0	0	54.8

Table 24. Net thicknesses of plates and net section moduli for frames and bulkheads

Draught	thk.	thk.	thk.	thk.	thk.	thk.	thk.	w_{N-BV}
T	bottom	bilge	side	sheer strake	deck	hatch	tr.wall	frames
[m]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[cm^3]
1.212	7.34	8.44	5.21	12.99	5.18	6.16	3.59	12.77
2.420	5.72	6.58	5.21	12.99	5.18	6.18	3.59	28.85
Allow. thk.	6.24	8.24	6.24	15.24	8.24	7.24	4.24	33.90

3.4.4.2. Remarks

It can be seen that all elements are within allowable limits except the following parts:

- Bottom plates which exceed the allowable limit from buckling condition for light ship (t_3) (highlighted in Table 24);
- Webs of main supporting structure (floors, web frames) do not comply with the minimum thickness condition (t_1)

In Annex 7.5 the analysis of the variation of the thicknesses for different types of structural elements based on three Rules criteria (t_1, t_2, t_3) as well as for section modulus of the structural elements of the transverse and longitudinal bulkheads of the cargo hatch (w_N) is presented.

3.4.5. Analysis of the Obtained Results

As it can be seen above, three cases have been analysed based on different lengths of the vessel for light ship and fully loaded condition.
In the table below are presented the values of the cargo that can be transported and the corresponding draughts. As presented above, ship’s hull structure is able to withstand these load cases. The only remaining issues are:

- The bottom plates do not comply with the BV rule requirements regarding buckling (also for the initial vessel) for the light ship condition,
- BV requirements regarding minimum web thicknesses, for main supporting structure.

Table 25. Cargo weight versus draught and ship’s lengthening values

Length over all	Cargo weight	Draught
[m]	[t]	[m]
57.50	538	2.429
63.50	615	2.429
69.50	690	2.420

Figure 16. Cargo weight versus ship’s lengthening values

3.4.6. *Cost Assessment*

3.4.6.1. *Effect of the Lengthening on the Ship’s Cargo and Draught*

In this section, the effect of the lengthening is presented. Similar to the investigations in chapter 3 two variants are in the scope of interest: Variant “A” with increased cargo capacity and constant draught and variant “B” with constant cargo capacity and reduced draft.
Variant “A” leads to an average cargo benefit of 13.0 t/m (+2.4 %/m) (tons per lengthening meter of the vessel). The figures are presented in Table 26 and Figure 17. Hence, the maximum additional cargo is 156.2 t for an additional section of 12.0 m.

Table 26. Cargo increasing for the same draft (T=2.43m)

L_{OA}	W total	W light ship	W others	W cargo	ΔL	ΔW
[m]	[t]	[t]	[t]	[t]	[m]	[t]
57.5	723.4	168.7	16.9	537.8	0.0	0.0
63.5	815.2	182.7	16.9	615.6	6.0	77.8
69.5	907.1	196.2	16.9	694.0	12.0	156.2

Average: ΔW/ΔL = 13.0 t/m

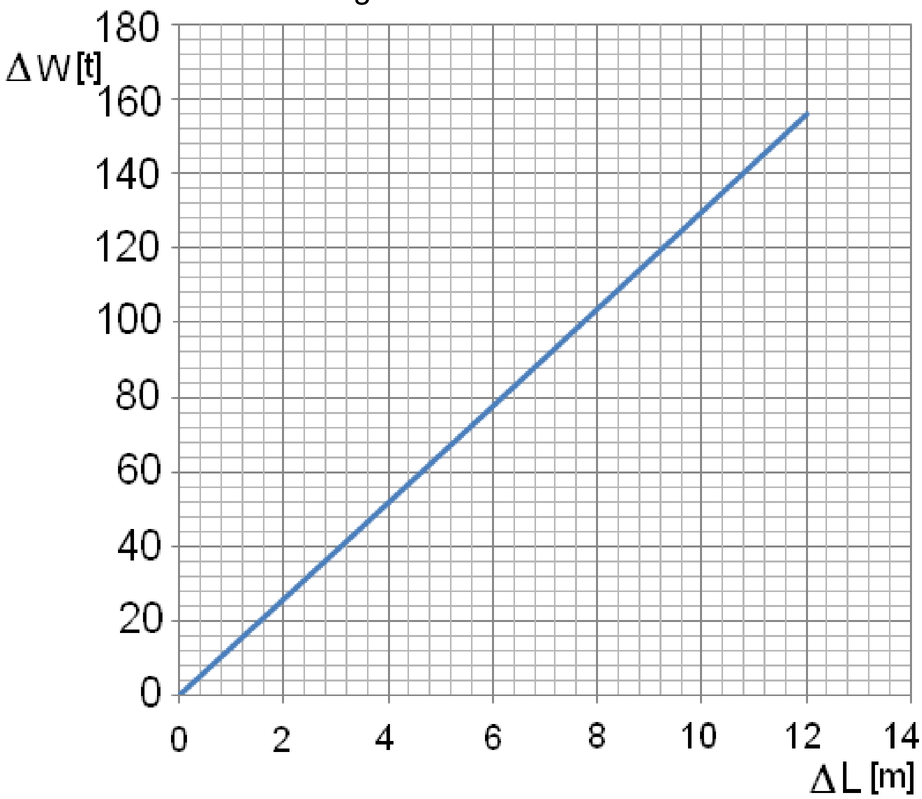

Figure 17. Variation of increase of additional cargo ΔW versus lengthening step ΔL

An approximate draught reduction per lengthening meter of the ship at constant cargo (Variant “B”) of -2.7 cm/m (-1.1 %/m) can be reached. The maximum reduction sums up to -0.335 m for a lengthening step of 12.0 m.

Table 27. Draft reduction for the same cargo (W = 537.8 t)

L_{OA}	W light ship	W others	W total	T	ΔL	ΔT
[m]	[t]	[t]	[t]	[m]	[m]	[m]
57.5	168.7	16.9	723.4	2.378	0.0	0.000
63.5	182.7	16.9	737.4	2.218	6.0	-0.160
69.5	196.2	16.9	750.9	2.043	12.0	-0.335

Average: ΔT/ΔL = -0.027 m/m

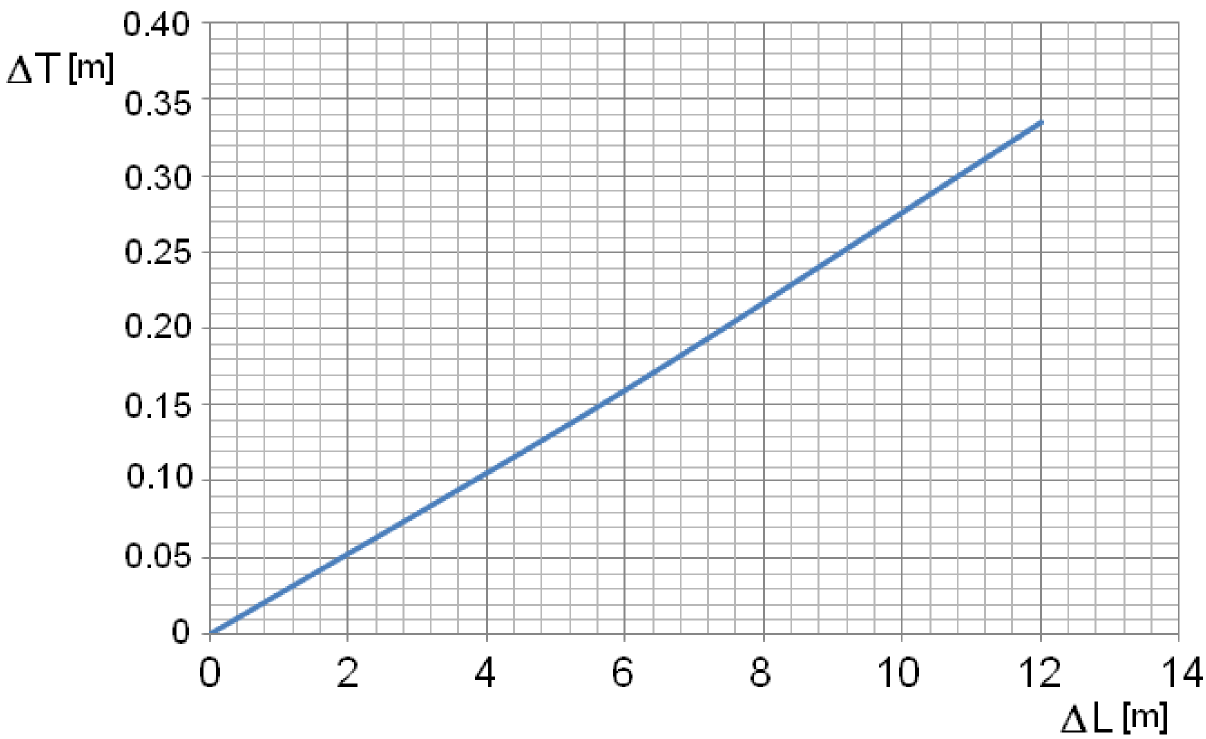

Figure 18. Variation of decrease of the draught ΔT versus lengthening step ΔL

3.4.6.2. *Costs for the lengthening sections*

Production

The production cost calculation is based on the following input parameters:

- Price per new construction weight: 3 €/kg
- Total weight of the inserting module of ΔL = 6.0 m: 10 t

The data results in production costs of 30000 € for inserting one module of ΔL = 6.0 m, which corresponds to 5000 €/m.

Docking

The subsequent parameters serve as input for the docking cost estimation:

- Price for docking: 800 €/day
- Module inserting time: 6 days

The docking costs amount to 4800 €, corresponding to 800 €/m for the 6.0 m lengthening step and 400 €/m for the 12.0 m lengthening step respectively.
Based on the figures presented above, it can be concluded that the costs for a lengthening meter of the 6.0 m step are approximately 5800 €/m and 5400 €/m for the 12.0 m step.

4. CONCLUSIONS

4.1. Remarks on the Lengthening of MV “Hendrik”

The analysis shows the principle feasibility of improving the competitiveness of small inland navigation vessels by lengthening procedures. The maximum additional section length is 18.0 m, resulting in an extra cargo hold and leading to a L_{OA} of 88.0 m. The length is limited by the existing plate thicknesses “as built” because replacing plates at a defined area would effort numerous man hours and thus, result in a costly solution and has to be avoided in any case. Critical structural members are the bottom plate, the chine radius and the hatch coaming whose thicknesses are exceeded at a L_{OA} of 90.0 m. In principle, lengthening steps of 20.0 m and 25.0 m are feasible but the retrofitting effort would be too comprehensive. It has to be noted that various additional changes in the structure of the forward and aft part of the vessel might be necessary to meet the GL requirements. However, they are not in the scope of interest in this case.

The required modifications of the existing hull structure comprise an upgrade of the ordinary side frames from a bulb flat 140x7 to a bulb flat 160x9 equivalent by welding a flat bar 40x9 onto the topside of the bulb flat profile. Furthermore, every fourth ordinary side frame has to be replaced by a side web girder bulb flat 300x13 profile to meet the transversal strength requirements. The longitudinal strength criterion requires a replacement of the existing hatch coaming secondary stiffener (flat bar 75x10) by a flat bar 160x15.

Considering a lengthening of the ship’s hull at constant draught results in an approximate cargo benefit of 21.6 t/m (+1.9 %/m). The draught reduction for a constant amount of cargo is located at around -3.4 cm/m (-1.2 %/m). In total, the additional light ship weight per additional meter ship length is 3.5 t including hatch covers but neglecting outfitting, piping and mooring equipment.

The estimated production costs including docking amount to 11700 €/m for the 6.0 m section and to 10100 €/m for the 18.0 m section.

4.2. Remarks on the Lengthening of MV “Rheinland”

Based on the analysis presented in chapter 3 it can be concluded that the amount of transported cargo can be increased by ship’s lengthening. The analysis confirms that the hull overall strength is not affected by the lengthening, excepting the bottom plates which, for light ship situation, does not comply with rules requirements regarding buckling for actual thickness of 7 mm.

To solve this issue, it is necessary to add longitudinal elements between the bottom longitudinal girders. In Table 28 values of the required thicknesses t_3 in terms of the longest side of plate panel “b” (see Annex 7.3) and the ship’s length are indicated. It can be noted, by adding these elements, the obtained values are within allowable limits.

Moreover, the imposed value of the minimum thickness for web plates of the main supporting structure t_1 has to be regarded (see Annex 7.3 and 7.5). The current thickness is 5 mm and deducting the corrosion addition it results in 4 mm. The required value for this thickness is 4.9 mm. Accepting the actual thickness is valid only if the corrosion addition is considered to be zero or if the classification society advisor accepts this value based on direct calculation of the ship’s structural elements.

Table 28. Required additional stiffeners for MV “Rheinland”

	Actual structure		With additional longitudinals	
L_{OA}	b	thk. bott.	b	thk. bott.
[m]	[m]	[mm]	[m]	[mm]
57.50	1.500	6.40	0.750	4.92
63.50	1.500	6.88	0.750	5.29
69.50	1.500	7.34	0.750	5.65

4.3. Summary of Characteristic Values

A summary of major values relating to the lengthening of the two inland navigation vessels, MV “Hendrik” and MV “Rheinland”, is presented in Table 29. Those values are the result of the investigations described in the previous chapters.

Table 29. Summary of characteristic values

		MV “Hendrik”	**MV “Rheinland”**
Base L_{OA}	[m]	70.0	57.5
Maximum reasonable lengthening section	[m]	18.0	12.0
Lengthening costs for an additional meter ship length	[€/m]	~ 10900 (including hatch covers)	~ 5600
Additional cargo for an additional meter ship length	[t/m]	+21.6	+13.0
Additional light ship weight for an additional meter ship length	[t/m]	3.5 (including hatch covers)	1.7
Change of draught for an additional meter ship length	[cm/m]	-3.4	-2.7

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6. INDEXES

6.1. Index of Figures

6.2. Index of Tables

6.3. List of Abbreviations

BHD	Bulkhead
BV	Bureau Veritas
CEMT	Conférence Européenne des Ministres de Transport
CREATE3S	Innovative Concepts realized by advanced design & production to improve total efficiency of new generation Short Sea Shipping
D	Depth
DNV	Det Norske Veritas
FEM	Finite Element Method
GL	Germanischer Lloyd
L	Scantling length
LC	Load case
L_{OA}	Length over all
MV	Motor vessel
S	Frame spacing
T	Draught
T	Plate thickness
TEU	Twenty foot equivalent unit container
V_{CG}	Vertical centre of gravity
W	Cargo

w	Section modulus
σ	Normal stress
τ	Shear stress

7. ANNEXES

7.1. Graphs of Plate Thicknesses of Structural Parts for Different Lengthening Sections of MV “Hendrik”

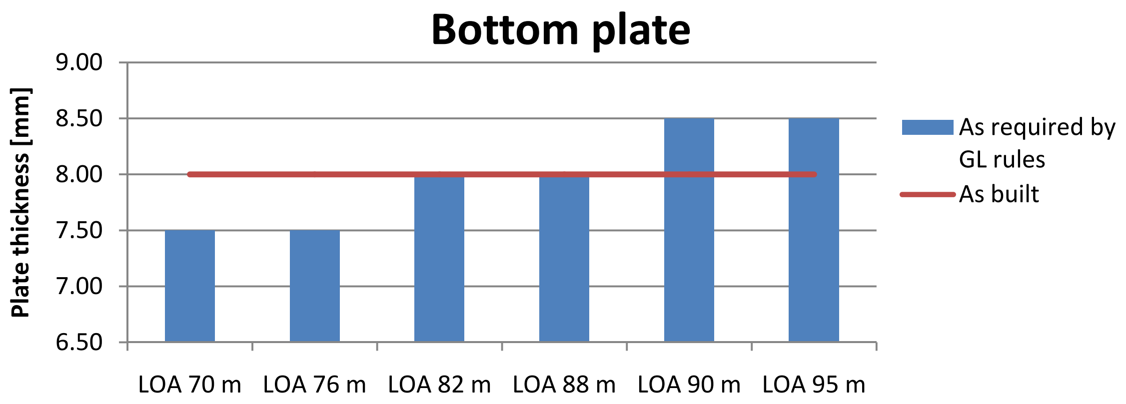

Figure 19. Scantlings bottom plate

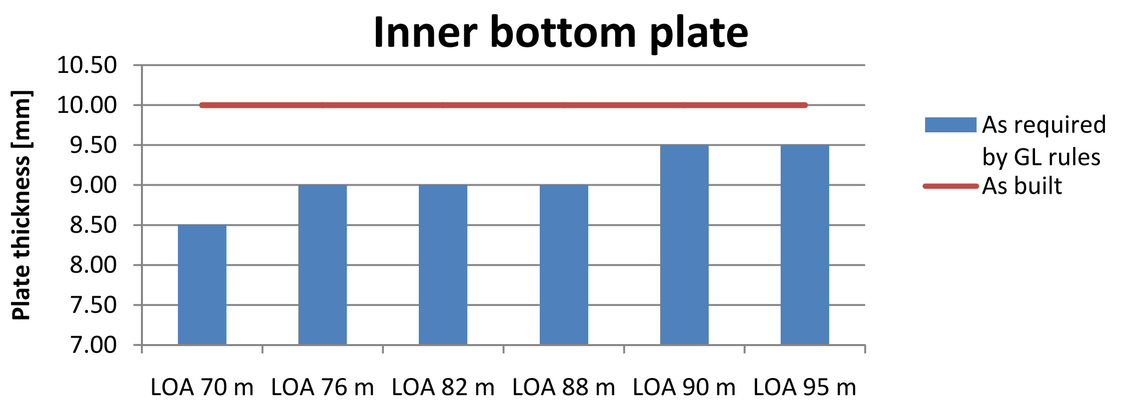

Figure 20. Scantlings inner bottom plate

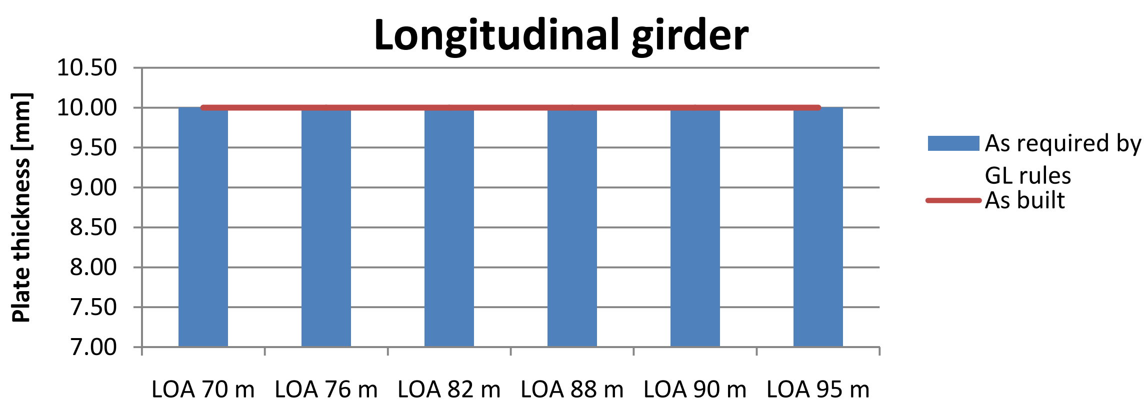

Figure 21. Scantlings longitudinal girder

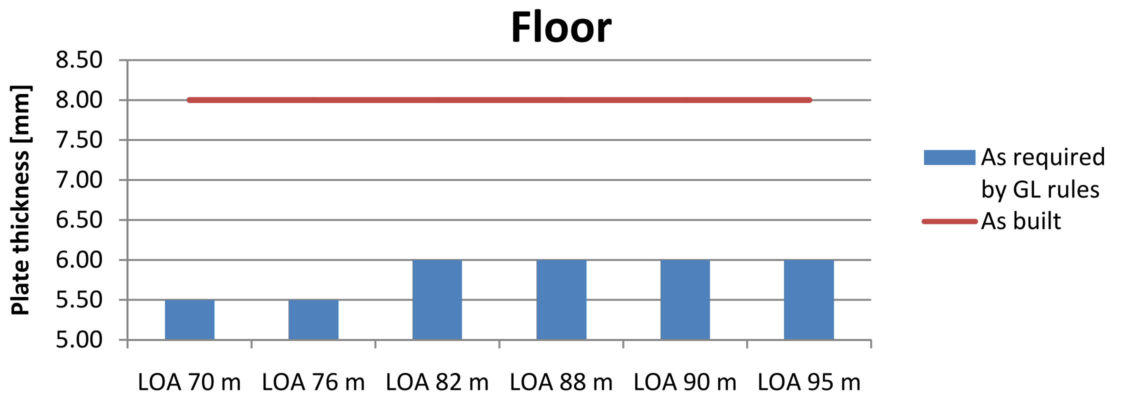

Figure 22. Scantlings floor

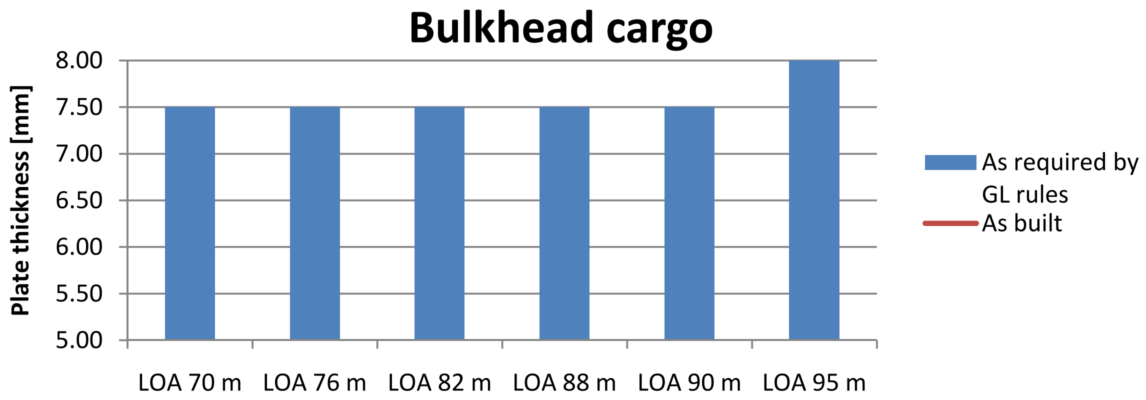

Figure 23. Scantlings bulkhead cargo

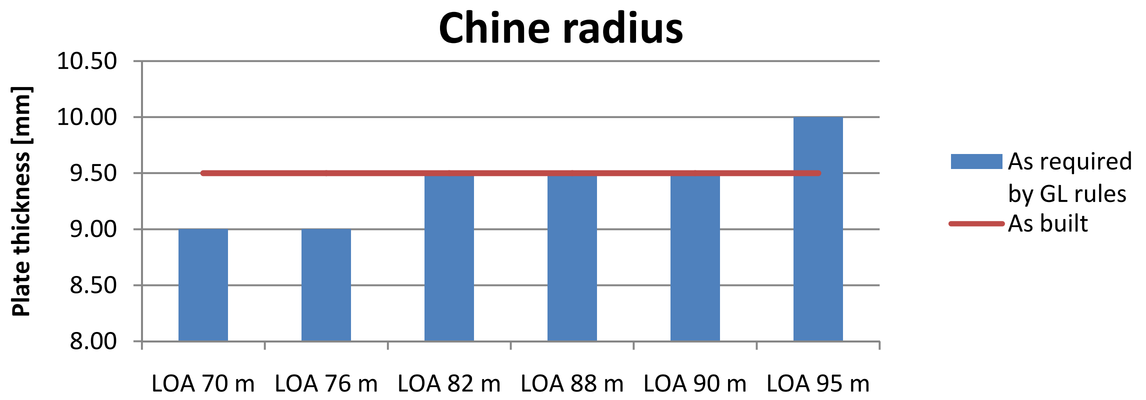

Figure 24. Scantlings chine radius

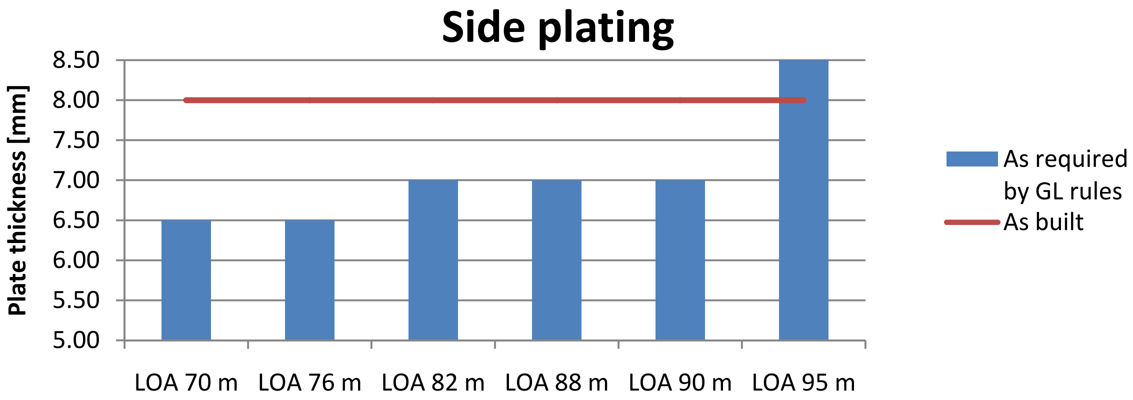

Figure 25. Scantlings side plating

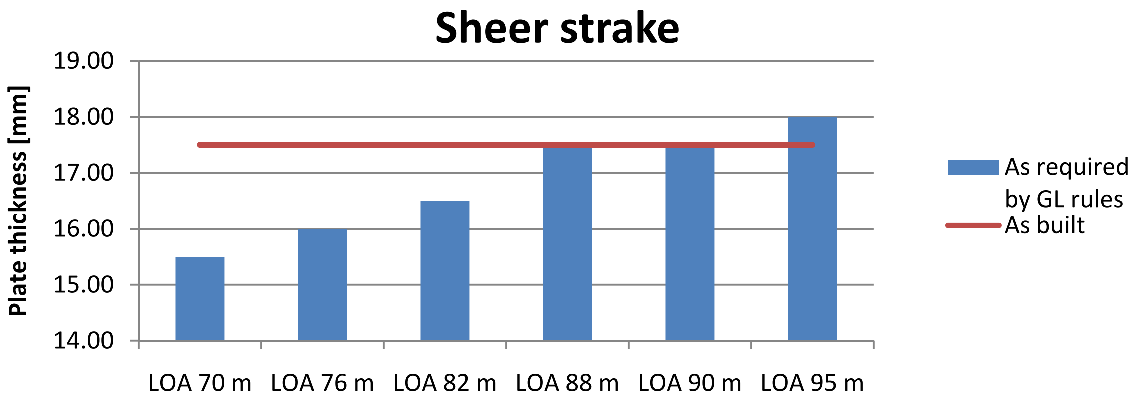

Figure 26. Scantlings sheer strake

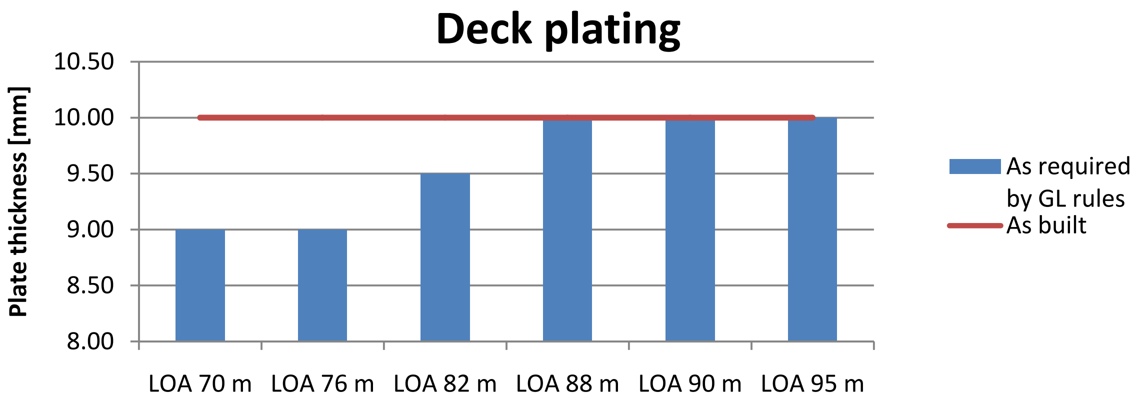

Figure 27. Scantlings deck plating

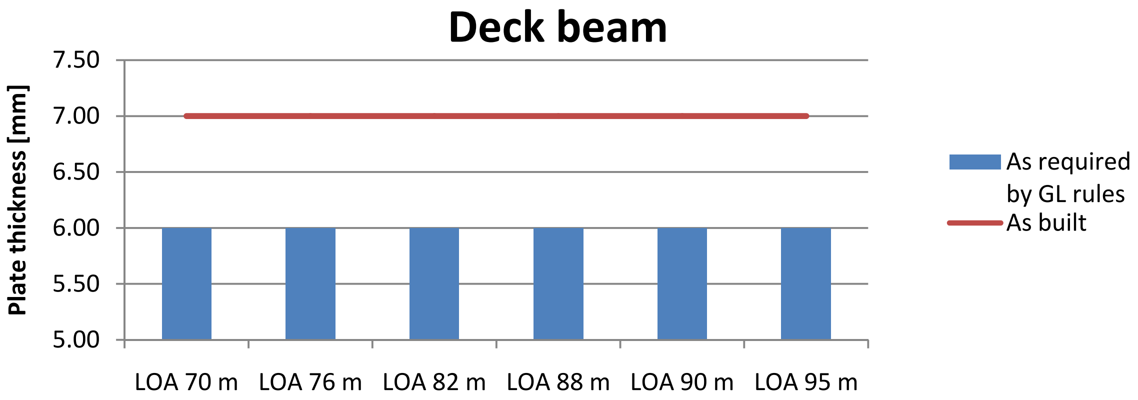

Figure 28. Scantlings deck beam

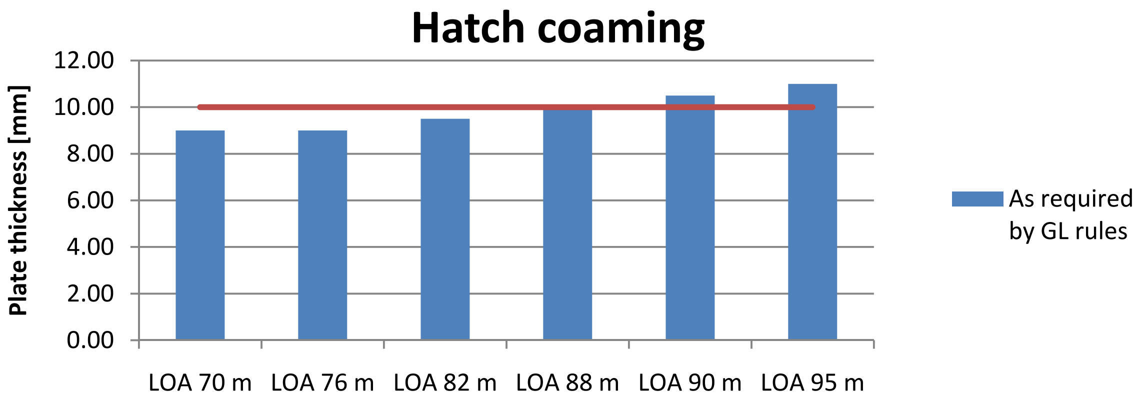

Figure 29. Scantlings hatch coaming

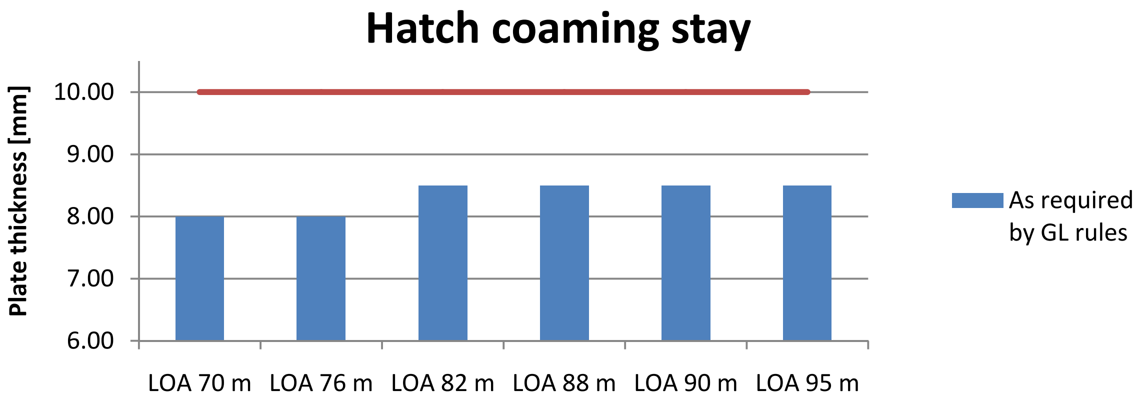

Figure 30. Scantlings hatch coaming stay

7.2. Scantlings for Different Lengthening Steps

HENDRIK Item as build 1975 LOA 70m						
Item	Selected thickness or Type of profile	Gross thickness or Type of profile	Corrosion addition			Net thickness
			Inner face	Outer face	Total	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	8.00	8.00	0.80	0.80	1.60	6.40
Inner Bottom	10.00	10.00	3.00	1.00	4.00	6.00
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	web: 320x8, flange: 100x10	web: 320x8, flange: 100x10	0.50	0.50	1.00	web: 320x7, flange: 100x9
Floor face	10.00	10.00	1.00	1.00	2.00	8.00
Bulkhead cargo	n/a	n/a	n/a	n/a	n/a	n/a
Bulkhead cargo vertical stiffeners	n/a	n/a	n/a	n/a	n/a	n/a
Bulkhead cargo horizontal stiffener	n/a	n/a	n/a	n/a	n/a	n/a
Chine radius	9.50	9.50	1.00	1.00	2.00	7.50
Side plating	8.00	8.00	0.50	1.00	1.50	6.50
Side frame trans.	HP 140x7	HP 140x7	0.50	0.50	1.00	HP 140x6
Side web girder	n/a	n/a	0.00	0.00	0.00	n/a
Sheer strake	17.50	17.50	1.00	1.75	2.75	14.75
Deck	10.00	10.00	1.00	1.00	2.00	8.00
Deck beam	7.00	7.00	0.50	0.50	1.00	6.00
Deck girder (longitudinal)	Flat 200x10	Flat 200x10	0.50	0.50	1.00	Flat 200x9
Hatch coaming	10.00	10.00	1.00	1.00	2.00	8.00
Hatch coaming top stiffener	15.00	15.00	0.50	0.50	1.00	14.00
Hatch coaming sec. stiffener	75x10	75x10	0.50	0.50	1.00	75x9
Hatch coaming vertical stiffener (stay)	L 100x100x10	L 100x100x10	0.50	0.50	1.00	L 100x100x9

HENDRIK as required by GL rules LOA 70m						
Item	**Selected thickness or Type of profile**	**Gross thickness or Type of profile**	**Corrosion addition**			**Net thickness**
			Inner face	**Outer face**	**Total**	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	7.50	7.73	0.80	0.80	1.60	6.13
Inner Bottom	8.50	8.97	1.00	1.00	4.00	4.97
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	5.50 (web:330x5 .5, flange: 100x10)	5.89	0.50	0.50	1.00	4.89
Floor face	10.00	6.97	1.00	1.00	2.00	4.97
Bulkhead cargo	7.50	7.68	2.15	0.65	2.80	4.88
Bulkhead cargo vertical stiffeners	Web: 250x11, flange: 150x14		0.50	0.50	1.00	Web: 250x10, flange: 150x13
Bulkhead cargo horizontal stiffener	HP 120x7		0.50	0.50	1.00	HP 120x6
Chine radius	9.00	9.04	1.00	1.00	2.00	7.04
Side plating	6.50	6.71	0.50	1.00	1.50	5.21
Side frame trans.	HP 160x9		0.50	0.50	1.00	HP 160x8
Side web girder	HP 300x13		0.50	0.50	1.00	HP 300x12
Sheer strake	15.50	15.62	1.00	1.75	2.75	12.87
Deck	9.00	9.12	1.00	1.00	2.00	7.12
Deck beam	6.00	6.00	0.50	0.50	1.00	5.00
Deck girder (longitudinal)	Flat 90x10		0.50	0.50	1.00	Flat 90x9
Hatch coaming	9.00	9.12	1.00	1.00	2.00	7.12
Hatch coaming top stiffener	U-profile 370x90x15		0.50	0.50	1.00	U-profile 370x90x13
Hatch coaming sec. stiffener	Flat bar 160x15		0.50	0.50	1.00	Flat bar 160x14
Hatch coaming vertical stiffener (stay)	8.00	8.42	0.50	0.50	1.00	7.42

HENDRIK as required by GL rules LOA 76m						
Item	Selected thickness or Type of profile	Gross thickness or Type of profile	Corrosion addition			Net thickness
			Inner face	Outer face	Total	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	7.50	7.98	0.80	0.80	1.60	6.38
Inner Bottom	9.00	9.16	1.00	1.00	4.00	5.16
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	5.50 (web:320x6 , flange: 100x10)	5.98	0.50	0.50	1.00	4.98
Floor face	10.00	7.16	1.00	1.00	2.00	5.16
Bulkhead cargo	7.50	7.76	2.15	0.65	2.80	4.96
Bulkhead cargo vertical stiffeners	Web: 250x11, flange: 150x14		0.50	0.50	1.00	Web: 250x10, flange: 150x13
Bulkhead cargo horizontal stiffener	HP 120x7		0.50	0.50	1.00	HP 120x6
Chine radius	9.00	9.34	1.00	1.00	2.00	7.34
Side plating	6.50	6.92	0.50	1.00	1.50	5.42
Side frame trans.	HP 160x9		0.50	0.50	1.00	HP 160x8
Side web girder	HP 300x13		0.50	0.50	1.00	HP 300x12
Sheer strake	16.00	16.26	1.00	1.75	2.75	13.51
Deck	9.00	9.35	1.00	1.00	2.00	7.35
Deck beam	6.00	6.00	0.50	0.50	1.00	5.00
Deck girder (longitudinal)	Flat 100x9		0.50	0.50	1.00	Flat 100x8
Hatch coaming	9.00	9.35	1.00	1.00	2.00	7.35
Hatch coaming top stiffener	U-profile 370x90x15		0.50	0.50	1.00	U-profile 370x90x13
Hatch coaming sec. stiffener	Flat bar 160x15		0.50	0.50	1.00	Flat bar 160x14
Hatch coaming vertical stiffener (stay)	8.00	8.47	0.50	0.50	1.00	7.47

HENDRIK as required by GL rules LOA 82m						
Item	Selected thickness or Type of profile	Gross thickness or Type of profile	Corrosion addition			Net thickness
			Inner face	Outer face	Total	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	8.00	8.25	0.80	0.80	1.60	6.65
Inner Bottom	9.00	9.37	1.00	1.00	4.00	5.37
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	6.00 (web:320x6 , flange: 100x10)	6.07	0.50	0.50	1.00	5.07
Floor face	10.00	7.37	1.00	1.00	2.00	5.37
Bulkhead cargo	7.50	7.83	2.15	0.65	2.80	5.03
Bulkhead cargo vertical stiffeners	Web: 250x11, flange: 150x14		0.50	0.50	1.00	Web: 250x10, flange: 150x13
Bulkhead cargo horizontal stiffener	HP 120x7		0.50	0.50	1.00	HP 120x6
Chine radius	9.50	9.65	1.00	1.00	2.00	7.65
Side plating	7.00	7.15	0.50	1.00	1.50	5.65
Side frame trans.	HP 160x9		0.50	0.50	1.00	HP 160x8
Side web girder	HP 300x13		0.50	0.50	1.00	HP 300x12
Sheer strake	16.50	16.90	1.00	1.75	2.75	14.15
Deck	9.50	9.67	1.00	1.00	2.00	7.67
Deck beam	6.00	6.00	0.50	0.50	1.00	5.00
Deck girder (longitudinal)	Flat 100x9		0.50	0.50	1.00	Flat 100x8
Hatch coaming	9.50	9.67	1.00	1.00	2.00	7.67
Hatch coaming top stiffener	U-profile 370x90x15		0.50	0.50	1.00	U-profile 370x90x13
Hatch coaming sec. stiffener	Flat bar 160x15		0.50	0.50	1.00	Flat bar 160x14
Hatch coaming vertical stiffener (stay)	8.50	8.53	0.50	0.50	1.00	7.53

HENDRIK as required by GL rules LOA 88m						
Item	**Selected thickness or Type of profile**	**Gross thickness or Type of profile**	**Corrosion addition**			**Net thickness**
			Inner face	**Outer face**	**Total**	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	8.00	8.36	0.80	0.80	1.60	6.76
Inner Bottom	9.00	9.43	1.00	1.00	4.00	5.43
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	6.00 (web:320x6 , flange: 100x10)	6.17	0.50	0.50	1.00	5.17
Floor face	10.00	7.43	1.00	1.00	2.00	5.43
Bulkhead cargo	7.50	7.91	2.15	0.65	2.80	5.11
Bulkhead cargo vertical stiffeners	Web: 250x11, flange: 150x14		0.50	0.50	1.00	Web: 250x10, flange: 150x13
Bulkhead cargo horizontal stiffener	HP 120x7		0.50	0.50	1.00	HP 120x6
Chine radius	9.50	9.77	1.00	1.00	2.00	7.77
Side plating	7.00	7.25	0.50	1.00	1.50	5.75
Side frame trans.	HP 160x9		0.50	0.50	1.00	HP 160x8
Side web girder	HP 300x13		0.50	0.50	1.00	HP 300x12
Sheer strake	17.50	17.54	1.00	1.75	2.75	14.79
Deck	10.00	10.00	1.00	1.00	2.00	8.00
Deck beam	6.00	6.00	0.50	0.50	1.00	5.00
Deck girder (longitudinal)	Flat 110x9		0.50	0.50	1.00	Flat 110x8
Hatch coaming	10.00	10.12	1.00	1.00	2.00	8.12
Hatch coaming top stiffener	U-profile 370x90x15		0.50	0.50	1.00	U-profile 370x90x13
Hatch coaming sec. stiffener	Flat bar 160x15		0.50	0.50	1.00	Flat bar 160x14
Hatch coaming vertical stiffener (stay)	8.50	8.60	0.50	0.50	1.00	7.60

HENDRIK as required by GL rules LOA 90m						
Item	Selected thickness or Type of profile	Gross thickness or Type of profile	Corrosion addition			Net thickness
			Inner face	Outer face	Total	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	8.50	8.51	0.80	0.80	1.60	6.91
Inner Bottom	9.50	9.56	1.00	1.00	4.00	5.56
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	6.00 (web:320x6 , flange: 100x10)	6.20	0.50	0.50	1.00	5.20
Floor face	10.00	7.56	1.00	1.00	2.00	5.56
Bulkhead cargo	7.50	7.93	2.15	0.65	2.80	5.13
Bulkhead cargo vertical stiffeners	Web: 250x11, flange: 150x14		0.50	0.50	1.00	Web: 250x10, flange: 150x13
Bulkhead cargo horizontal stiffener	HP 120x7		0.50	0.50	1.00	HP 120x6
Chine radius	9.50	9.95	1.00	1.00	2.00	7.95
Side plating	7.00	7.37	0.50	1.00	1.50	5.87
Side frame trans.	HP 160x9		0.50	0.50	1.00	HP 160x8
Side web girder	HP 300x13		0.50	0.50	1.00	HP 300x12
Sheer strake	17.50	17.75	1.00	1.75	2.75	15.00
Deck	10.00	10.17	1.00	1.00	2.00	8.17
Deck beam	6.00	6.00	0.50	0.50	1.00	5.00
Deck girder (longitudinal)	Flat 110x10		0.50	0.50	1.00	Flat 110x9
Hatch coaming	10.50	10.81	1.00	1.00	2.00	8.81
Hatch coaming top stiffener	U-profile 370x90x15		0.50	0.50	1.00	U-profile 370x90x13
Hatch coaming sec. stiffener	Flat bar 160x15		0.50	0.50	1.00	Flat bar 160x14
Hatch coaming vertical stiffener (stay)	8.50	8.63	0.50	0.50	1.00	7.63

HENDRIK as required by GL rules LOA 95m						
Item	**Selected thickness or Type of profile**	**Gross thickness or Type of profile**	**Corrosion addition**			**Net thickness**
			Inner face	**Outer face**	**Total**	
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	8.50	8.77	0.80	0.80	1.60	7.17
Inner Bottom	9.50	9.81	1.00	1.00	4.00	5.81
Longitudinal girders	10.00	10.00	0.50	0.50	1.00	9.00
Floor	6.00 (web:320x6 , flange: 100x10)	6.27	0.50	0.50	1.00	5.27
Floor face	10.00	7.81	1.00	1.00	2.00	5.81
Bulkhead cargo	8.00	8.00	2.15	0.65	2.80	5.20
Bulkhead cargo vertical stiffeners	Web: 250x11, flange: 150x14		0.50	0.50	1.00	Web: 250x10, flange: 150x13
Bulkhead cargo horizontal stiffener	HP 120x7		0.50	0.50	1.00	HP 120x6
Chine radius	10.00	10.25	1.00	1.00	2.00	8.25
Side plating	8.50	8.50	0.50	1.00	1.50	7.00
Side frame trans.	HP 160x9		0.50	0.50	1.00	HP 160x8
Side web girder	HP 300x13		0.50	0.50	1.00	HP 300x12
Sheer strake	18.00	18.29	1.00	1.75	2.75	15.54
Deck	10.00	10.49	1.00	1.00	2.00	8.49
Deck beam	6.00	6.00	0.50	0.50	1.00	5.00
Deck girder (longitudinal)	Flat 110x10		0.50	0.50	1.00	Flat 110x9
Hatch coaming	11.00	11.44	1.00	1.00	2.00	9.44
Hatch coaming top stiffener	U-profile 370x90x15		0.50	0.50	1.00	U-profile 370x90x13
Hatch coaming sec. stiffener	Flat bar 160x15		0.50	0.50	1.00	Flat bar 160x14
Hatch coaming vertical stiffener (stay)	8.50	8.70	0.50	0.50	1.00	7.70

7.3. Mass table

Table 30. Detailed masses of structural members for MV “Hendrik”

Item	Additional masses according to GL Rules 2011									
	LOA 76 m		LOA 82 m		LOA 88 m		LOA 90 m		LOA 95 m	
	Stiffener [t]	Plate [t]	Stiffener [t]	Plate [t]	Stiffener [t]	Plate [t]	Stiffener [t]	Plate [t]	Stiffener [t]	Plate [t]
Bottom plate		2.77		5.91		8.86		10.46		13.08
Inner Bottom		3.60		7.21		10.81		12.68		15.85
Longitudinal girders		0.48		0.96		1.44		1.60		2.00
Floor		1.45		3.17		4.76		5.28		6.61
Floor face		0.80		1.60		2.40		2.67		3.34
Bulkhead cargo				3.66		3.66		3.66		3.66
Bulkhead cargo vertical stiffeners			1.54		1.54		1.54		1.54	
Bulkhead cargo horizontal stiffener			0.98		0.98		0.98		0.98	
Bulkhead watertight										
Bulkhead watertight vertical stiffeners										
Bulkhead watertight horizontal stiffener										
Chine radius		0.44		0.93		1.39		1.55		2.03
Side plating		1.39		2.99		4.49		4.99		7.57
Side frame trans.	0.52		0.97		1.42		1.57		1.94	
Side web girder	0.44		1.11		1.77		1.99		2.54	
Sheer strake		0.60		1.24		1.98		2.20		2.83
Deck		0.76		1.61		2.54		2.83		3.53
Deck beam	0.41		0.81		1.22		1.36		1.70	
Deck girder (longitudinal)	0.09		0.17		0.28		0.35		0.43	
Hatch coaming		1.12		2.37		3.74		4.37		5.72
Hatch coaming top stiffener	0.78		1.55		2.33		2.59		3.24	
Hatch coaming sec. Stiffener	0.23		0.45		0.68		0.75		0.94	
Hatch coaming vertical stiffener (stay)	0.06		0.17		0.28		0.31		0.40	
Side web frame replacement	3.05		3.05		3.05		3.05		3.05	
Side frame upgrade	0.94		0.94		0.94		0.94		0.94	
Σ [t]	**6.51**	**13.43**	**11.74**	**31.66**	**14.48**	**46.08**	**15.42**	**52.29**	**17.69**	**66.22**
Total Σ [t]	**19.94**		**43.40**		**60.56**		**67.71**		**83.91**	
Hatch cover [t]	**1.00**		**2.00**		**3.00**		**3.33**		**4.17**	
Total mass [t]	**20.94**		**45.40**		**63.56**		**71.04**		**88.08**	
VCG [m]	**1.71**		**1.66**		**1.61**		**1.57**		**1.55**	

7.4. Exemplary Calculation Procedure According to BV Rules for the Verification of the Ship’s Structural Elements

7.4.1. General

The scantlings of the ship have been executed according to BV NR217- Rules for the Classification of Inland Navigation Vessels, Nov. 2011.

7.4.2. Calculation of the Ship’s Bending Moments

According to Pt.B, Ch.3, Sec.2, [1.1.1] the values of design still water bending moments, M_H and M_S, are to be provided by the designer, for all load cases considered.
It has been assumed that the loading/unloading will be done in two runs.
Notations for the still water bending moments are presented in Table 31.

Table 31. Still water bending moments

Load case	Hogging	Sagging
Navigation	M_H	M_S
Harbour 2R	M_{HH}	M_{SH}

According to Pt.B, Ch.3, Sec.2, [3.2.1] for range of navigation IN (0,6), the absolute value of the additional wave bending moment amidships is to be obtained, in kN.m, from the following formula:

$$M_W = 0{,}045\ L^2\ B\ C_B$$

According to Pt.B, Ch.3, Sec.2, [4.1.1] the total vertical bending moments are to be determined as specified in Table 32.

Table 32. Total vertical bending moments

Load case	Hogging	Sagging
Navigation	$M_{TH}=M_H+M_W$	$M_{TS}=M_S+M_W$
Harbour 2R	$M_{TH}=M_{HH}$	$M_{TS}=M_{SH}$

7.4.3. Vessel Motions and Accelerations

For the scantlings it is necessary to determine the pressure values induced by ship’s motion. These values have been determined by using [7] BV Mars Inland software.
In particular, the parameter which interests for the scantlings is the vertical acceleration a_{Z1} (upright vessel condition).

7.4.4. Corrosion Addition and Net Thicknesses

According to Pt.B, Ch.2, Sec.5, [3] the values of corrosion addition for structural elements of transversal midship section are presented in Table 33. For the calculations it has been considered that the cargo is stored on wooden floor and do not make direct contact with the steel structure.

Table 33. Corrosion addition

Element	t_{GROSS}	t_{C1}	t_{C2}	t_C= min(0.2 t_{GROSS},t_{C1} +t_{C2})	t_{NET}= t_{GROSS}-t_C
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	7.0	0.50	0.50	1.00	6.00
Bilge plate	9.0	0.50	0.50	1.00	8.00
Side plate	7.0	0.50	0.50	1.00	6.00
Shear strake plate	16.0	0.50	0.50	1.00	15.00
Deck plate	9.0	0.50	0.50	1.00	8.00
Hatch coaming lower part	8.0	0.50	0.50	1.00	7.00
Hatch coaming upper part	16.0	0.50	0.50	1.00	15.00
Transversal cargo walls lower part	8.0	0.00	0.50	0.50	7.50
Transversal cargo walls upper part	5.0	0.00	0.50	0.50	4.50
Bottom floors and girders (web)	5.0	0.50	0.50	1.00	4.00
Side frame (T80x6.5)	6.5	0.50	0.50	1.00	5.50
Side web frame	5.0	0.50	0.50	1.00	4.00
Deck web beam	5.0	0.50	0.50	1.00	4.00

For the following calculations, the net thicknesses t_{NET} have been utilised from Table 33.

7.4.5. Hull Girder Section Modulus

According to Pt.B, Ch.4, Sec.1, [2.2.1] the net section modulus at any point of a hull transverse section is obtained, in cm^3, from the following formula:

$$Z = \frac{I_Y}{100 \cdot |z - N|}$$

where:

I_Y: Moment of inertia, in cm^4, of the hull girder transverse section about its horizontal neutral axis

N: Z co-ordinate, in m, of the centre of gravity of the hull transverse section

z: Z co-ordinate, in m, of the calculation point of a structural element.

In the present calculation, ship's transversal section, in the midship area, is constant. In Table 34 are presented the net values for section modulus of the barge's transverse section in the midship area.

Table 34. Net section moduli at the main frame

	Area A	1198.5	cm^2
	Neutral axis N	1.282	m
	Moment of inertia I_Y	17430391	cm^4
	Section modulus	z	Z_i
Item “i”	Position	[m]	[cm^3]
1	The upper edge of hatch coaming	3.2360	89203.6
2	The upper edge of horizontal stiffeners of hatch coaming	3.0440	98923.9
3	Upper part of deck plating	2.5450	138007.8
4	Lower part of bottom plating	-0.0060	135329.1

7.4.6. Bottom Scantlings

7.4.6.1. Design lateral pressure

According to Pt.B, Ch.5, Sec.2, [2.2.1] the design lateral pressures p to be used for bottom plating scantling are given in Table A5.

Table 35. Design lateral pressures

Structure	Structural item	Design lateral pressure p [kN/m^2]
Single bottom	Bottom plating	• p_E • $p_C - p_{Em}$

where:

p_E – external pressure, in kN/m^2, defined in Pt.B, Ch 3, Sec 4, [2]

p_{Em} – river counter pressure. $p_{Em}=0\ kN/m^2$

p_C – dry bulk cargoes pressure, in kN/m^2, defined from Pt.B, Ch 3, Sec 4, [3.2]

Also, according to Pt.B, Ch.3, Sec.4, [4.1.1] the plating and stiffeners of compartments not intended to carry liquids will be checked in flooding condition at pressure p_{FL}.

7.4.6.2. External pressure pE

According to Pt.B, Ch 3, Sec 4, [2]:

$p_E = p_{SE} + p_{WE}$

$p_{SE} = 9,81\ (T_1 - z)$

$$p_{WE} = 9,81\gamma_{W2}h_1\left(\frac{0,23(z - T_1)}{T_1} + 1\right)$$

7.4.6.3. Dry bulk cargo pC

According to Pt.B, Ch 3, Sec 4, [3.2]:

$$p_C = \left(\frac{D - z}{D - z_H}\right)p_0$$

p_0: Mean total pressure on bottom, in kN/m²:

$p_0 = p_S + p_W \geq 0$

p_S: Mean still water pressure on bottom, in kN/m²:

$$p_S = \frac{9,81 m_B}{L_H B_1}$$

p_W: Mean inertial pressure on bottom, in kN/m²:

$$p_W = \frac{a_{Z1}\gamma_{W2}m_B}{L_H B_1}$$

L_H, B_1: Length and breadth, in m, of the hold.

m_B: Mass of dry bulk cargo, in t, in the hold considered

γ_{W2}: Partial safety factor covering uncertainties regarding wave loads

$\gamma_{W2} = 1$ for $n < 1,02$

z_H: Z co-ordinate, in m, of the bottom

$z = 0$ for bottom

7.4.6.4. Flooding pressure

According to Pt.B, Ch.3, Sec.4, [4.1.1] the still water pressure p_{FL} to be considered as acting on plating and stiffeners of watertight bulkheads of compartments not intended to carry liquids is obtained, in kN/m², from the following formula:

$p_{FL} = 9,81\ (z_{TOP} - z)$

z_{TOP}: Z co-ordinate, in m, of the highest point of the tank or compartment

z: Z co-ordinate, in m, of the calculation point

7.4.6.5. Hull girder normal stresses

According to Pt.B, Ch.5, Sec.2, [2.2.1] the hull girder normal stresses to be considered for the strength check of plating subjected to lateral pressure are to be determined using the formula:

$$\sigma_{X1} = 10^5\left|\frac{\max(M_{TH}; M_{TS})}{I_Y}(z - N)\right|$$

7.4.6.6. Plating net thicknesses

According to Pt.B, Ch.5, Sec.2, [4.1.1] in the central part, the bottom plating net thicknesses, in mm, are not to be less than the values t_1 and t_2 given in Table A6.

Table 36. Bottom plating

Plating	Transverse framing
Bottom	$t_1 = 1{,}85 + 0{,}03\ L\ k^{0{,}5} + 3{,}6\ s$ $t_2 = 1{,}24 C_a C_r s \sqrt{\frac{kp}{\lambda_T}}$

where: $\lambda_T = 1 - 0{,}0038\ \sigma_{X1}$

s = 0.500 m;

C_r=1;

C_a: Aspect ratio, equal to:

$$c_a = 1{,}21\sqrt{1 + 0{,}33\left(\frac{s}{\ell}\right)^2} - 0{,}69\frac{s}{\ell} \le 1$$

l = 1.500 m for bottom plate;

7.4.6.7. Buckling strength check

According to Pt.B, Ch.5, Sec.2, [4.3.1] the bottom plating thicknesses, in mm, are to comply with the following formulae:

$$t_3 = 2{,}45b\sqrt{\frac{\sigma_b}{k_0 K_1 F_1}} \quad \text{for} \quad \sigma_b \le \frac{R_{eH}}{2}$$

$$t_3 = 1{,}158b\sqrt{\frac{R_{eH}^2}{k_0 K_1 F_1 (R_{eH} - 1{,}12\sigma_b)}} \quad \text{for} \quad \sigma_b > \frac{R_{eH}}{2}$$

where σ_b is the maximum hull girder compression stress on the plate:

$$\sigma_{X1} = 10^3\left|\frac{M_{TH}}{I_Y}(z - N)\right|$$

K_0, K_1, F_1: according to Pt.B, Ch.5, Sec.1, [4]

7.4.7. Side Scantlings

7.4.7.1. Design lateral pressure

According to Pt.B, Ch.5, Sec.3, [2.2.1] the design lateral pressures p to be used for side plating and structural members are given in Table 37.

Table 37. Design lateral pressure

Structure	Structural item	Design lateral pressure p, kN/m^2
Single side	Side plating and structural members	p_E p_C - p_{Em}

where:

p_E – external pressure, in kN/m^2, defined in Pt.B, Ch 3, Sec 4, [2]

p_{Em} – river counter pressure. p_{Em}=0 kN/m^2

p_C – dry bulk cargoes pressure. , in kN/m^2, defined from Pt.B, Ch 3, Sec 4, [3.2]

Also, according to Pt.B, Ch.3, Sec.4, [4.1.1] the plating and stiffeners of compartments not intended to carry liquids will be checked in flooding condition at pressure p_{FL}.

7.4.7.2. External pressure pE

According to Pt.B, Ch 3, Sec 4, [2]:

$p_E = p_{SE} + p_{WE}$

$p_{SE} = 9{,}81\,(T_1 - z)$

$$p_{WE} = 9,81\,\gamma_{W2} h_1 \left(\frac{0,23(z - T_1)}{T_1} + 1\right)$$

7.4.7.3. Dry bulk cargo pC

According to Pt.B, Ch 3, Sec 4, [3.2]:

$$p_C = \left(\frac{D - z}{D - z_H}\right) p_0$$

p_0: Mean total pressure on bottom, in kN/m^2:

$p_0 = p_S + p_W \geq 0$

p_S: Mean still water pressure on bottom, in kN/m^2:

$$p_S = \frac{9,81\,m_B}{L_H B_1}$$

p_W: Mean inertial pressure on bottom, in kN/m^2:

$$p_W = \frac{a_{Z1}\gamma_{W2} m_B}{L_H B_1}$$

L_H, B_1: Length and breadth, in m, of the hold.

m_B: Mass of dry bulk cargo, in t, in the hold considered

γ_{W2}: Partial safety factor covering uncertainties regarding wave loads

$\gamma_{W2} = 1$ for $n < 1{,}02$

z_H: Z co-ordinate, in m, of the bottom

z: Z co-ordinate, in m, of the calculation point

7.4.7.4. Flooding pressure

According to Pt.B, Ch.3, Sec.4, [4.1.1] the still water pressure p_{FL} to be considered as acting on plating and stiffeners of watertight bulkheads of compartments not intended to carry liquids is obtained, in kN/m^2, from the following formula:

$p_{FL} = 9{,}81\,(z_{TOP} - z)$

z_{TOP}: Z co-ordinate, in m, of the highest point of the tank or compartment

z: Z co-ordinate, in m, of the calculation point

7.4.7.5. Hull girder normal stresses

According to Pt.B, Ch.5, Sec.3, [2.2.1] the hull girder normal stresses to be considered for the strength check of plating subjected to lateral pressure are to be determined using the formula:

$$\sigma_{X1} = 10^5 \left|\frac{\max(M_{TH};M_{TS})}{I_Y}(z - N)\right|$$

7.4.7.6. Plating net thicknesses

According to Pt.B, Ch.5, Sec.3, [4.1.1] in the central part, the side plating net thicknesses, in mm, are not to be less than the values t_1 and t_2 given in Table 38.

Table 38. Plating net thicknesses

Plating	Transverse framing
Side	$t_1 = 1{,}68 + 0{,}025\,L\,k^{0{,}5} + 3{,}6\,s$ $t_2 = 1{,}24 C_a C_r s \sqrt{\frac{kp}{\lambda_T}}$

where: $\lambda_T = 1 - 0{,}0038\,\sigma_{X1}$

s = 0.500 m;

$C_r = 1$;

C_a: Aspect ratio, equal to:

$$c_a = 1{,}21\sqrt{1 + 0{,}33\left(\frac{s}{\ell}\right)^2} - 0{,}69\frac{s}{\ell} \le 1$$

l = 1.700 m for side plate.

7.4.7.7. *Buckling strength check*

According to Pt.B, Ch.5, Sec.3, [4.3.1] the bottom plating thicknesses, in mm, are to comply with the following formulae:

$$t_3 = 2{,}45 b \sqrt{\frac{\sigma_b}{k_0 K_1 F_1}} \qquad \text{for} \quad \sigma_b \le \frac{R_{eH}}{2}$$

$$t_3 = 1{,}158 b \sqrt{\frac{R_{eH}^2}{k_0 K_1 F_1 (R_{eH} - 1{,}12\sigma_b)}} \qquad \text{for} \quad \sigma_b > \frac{R_{eH}}{2}$$

where σ_b is the maximum hull girder compression stress on the plate:

- for Z<N:

$$\sigma_{X1} = 10^3 \left|\frac{M_{TH}}{I_Y}(z - N)\right|$$

- for Z≥N:

$$\sigma_{X1} = 10^3 \left|\frac{M_{TS}}{I_Y}(z - N)\right|$$

K_0, K_1, F_1: according to Pt.B, Ch.5, Sec.1, [4]

7.4.7.8. *Structural member scantlings*

Minimum web net thicknesses

According to Pt.B, Ch.5, Sec.3, [5.1.1] the minimum web net thicknesses are:

- for ordinary stiffeners: $t = 1{,}63 + 0{,}004\,L\,k^{0{,}5} + 4{,}5\,s$
- for p**rimary supporting members:** $t = 3{,}8 + 0{,}016\,L\,k^{0{,}5}$

Net section modulus and net shear sectional area of structural members

According to Pt.B, Ch.5, Sec.3, [5.2.1] the net scantlings of single side structural members are not to be less than the values obtained from Table 39.

Table 39. Net section modulus

Item		w, cm^3	A_{sh}, cm^2
Side frames	if $\ell_0 \le \ell$:	$w = \beta_b \frac{s}{m(226/k)}(6\ell\ell_0^2 + 1{,}45\lambda_W p_F \ell_F^2)10^3$	$A_{sh} = 91\beta_s \frac{\ell}{226/k}\eta s \ell_0$
	if $\ell_0 > \ell$:	$w = \beta_b \frac{s}{m(226/k)}(\lambda_b p \ell^2 + 1{,}45\lambda_W p_F \ell_F^2)10^3$	$A_{sh} = 13\lambda_s \beta_s \frac{p}{226/k}\eta s \ell$

where:

m = 12;

s = 0.500 m;
l = 2.150m – for side frames;
β_B = 0.823 – for side frames (bracket at the upper end h=200mm)
$l_0 = p_d /9,81$
p_d: total pressure, in kN/m^2, at the lower end of the stiffener
p_u: pressure, in kN/m^2, at the upper end of the structural member considered

$$\lambda_b = 1 + 0.2\left|\frac{p_d - p_u}{p_d + p_u}\right|$$

7.4.8. Deck Scantlings

7.4.8.1. Design lateral pressure

According to Pt.B, Ch.5, Sec.4, [2.2.1] the design lateral pressures p to be used for deck plating and structural members are:

- for open deck stringer plate: $p = p_E = 3,75 (n + 0,8) = 4.91$ kN/m^2;
- for hatch coaming : $p = 3.00$ kN/m^2.

7.4.8.2. Hull girder normal stresses

According to Pt.B, Ch.5, Sec.4, [3.2.1] the hull girder normal stresses to be considered for the strength check of plating subjected to lateral pressure are to be determined using the formula:

$$\sigma_{X1} = 10^3\left|\frac{\max(M_{TH};M_{TS})}{I_Y}(z - N)\right|$$

7.4.8.3. Buckling strength check

According to Pt.B, Ch.5, Sec.4, [4.1.1] the plating net thicknesses of deck, stringer plate, hatch coaming, in mm, are to comply with the following formulae:

$$t_3 = 2,45b\sqrt{\frac{\sigma_b}{k_0 K_1 F_1}} \qquad \text{for} \quad \sigma_b \le \frac{R_{eH}}{2}$$

$$t_3 = 1,158b\sqrt{\frac{R_{eH}^2}{k_0 K_1 F_1 (R_{eH} - 1,12\sigma_b)}} \quad \text{for} \quad \sigma_b > \frac{R_{eH}}{2}$$

where σ_b is the maximum hull girder compression stress on the plate :

$$\sigma_{X1} = 10^3\left|\frac{M_{TS}}{I_Y}(z - N)\right|$$

K_0, K_1, F_1: according to Pt.B, Ch.5, Sec.1, [4]

7.4.8.4. Stringer plate net thickness

According to Pt.B, Ch.5, Sec.4, [5.1.2] the net thickness of the stringer plate, in mm, is not to be less than the values t_1 and t_2:

$t_1 = 2 + 0,02\ L\ k^{0,5} + 3,6\ s$

$$t_2 = 1,24 C_a C_r s\sqrt{\frac{kp}{\lambda_T}}$$

where: $\lambda_T = 1 - 0,0038\ \sigma_{X1}$
s = 0.500 m;
l = 0.750 m;
C_a: Aspect ratio, equal to:

$$c_a = 1,21\sqrt{1+0,33\left(\frac{s}{\ell}\right)^2} - 0,69\frac{s}{\ell} \le 1$$

C_r=1;

7.4.8.5. Sheer strake

According to Pt.B, Ch.5, Sec.4, [5.2.2] the sheer strake net thickness is not to be less than that of the stringer plate nor than that of the side shell plating.
The net thickness of sheer strake, in mm, is not to be less than:

$t_1 = 3,6 + 0,11\ L\ k^{0,5} + 3,6\ s$

The sheer strake is to extend over a height b3, measured from the deck line, in compliance with the following:

$0,08\ D \le b3 \le 0,15\ D$

7.4.8.6. Hatch coaming

According to Pt.B, Ch.5, Sec.4, [5.3.4] the net thickness of the hatch coaming plating is to be maintained over the length of the hold and is not to be less than t_1 and t_2:

$t_1 = 1,6 + 0,04\ L\ k^{0,5} + 3,6\ s$

$$t_2 = 1,24 C_a C_r s\sqrt{\frac{kp}{\lambda_T}}$$

where: $\lambda_T = 1 - 0,0038\ \sigma_{X1}$

s = 0.730 m;

l = 2.250 m;

C_a: Aspect ratio, equal to:

$$c_a = 1,21\sqrt{1+0,33\left(\frac{s}{\ell}\right)^2} - 0,69\frac{s}{\ell} \le 1$$

C_r=1;

7.4.8.7. Cargo Bulkhead Scantlings

7.4.8.8. Design lateral pressure

According to Pt.B, Ch.5, Sec.5, [2.2.1] the design lateral pressures p to be used for bulkhead plating and structural members are given in Table 40.

Table 40. Design lateral pressure

Type of bulkhead	Lateral pressure p, in kN/m^2
Hold bulkhead	p_C
Watertight bulkhead of compartments not intended to carry liquids	p_{FL}

Dry bulk cargo p_C

According to Pt.B, Ch 3, Sec 4, [3.2]:

$$p_C = \left(\frac{D-z}{D-z_H}\right)p_0$$

p_0: Mean total pressure on bottom, in kN/m^2:

$p_0 = p_S + p_W \geq 0$

p_S: Mean still water pressure on bottom, in kN/m^2:

$$p_S = \frac{9,81 m_B}{L_H B_1}$$

p_W: Mean inertial pressure on bottom, in kN/m^2:

$$p_W = \frac{a_{Z1} \gamma_{W2} m_B}{L_H B_1}$$

L_H, B_1: Length and breadth, in m, of the hold.

m_B: Mass of dry bulk cargo, in t, in the hold considered

γ_{W2}: Partial safety factor covering uncertainties regarding wave loads

$\gamma_{W2} = 1$ for $n < 1,02$

z_H: Z co-ordinate, in m, of the bottom

z: Z co-ordinate, in m, of the calculation point

Flooding pressure

According to Pt.B, Ch.3, Sec.4, [4.1.1] the still water pressure p_{FL} to be considered as acting on plating and stiffeners of watertight bulkheads of compartments not intended to carry liquids is obtained, in kN/m^2, from the following formula:

$p_{FL} = 9,81 (z_{TOP} - z)$

z_{TOP}: Z co-ordinate, in m, of the highest point of the tank or compartment

z: Z co-ordinate, in m, of the calculation point

7.4.8.9. Plating net thicknesses

According to Pt.B, Ch.3, Sec.5, [4.1.1] the bulkhead plating net thickness, in mm, is not to be less than the values t_1 and t_2 :

$t_1 = 0,026 \, L \, k^{0,5} + 3,6 \, s$

$t_2 = C_a C_r s \sqrt{kp}$

where: s = 0.500 m;

l = 2.600 m;

C_a: Aspect ratio, equal to:

$$c_a = 1,21 \sqrt{1 + 0,33\left(\frac{s}{\ell}\right)^2} - 0,69\frac{s}{\ell} \leq 1$$

$C_r = 1$;

7.4.8.10. Structural member scantlings

Minimum web net thicknesses

According to Pt.B, Ch.5, Sec.5, [5.1.1] the minimum web net thicknesses for ordinary stiffeners are:

$t = 1,1 + 0,0048 \, L \, k^{0,5} + 4,8 \, s$

Net section modulus and net shear sectional area of structural members

According to Pt.B, Ch.5, Sec.3, [5.2.1] the net scantlings of bulkhead structural members are not to be less than the values obtained from Table 41.

Table 41. Net section modulus

Item	w, cm^3	A_{sh}, cm^2
Vertical stiffeners	$w = \lambda_b \beta_b \frac{p}{m(\sigma_p / k)} s \ell^2 10^3$	$A_{sh} = 10 \lambda_s \beta_s \frac{p}{\sigma_p / k} \eta s \ell$

where:

m =12;
s = 0.500 m;
l = 2.600 m;
β_B = 0.817 (with brackets at the ends)
σ_p = 226 N/mm^2.

7.4.9. Allowable Values for Scantlings

This calculation being a verification of the structure for an existing ship, two checking criteria have been followed:

a) Allowable values imposed by the Rules:

- Hull girder stress (acc. Pt.B, Ch.4, Sec.2, [1.1] and [1.2])

The hull girder normal stresses induced by vertical bending moments are obtained, in N/mm^2, from the following formulae:

in hogging conditions:

$$\sigma_1 = \frac{M_{TH}}{Z} 10^3$$

in sagging conditions:

$$\sigma_1 = \frac{M_{TS}}{Z} 10^3$$

It is to be checked that the normal hull girder stresses, in N/mm^2, at any point of the net hull girder transverse section are in compliance with the following:

$\sigma_1 \leq 192 / k$

b) Allowable values imposed by the ship's existing structure. These values refer to plates and profiles thicknesses and also to structural elements net section modulus.

According to Pt.B, Ch.1, Sec.1, [3.1.1] the plate thicknesses rounded off to the nearest half-millimeter.

According to Pt.B, Ch.1, Sec.1, [3.1.2] no reduction of stiffener section moduli may exceed 3%.

Table 42 presents the allowable net values of the thicknesses considered for the present calculation.

Table 42. The allowable net values of the thicknesses

Element	t_{GROSS}	t_{GROSS1}	t_C	$t_{NET-ALLOWABLE}$
	[mm]	[mm]	[mm]	[mm]
Bottom plate	7.0	7.240	1.00	6.240
Bilge plate	9.0	9.240	1.00	8.240
Side plate	7.0	7.240	1.00	6.240
Shearstrake plate	16.0	16.240	1.00	15.240
Deck plate	9.0	9.240	1.00	8.240
Hatch coaming lower part	8.0	8.240	1.00	7.240
Hatch coaming upper part	16.0	16.240	1.00	15.240
Transversal cargo walls lower part	8.0	8.240	1.00	7.240

Element	t_{GROSS}	t_{GROSS1}	t_C	$t_{NET-ALLOWABLE}$
	[mm]	[mm]	[mm]	[mm]
Transversal cargo walls upper part	5.0	5.240	1.00	4.240
Bottom floors and girders (web)	5.0	5.240	1.00	4.240
Side frame (T80x6.5)	6.5	6.740	1.00	5.740
Side web frame	5.0	5.240	1.00	4.240
Deck web beam	5.0	5.240	1.00	4.240

Notations:

t_{GROSS} – initial thickness of plates;

t_{GROSS1} – initial thickness of plates rounded up according Rules;

t_C – corrosion addition;

$t_{NET-ALLOWABLE}$ – allowable net values for plate thicknesses;

With regards to the section modulus of the shell frames (T80x6.5), increased allowable net values with 3% are:

- for single frames: $w_{NET-ALLOWABLE}$ = 33.9 cm³;

With regard to section modulus of the vertical stiffeners of the transversal bulkheads (T80x6.5), allowable net values increased with 3% are:

- for ordinary stiff. of transversal bulkheads: $w_{NET-ALLOWABLE}$ = 33.9 cm³.

7.5. Strength Calculation of MV “Rheinland”

7.5.1. Ship Calculation – LOA 57.5 m

7.5.1.1. Hydrostatics

trim: 0.000

d m	Dfw t	LCF m	LCB m	KB m	KMT m	TPC t/cm	MTC tm/cm
0.500	129.78	29.745	30.073	0.256	6.314	2.721	8.122
0.600	157.33	29.577	30.000	0.308	5.389	2.757	8.419
0.700	185.25	29.407	29.924	0.359	4.757	2.793	8.721
0.800	213.50	29.230	29.844	0.411	4.281	2.824	8.995
0.900	242.09	29.016	29.759	0.463	3.933	2.860	9.317
1.000	271.15	28.600	29.659	0.515	3.685	2.920	9.910
1.100	300.77	28.256	29.537	0.568	3.468	2.968	10.417
1.200	330.86	27.933	29.406	0.621	3.294	3.011	10.903
1.300	361.49	27.561	29.265	0.674	3.155	3.058	11.464
1.400	392.45	27.436	29.126	0.727	3.041	3.088	11.725
1.500	423.62	27.325	28.997	0.781	2.945	3.109	11.940
1.600	455.01	27.221	28.878	0.834	2.870	3.131	12.164
1.700	486.61	27.124	28.768	0.887	2.809	3.151	12.380
1.800	518.41	27.035	28.664	0.940	2.761	3.171	12.590
1.900	550.41	26.944	28.567	0.993	2.725	3.191	12.801
2.000	582.61	26.853	28.474	1.045	2.698	3.211	13.013
2.100	615.01	26.783	28.387	1.098	2.681	3.231	13.236
2.200	647.62	26.715	28.305	1.151	2.671	3.252	13.457
2.300	680.44	26.648	28.226	1.204	2.666	3.272	13.677
2.400	713.46	26.584	28.152	1.257	2.667	3.292	13.896
2.500	746.68	26.533	28.081	1.310	2.175	2.182	13.560

7.5.1.2. Weight distribution

Lightship

Structure

Position	Weight[t]	LCG[m]	VCG[m]	St.FR	EndFR
Aft - Fr. 2	3.260	-0.237	2.593	-4	2
Fr. 2 - Fr.14	12.010	4.016	2.205	2	14
Fr. 14 - Fr.23	11.090	9.302	2.271	14	23
Fr. 23 - Fr.25	2.000	12.006	1.829	23	25
Fr. 25 - Fr.57	21.750	20.553	1.155	25	57
Fr. 57 - Fr.60	4.780	29.260	1.593	57	60
Fr. 60 - Fr.93	22.760	38.295	1.198	60	93
Fr. 93 - Fr.98	5.680	47.775	1.827	93	98
Fr. 98 - Fr.100	2.210	49.491	2.055	98	100
Fr.100 - Fr.106	5.200	51.439	1.979	100	106
Fr.106 - Fore	2.550	54.159	2.494	106	111
Weld+spare 7%	6.500	25.919	1.666	-3	112
TOTAL CHAPTER	99.790	25.934	1.665		

Outfitting

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Aft gear	4.500	-0.500	2.000	-4	2
Prop+ER aft	4.200	4.000	0.800	2	14
ER fore	12.800	9.000	1.200	14	23
Accomodation aft	7.500	6.800	3.000	3	23
Hatches aft	6.200	20.500	3.100	25	57
Wood floor aft	1.500	20.500	0.600	25	57
Gear center	1.500	29.250	1.800	57	60
Hatches fore	6.200	38.250	3.200	60	93
Wood floor fore	1.500	38.250	0.600	60	93
Accomodation fore	3.500	49.800	2.500	95	105
Fore gear	4.500	54.000	3.300	105	111
Other	15.000	24.000	1.800	-4	112
TOTAL CHAPTER	68.900	21.107	2.096		
TOTAL Light ship	**168.690**	**23.962**	**1.841**		

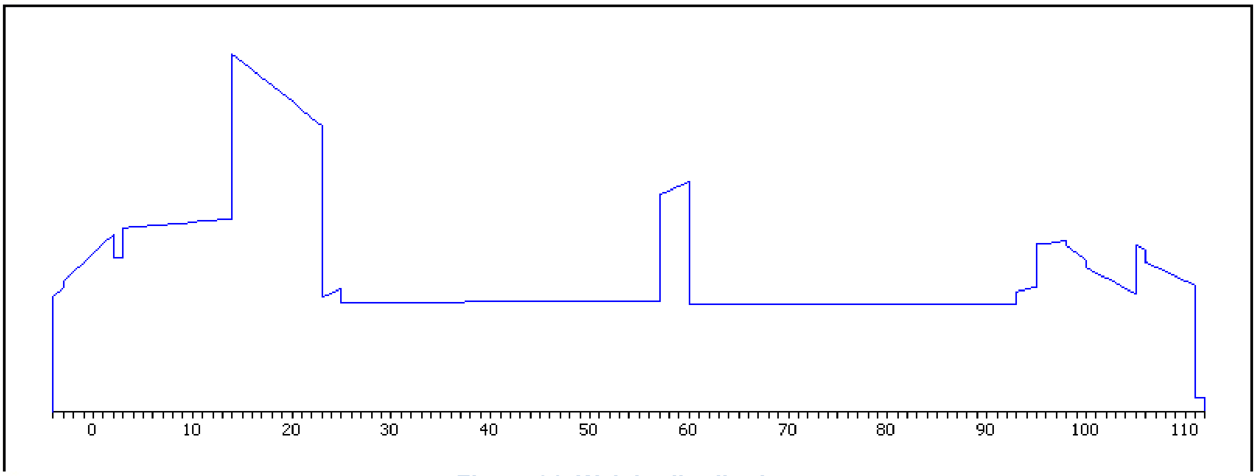

Figure 31. Weight distribution

Other weight groups

Constant

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Crew	1.000	6.800	3.000	3	23
Materials	1.000	26.000	2.600	-2	111
Working liquids	2.000	9.000	1.000	14	23
TOTAL CHAPTER	4.000	12.700	1.900		

100% store

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
FO	8.200	4.900	1.800	4	14
FW	2.400	8.000	2.000	15	17
LO	2.300	12.000	1.500	23	25
TOTAL CHAPTER	12.900	6.743	1.784		

10% store

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR

FO	0.820	4.900	1.800	4	14
FW	0.250	8.000	2.000	15	17
LO	0.230	12.000	1.500	23	25
TOTAL CHAPTER	1.300	6.752	1.785		

Distribution of cargo

100% hom.cargo

Position	Weight[t]	LCG[m]	VCG[m]	St.FR	EndFR
Hold I	102.000	45.000	1.500	83	98
Hold II	92.000	38.500	1.500	71	83
Hold III	86.000	32.500	1.500	59	71
Hold IV	88.600	26.000	1.500	46	58
Hold V	84.000	20.250	1.500	35	46
Hold VI	85.000	14.500	1.500	23	35
TOTAL CHAPTER	537.600	30.067	1.500		

Payload 537 t => hom. cargo density 0.8935 t/mc

7.5.1.3. Case 1 - Ship without cargo

Weights

Weight group	Weight[t]	LCG[m]	TCG[m]	VCG[m]
Light ship	168.690	23.962	0.000	1.841
Constant	4.000	12.700	0.000	1.900
100% store	12.900	6.743	0.000	1.784
TOTAL	185.590	22.523	0.000	1.83

```
   Draughts [m]
      at LBP/2                    0.715
      at LCF                      0.737
      at fore perpendicular       0.006
      at aft perpendicular        1.425
   Trim at perpendiculars [m]    -1.418
```

Longitudinal strength

```
       Maximum values
       SF+       392.91   at FR    23
       SF-      -241.38   at FR    83
       BM+      5154.95   at FR    46
       BM-         0.00   at FR    -4
```

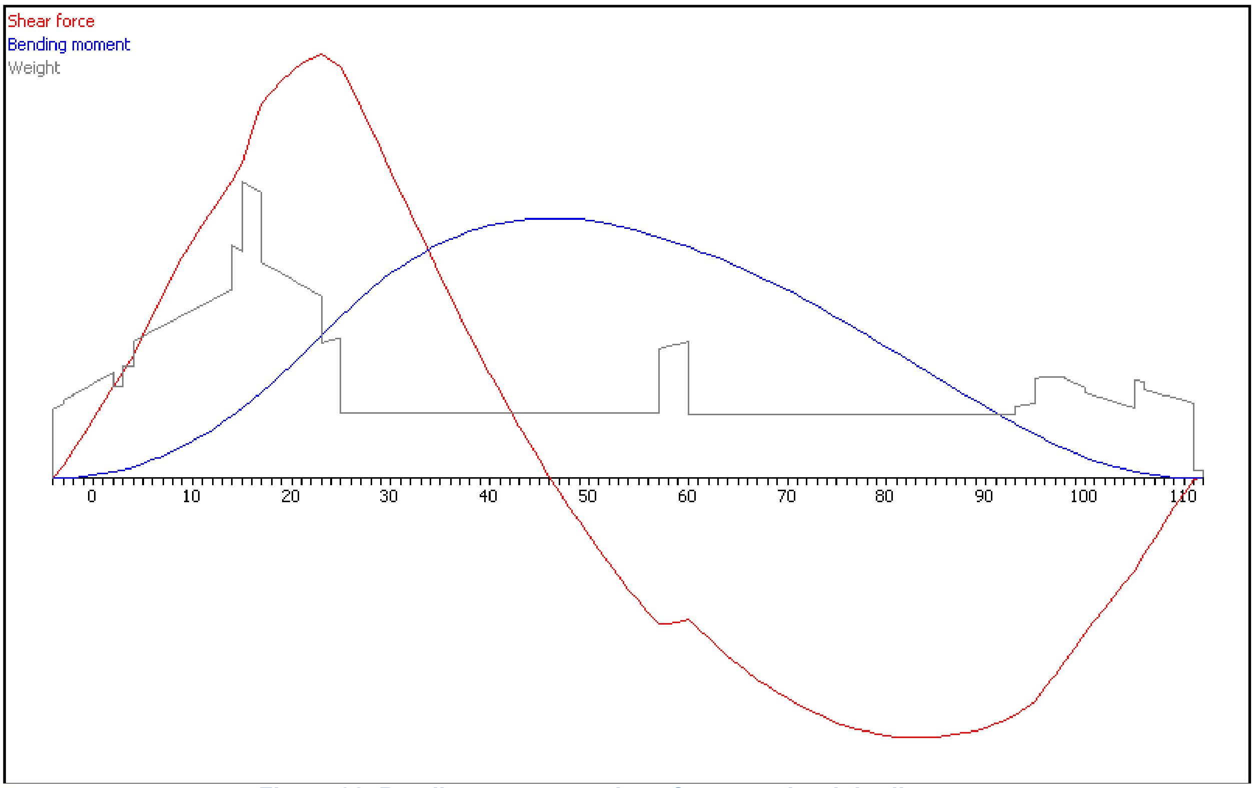

Figure 32. Bending moments, shear forces and weight diagrams

Results of scantling

For scantling formulas see Annex 7.3.

Table 43. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Navigation	5155.0	0.0	776.7	776.7	5931.7	776.7
Harbour 2R	0.0	0.0	0.0	0.0	0.0	0.0

Table 44. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging
	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	66.5	8.7	0.0	0.0
Upper edge of horizontal stiffeners of hatch coaming	60.0	7.9	0.0	0.0
Upper edge of deck plating	43.0	5.6	0.0	0.0

Lower edge of bottom plaiting	43.8	5.7	0.0	0.0

Table 45. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1	t_2	t_3	t_{MAX}	$t_{ALLOW.}$
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	5.360	2.741	6.402	6.402	6.240
Bilge plate				7.362	8.240
Side plate	4.905	2.519	4.385	4.905	6.240
Sheerstrake doubling plate	11.670			11.670	15.240
Deck plate	4.940	1.255	1.758	4.940	8.240
Hatch coaming	5.680	1.038	2.465	5.680	7.240
Transversal wall	3.282	0.000		3.282	4.240

Table 46. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]		Modulus [cm^3]	
	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.11	5.74	15.30	33.90
Vertical wall stiffeners	3.77	5.74	0.00	33.90
Web frames	4.71	4.24	-	-

7.5.1.4. *Case 2 - Ship with full cargo*

Weights

Weight group	Weight [t]	LCG [m]	TCG [m]	VCG [m]
Light ship	168.690	23.962	0.000	1.841
Constant	4.000	12.700	0.000	1.900
100% store	12.900	6.743	0.000	1.784
100% hom.cargo	537.600	30.067	0.000	1.500
TOTAL	723.190	28.131	0.000	1.587

Draughts [m]	
at LBP/2	2.429
at LCF	2.429
at fore perpendicular	2.429
at aft perpendicular	2.429
Trim at perpendiculars [m]	0.000

Longitudinal strength

Maximum values

SF+	294.30	at FR	98
SF-	-318.82	at FR	23
BM+	135.48	at FR	8
BM-	-3272.81	at FR	56

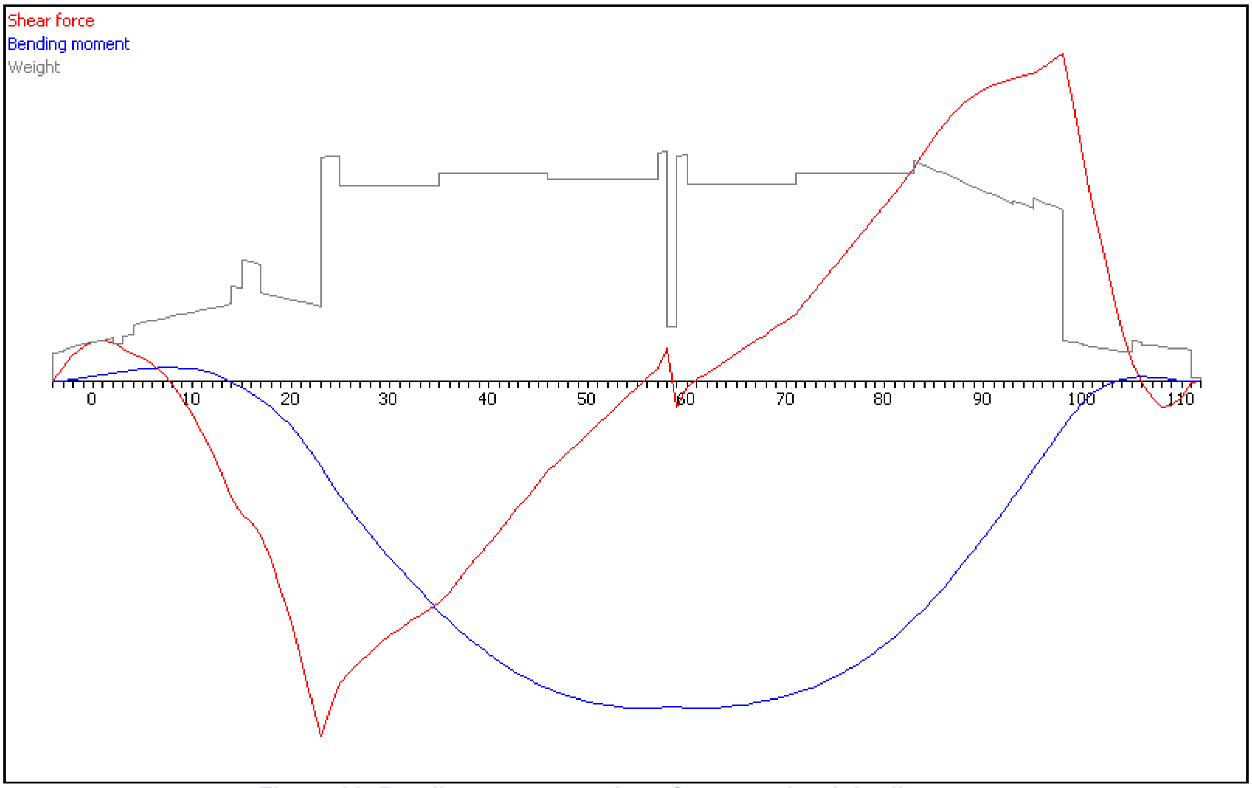

Figure 33. Bending moments, shear forces and weight diagrams

Results of scantling

For scantling formulas see Annex 7.3.

Table 47. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Navigation	135.5	3272.8	776.7	776.7	912.2	4049.5
Harbour 2R	0.0	0.0	0.0	0.0	0.0	0.0

Table 48. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging
	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	10.2	45.4	0.0	0.0
Upper edge of horizontal stiffeners of hatch coaming	9.2	40.9	0.0	0.0
Upper edge of deck plating	6.6	29.3	0.0	0.0
Lower edge of bottom plaiting	6.7	29.9	0.0	0.0

Table 49. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1	t_2	t_3	t_{MAX}	$t_{ALLOW.}$
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	5.360	3.367	2.510	5.360	6.240
Bilge plate				6.164	8.240
Side plate	4.905	3.194	1.320	4.905	6.240
Shear strake doubling plate	11.670	0.000	2.558	11.670	15.240
Deck plate	4.940	1.218	4.015	4.940	8.240
Hatch coaming	5.680	0.987	5.627	5.680	7.240
Transversal wall	3.282	2.407		3.282	4.240

Table 50. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]	Modulus [cm^3]

	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.11	5.74	28.98	33.90
Vertical wall stiffeners	3.77	5.74	9.50	33.90
Web frames	4.71	4.24	-	-

7.5.1.5. *Case 3 - Ship in harbour condition (2R)*

Weights

```
Weight group                Weight[t]    LCG[m]     TCG[m]     VCG[m]
---------------------------------------------------------------------
Light ship                    168.690    23.962      0.000      1.841
Constant                        4.000    12.700      0.000      1.900
100% store                     12.900     6.743      0.000      1.784
---------------------------------------------------------------------
TOTAL                         185.590    22.523      0.000      1.838
```

Load sequence - 2R

```
--------------------------------------------------------------------------
Position                    Weight[t]    LCG[m]     VCG[m]   St.FR   EndFR
--------------------------------------------------------------------------
Run 1
S6 Hold I                    51.000    45.000     1.500      83      98
S5 Hold II                   46.000    38.500     1.500      71      83
S4 Hold III                  43.000    32.500     1.500      59      71
S3 Hold IV                   44.300    26.000     1.500      46      58
S2 Hold V                    42.000    20.250     1.500      35      46
S1 Hold VI                   42.500    14.500     1.500      23      35
Run 2
S7 Hold I                    51.000    45.000     1.500      83      98
S8 Hold II                   46.000    38.500     1.500      71      83
S9 Hold III                  43.000    32.500     1.500      59      71
S10 Hold IV                  44.300    26.000     1.500      46      58
S11 Hold V                   42.000    20.250     1.500      35      46
S12 Hold VI                  42.500    14.500     1.500      23      35
--------------------------------------------------------------------------
```

Si = cargo load at step "i"

Longitudinal strength

Table 51. Longitudinal strength

Step	Displ. [t]	Cargo [t]	T(L/2) [m]	Trim [m]	BMmax [kNm]	SFmax [kN]
S1	228	42.5	0.846	-1.889	**4952**	343
S2	270	84.5	0.977	-2.105	3786	252
S3	314	129	1.119	-2.106	2322	202
S4	357	172	1.261	-1.884	1118	188
S5	403	218	1.416	-1.439	650	181
S6	454	269	1.590	-0.696	1400	120
S7	505	320	1.760	0.039	2550	-257
S8	551	366	1.908	0.455	2505	-350
S9	594	409	2.043	0.632	-1894	-355
S10	638	453	2.181	0.591	-2760	-338

S11	681	495	2.307	0.377	-3306	-355

Results of scantling

For scantling formulas see Annex 7.3.

Table 52. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Harbour 2R	4952.0	0.0	0.0	0.0	4952.0	0.0

Table 53. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging
	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	0.0	0.0	55.5	0.0
Upper edge of horizontal stiffeners of hatch coaming	0.0	0.0	50.1	0.0
Upper edge of deck plating	0.0	0.0	35.9	0.0
Lower edge of bottom plaiting	0.0	0.0	36.6	0.0

Table 54. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1	t_2	t_3	t_{MAX}	$t_{ALLOW.}$
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	5.360	2.177	5.849	5.849	6.240
Bilge plate				6.727	8.240
Side plate	4.905	1.936	0.000	4.905	6.240
Shearstrake doubling plate	11.670	0.000	0.000	11.670	15.240
Deck plate	4.940	1.235	0.000	4.940	8.240
Hatch coaming	5.680	1.010	0.000	5.680	7.240
Transversal wall	3.282	0.677		3.282	4.240

Table 55. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]		Modulus [cm^3]	
	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.11	5.74	8.80	33.90
Vertical wall stiffeners	3.77	5.74	1.00	33.90
Web frames	4.71	4.24	-	-

7.5.2. Ship Calculation – LOA 63.5 m

The ship’s length was increased with 12 frame spaces (6000 mm) in midship area, same structure as existing. New scantling length is 63.0 m.

7.5.2.1. Hydrostatics

trim: 0.000

d m	Dfw t	LCF m	LCB m	KB m	KMT m	TPC t/cm	MTC tm/cm
0.500	148.55	32.752	33.080	0.256	6.381	3.098	10.684
0.600	179.90	32.582	33.008	0.307	5.440	3.134	11.032
0.700	211.60	32.411	32.931	0.358	4.794	3.170	11.386
0.800	243.65	32.234	32.851	0.410	4.310	3.201	11.704
0.900	276.03	32.019	32.767	0.461	3.953	3.237	12.077
1.000	308.87	31.607	32.667	0.513	3.697	3.296	12.750
1.100	342.28	31.272	32.546	0.566	3.476	3.343	13.318
1.200	376.13	30.966	32.418	0.618	3.299	3.387	13.854
1.300	410.45	30.630	32.282	0.671	3.158	3.435	14.453
1.400	445.18	30.441	32.144	0.724	3.042	3.465	14.819
1.500	480.14	30.329	32.016	0.777	2.944	3.486	15.065
1.600	515.32	30.225	31.897	0.830	2.868	3.508	15.320
1.700	550.71	30.128	31.787	0.883	2.806	3.528	15.567
1.800	586.30	30.038	31.683	0.935	2.757	3.548	15.805
1.900	622.09	29.946	31.586	0.988	2.719	3.568	16.045
2.000	658.08	29.854	31.494	1.040	2.692	3.587	16.286
2.100	694.28	29.784	31.406	1.093	2.673	3.608	16.539
2.200	730.68	29.715	31.324	1.146	2.662	3.629	16.790
2.300	767.29	29.648	31.245	1.198	2.656	3.649	17.040
2.400	804.10	29.583	31.171	1.251	2.656	3.669	17.288
2.500	841.11	29.535	31.100	1.304	2.071	2.182	16.354

7.5.2.2. Weight distribution

Light ship

Structure

Position	Weight[t]	LCG[m]	VCG[m]	St.FR	EndFR
Aft - Fr. 2	3.260	-0.237	2.593	-4	2
Fr. 2 - Fr.14	12.010	4.016	2.205	2	14
Fr. 14 - Fr.23	11.090	9.302	2.271	14	23
Fr. 23 - Fr.25	2.000	12.006	1.829	23	25
Fr. 25 - Fr.57	21.750	20.553	1.155	25	57
insertion 57-63	5.000	30.000	1.550	57	63
Fr. 63 - Fr.66	4.780	32.260	1.593	63	66
insertion 66-72	5.000	34.500	1.550	66	72
Fr. 60 - Fr.93 +12	22.760	44.295	1.198	72	105
Fr. 93 - Fr.98 +12	5.680	53.775	1.827	105	110
Fr. 98 - Fr.100 +12	2.210	55.491	2.055	110	112
Fr.100 - Fr.106 +12	5.200	57.439	1.979	112	118
Fr.106 - Fore +12	2.550	60.159	2.494	118	123
Weld+spare 7%	7.500	28.915	1.654	-3	112
TOTAL CHAPTER	110.790	28.915	1.654		

Outfitting

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Aft gear	4.500	-0.500	2.000	-4	2
Prop+ER aft	4.200	4.000	0.800	2	14
ER fore	12.800	9.000	1.200	14	23
Accomodation aft	7.500	6.800	3.000	3	23
Hatches aft	6.200	20.500	3.100	25	57
Wood floor aft	1.500	20.500	0.600	25	57
additional 57-63	1.500	30.000	1.550	57	63
Gear center	1.500	32.250	1.800	63	66
additional 66-72	1.500	34.500	1.550	66	72
Hatches fore	6.200	44.250	3.200	72	105
Wood floor fore	1.500	44.250	0.600	72	105
Accomodation fore	3.500	55.800	2.500	107	117
Fore gear	4.500	60.000	3.300	117	123
Other	15.000	28.000	1.800	-4	124
TOTAL CHAPTER	71.900	23.780	2.073		
TOTAL Light ship	182.690	26.894	1.819		

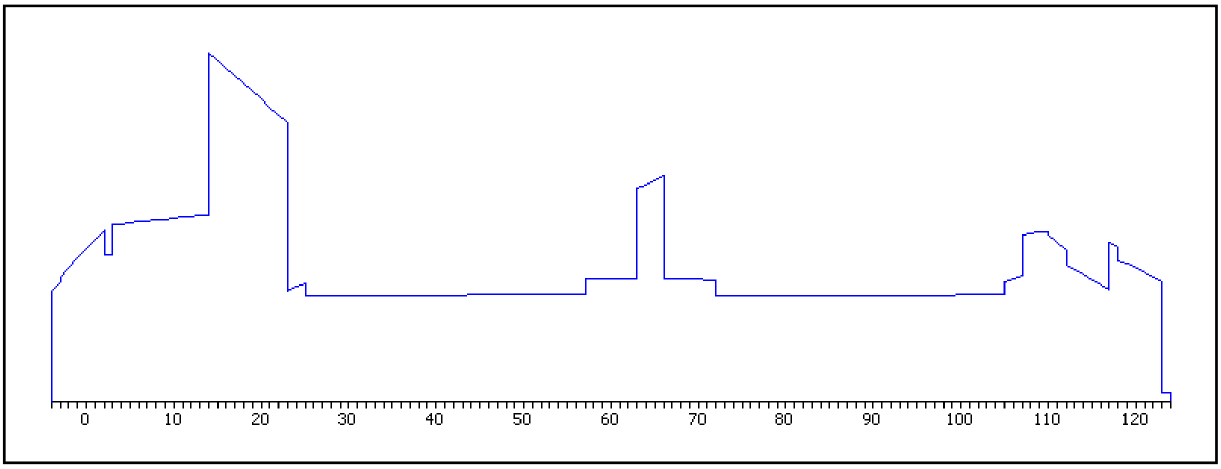

Figure 34. Weight distribution

Other weight groups

Constant

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Crew	1.000	6.800	3.000	3	23
Materials	1.000	29.000	2.600	-2	123
Working liquids	2.000	9.000	1.000	14	23
TOTAL CHAPTER	4.000	12.700	1.900		

100% store

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
FO	8.200	4.900	1.800	4	14
FW	2.400	8.000	2.000	15	17
LO	2.300	12.000	1.500	23	25
TOTAL CHAPTER	12.900	6.743	1.784		

10% store

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR

FO	0.820	4.900	1.800	4	14
FW	0.250	8.000	2.000	15	17
LO	0.230	12.000	1.500	23	25
TOTAL CHAPTER	1.300	6.752	1.785		

Distribution of cargo

100% homog. cargo

Position	Weight[t]	LCG[m]	VCG[m]	St.FR	EndFR
Hold I	102.400	51.000	1.500	95	110
Hold II	92.500	44.500	1.500	83	95
Hold III	123.900	37.000	1.500	65	83
Hold IV	126.600	27.500	1.500	46	64
Hold V	84.400	20.250	1.500	35	46
Hold VI	85.300	14.500	1.500	23	35
TOTAL CHAPTER	615.100	33.085	1.500		

Payload: 815-200 = 615 t => hom. cargo density 615/685 =0.8978 t/mc

7.5.2.3. Case 1 - Ship without cargo

Weights

Weight group	Weight[t]	LCG[m]	TCG[m]	VCG[m]
Light ship	182.690	26.894	0.000	1.819
Constant	4.000	13.450	0.000	1.900
100% store	12.900	6.743	0.000	1.784
TOTAL	199.590	25.322	0.000	1.818

Draughts [m]	
at LBP/2	0.679
at LCF	0.690
at fore perpendicular	0.050
at aft perpendicular	1.308
Trim at perpendiculars [m]	-1.257

Longitudinal strength

Maximum values

SF+	426.44	at FR	23
SF-	-241.50	at FR	93
BM+	5892.17	at FR	50
BM-	0.00	at FR	-4

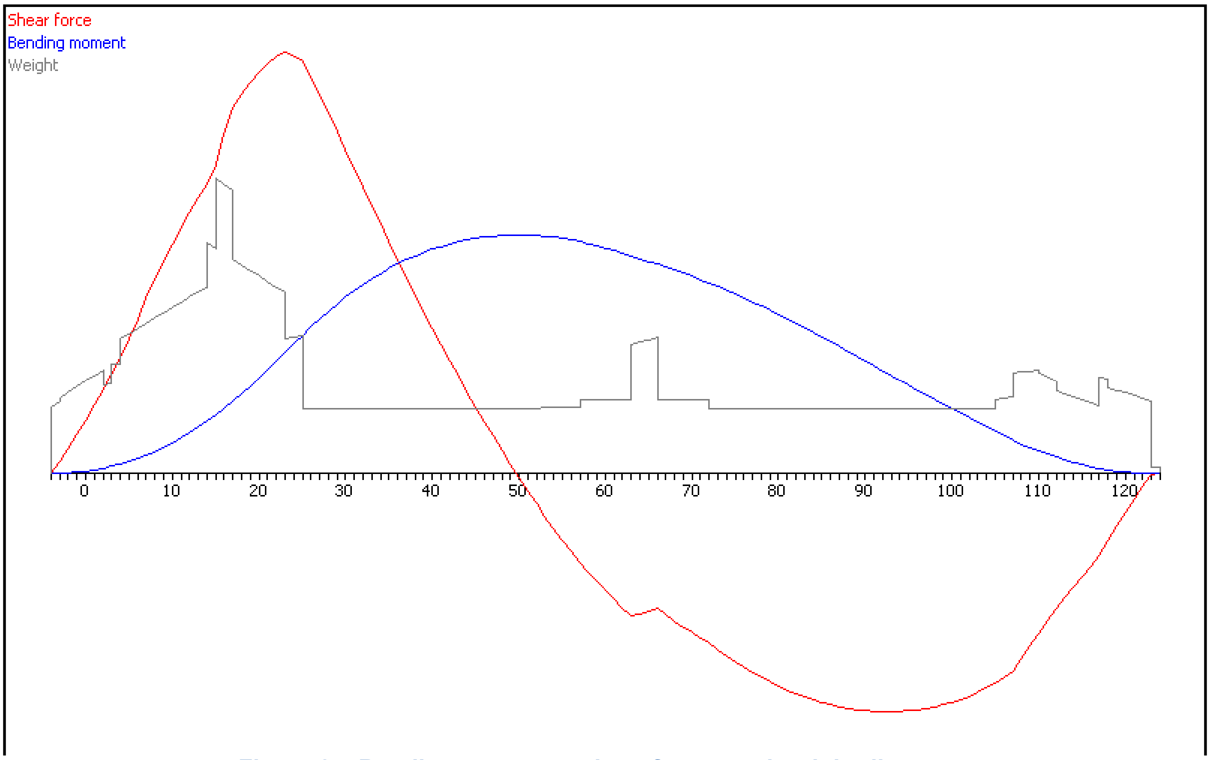

Figure 35. Bending moments, shear forces and weight diagrams

Results of scantling

For scantling formulas see Annex 7.3.

Table 56. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Navigation	5892.2	0.0	948.8	948.8	6841.0	948.8
Harbour 2R	0.0	0.0	0.0	0.0	0.0	0.0

Table 57. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging
	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	66.5	8.7	0.0	0.0
Upper edge of horizontal stiffeners of hatch coaming	60.0	7.9	0.0	0.0

Upper edge of deck plating	43.0	5.6	0.0	0.0
Lower edge of bottom plaiting	43.8	5.7	0.0	0.0

Table 58. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1	t_2	t_3	t_{MAX}	$t_{ALLOW.}$
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	5.540	2.684	6.875	6.875	6.240
Bilge plate				7.906	8.240
Side plate	5.055	2.446	4.702	5.055	6.240
Shearstrake doubling plate	12.330	0.000	1.238	12.330	15.240
Deck plate	5.060	1.274	1.943	5.060	8.240
Hatch coaming	5.920	1.066	2.724	5.920	7.240
Transversal wall	3.438	0.000		3.438	4.240

Table 59. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]		Modulus [cm^3]	
	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.13	5.74	13.90	33.90
Vertical wall stiffeners	3.80	5.74	0.00	33.90
Web frames	4.81	4.24	-	-

7.5.2.4. Case 2 - Ship with full cargo

Weights

Weight group	Weight [t]	LCG [m]	TCG [m]	VCG [m]
Light ship	182.690	26.894	0.000	1.819
Constant	4.000	13.450	0.000	1.900
100% store	12.900	6.743	0.000	1.784
100% homog. cargo	615.100	33.085	0.000	1.500
TOTAL	814.690	31.183	0.000	1.578

```
   Draughts  [m]
      at LBP/2                  2.429
      at LCF                    2.429
      at fore perpendicular     2.437
      at aft perpendicular      2.421
   Trim at perpendiculars  [m]  0.015
```

Longitudinal strength

```
   Maximum values
       SF+        300.73   at FR   110
       SF-       -322.90   at FR    23
       BM+        125.95   at FR     7
       BM-      -3425.32   at FR    61
```

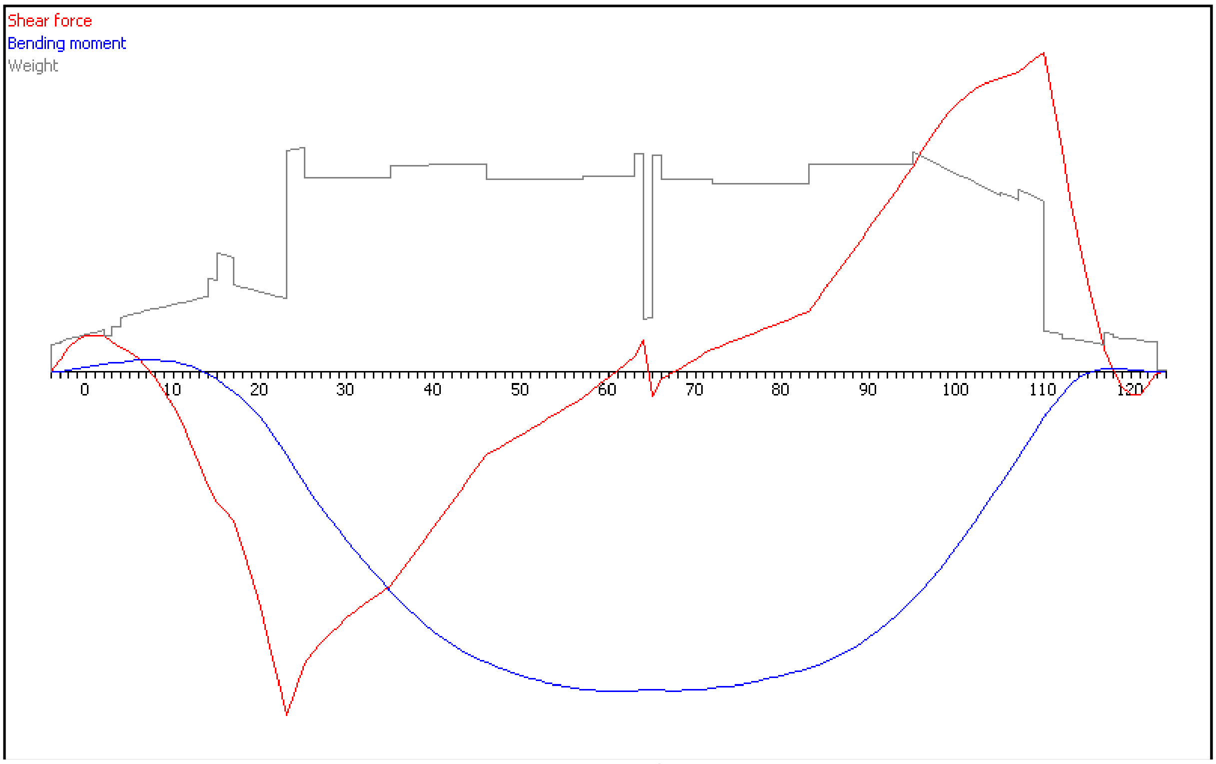

Figure 36. Bending moments, shear forces and weight diagrams

Results of scantling

For scantling formulas see Annex 7.3.

Table 60. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Navigation	126.0	3425.3	948.8	948.8	1074.8	4374.2
Harbour 2R	0.0	0.0	0.0	0.0	0.0	0.0

Table 61. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging
	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	12.0	49.0	0.0	0.0
Upper edge of horizontal stiffeners of hatch coaming	10.9	44.2	0.0	0.0
Upper edge of deck plating	7.8	31.7	0.0	0.0
Lower edge of bottom plaiting	7.9	32.3	0.0	0.0

Table 62. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1	t_2	t_3	t_{MAX}	$t_{ALLOW.}$
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	5.540	3.385	2.725	5.540	6.240
Bilge plate				6.371	8.240
Side plate	5.055	3.207	1.491	5.055	6.240
Shearstrake doubling plate	12.330	0.000	2.659	12.330	15.240
Deck plate	5.060	1.224	4.173	5.060	8.240
Hatch coaming	5.920	0.995	5.849	5.920	7.240
Transversal wall	3.438	2.574		3.438	4.240

Table 63. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]		Modulus [cm^3]	
	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.13	5.74	28.98	33.90
Vertical wall stiffeners	3.80	5.74	9.50	33.90
Web frames	4.81	4.24	-	-

7.5.3. Ship Calculation – LOA 69.5 m

The ship’s length was increased with 24 frame spaces (12000 mm) in midship area, same structure as existing. New scantling length is 69.0 m.

7.5.3.1. Hydrostatics

trim: 0.000

d m	Dfw t	LCF m	LCB m	KB m	KMT m	TPC t/cm	MTC tm/cm
0.500	167.33	35.757	36.085	0.255	6.434	3.474	13.617
0.600	202.46	35.587	36.013	0.306	5.479	3.510	14.016
0.700	237.96	35.415	35.937	0.358	4.822	3.547	14.422
0.800	273.79	35.237	35.857	0.409	4.332	3.578	14.786
0.900	309.96	35.022	35.773	0.460	3.970	3.614	15.210
1.000	346.60	34.610	35.673	0.512	3.706	3.673	15.970
1.100	383.79	34.275	35.553	0.564	3.482	3.720	16.608
1.200	421.44	33.970	35.425	0.617	3.303	3.764	17.208
1.300	459.54	33.635	35.291	0.669	3.160	3.811	17.877
1.400	498.07	33.446	35.153	0.722	3.042	3.842	18.288
1.500	536.82	33.333	35.026	0.774	2.944	3.863	18.564
1.600	575.79	33.228	34.908	0.827	2.866	3.884	18.852
1.700	614.97	33.131	34.798	0.879	2.803	3.905	19.128
1.800	654.35	33.040	34.695	0.932	2.753	3.925	19.395
1.900	693.94	32.948	34.598	0.984	2.715	3.944	19.664
2.000	733.72	32.855	34.506	1.037	2.687	3.964	19.935
2.100	773.70	32.785	34.418	1.089	2.667	3.985	20.218
2.200	813.89	32.715	34.336	1.141	2.655	4.006	20.500
2.300	854.29	32.648	34.258	1.194	2.648	4.026	20.779
2.400	894.89	32.582	34.183	1.246	2.647	4.046	21.057
2.500	935.69	32.536	34.112	1.299	1.989	2.182	19.232

Weight distribution

Light ship

Structure (FEM)

Position	Weight[t]	LCG[m]	VCG[m]	St.FR	EndFR
Aft - Fr. 2	3.260	-0.237	2.593	-4	2
Fr. 2 - Fr.14	12.010	4.016	2.205	2	14
Fr. 14 - Fr.23	11.090	9.302	2.271	14	23
Fr. 23 - Fr.25	2.000	12.006	1.829	23	25
Fr. 25 - Fr.57	21.750	20.553	1.155	25	57
insertie 57-63	5.000	30.000	1.550	57	63
insertie 63-69	5.000	33.000	1.550	63	69
Fr. 69 - Fr.72	4.780	35.260	1.593	69	72
insertie 72-78	5.000	37.500	1.550	72	78
insertie 78-84	5.000	40.500	1.550	78	84
Fr. 60 - Fr.93 +24	22.760	50.295	1.198	84	117
Fr. 93 - Fr.98 +24	5.680	59.775	1.827	117	122
Fr. 98 - Fr.100 +24	2.210	61.491	2.055	122	124
Fr.100 - Fr.106 +24	5.200	63.439	1.979	124	130
Fr.106 - Fore +24	2.550	66.159	2.494	130	135
Weld+spare 7%	8.000	31.900	1.645	-3	135
TOTAL CHAPTER	121.290	31.900	1.645		

Outfitting

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Aft gear	4.500	-0.500	2.000	-4	2
Prop+ER aft	4.200	4.000	0.800	2	14
ER fore	12.800	9.000	1.200	14	23
Accomodation aft	7.500	6.800	3.000	3	23
Hatches aft	6.200	20.500	3.100	25	57
Wood floor aft	1.500	20.500	0.600	25	57
additional 57-63	1.500	30.000	1.550	57	63
additional 63-69	1.500	33.000	1.550	63	69
Gear center	1.500	35.250	1.800	69	72
additional 72-78	1.500	37.500	1.550	72	78
additional 78-84	1.500	40.500	1.550	78	84
Hatches fore	6.200	50.250	3.200	84	117
Wood floor fore	1.500	50.250	0.600	84	117
Accomodation fore	3.500	61.800	2.500	119	129
Fore gear	4.500	66.000	3.300	129	135
Other	15.000	31.000	1.800	-4	136
TOTAL CHAPTER	74.900	26.278	2.052		
TOTAL Light ship	196.190	29.753	1.800		

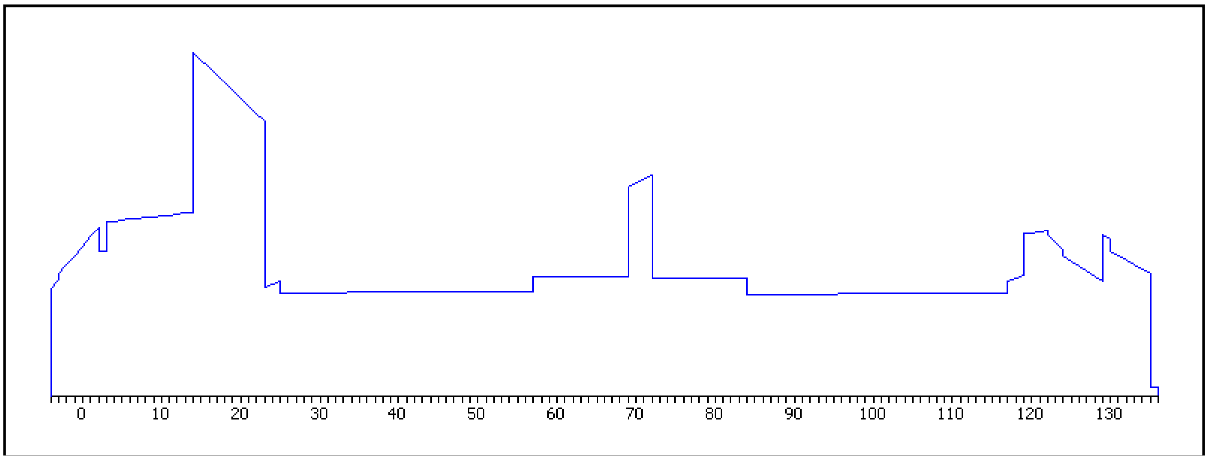

Figure 37. Weight distribution

Other weight groups

Constant

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Crew	1.000	6.800	3.000	3	23
Materials	1.000	32.000	2.600	-2	135
Working liquids	2.000	9.000	1.000	14	23
TOTAL CHAPTER	4.000	14.200	1.900		

100% store

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
FO	8.200	4.900	1.800	4	14
FW	2.400	8.000	2.000	15	17
LO	2.300	12.000	1.500	23	25
TOTAL CHAPTER	12.900	6.743	1.784		

10% store

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
FO	0.820	4.900	1.800	4	14
FW	0.250	8.000	2.000	15	17
LO	0.230	12.000	1.500	23	25
TOTAL CHAPTER	1.300	6.752	1.785		

Distribution of cargo

100% homog. cargo

Position	Weight [t]	LCG [m]	VCG [m]	St.FR	EndFR
Hold I	101.000	57.000	1.500	107	122
Hold II	91.000	50.500	1.500	95	107
Hold III	163.500	41.500	1.500	71	95
Hold IV	167.500	29.000	1.500	46	70
Hold V	83.000	20.250	1.500	35	46
Hold VI	84.000	14.500	1.500	23	35
TOTAL CHAPTER	690.000	36.078	1.500		

Payload: 903-213 = 690 t => hom. cargo density 690/778 =0.8869 t/mc

7.5.3.2. *Case 1 - Ship without cargo*

Weights

Weight group	Weight [t]	LCG [m]	TCG [m]	VCG [m]
Light ship	196.190	29.753	0.000	1.800
Constant	4.000	14.200	0.000	1.900
100% store	12.900	6.743	0.000	1.784
TOTAL	213.090	28.068	0.000	1.801

Draughts [m]

at LBP/2	0.647
at LCF	0.650
at fore perpendicular	0.082
at aft perpendicular	1.212
Trim at perpendiculars [m]	-1.130

Longitudinal strength

Maximum values

SF+	457.14	at FR	23
SF-	-243.28	at FR	103
BM+	6664.37	at FR	54
BM-	0.00	at FR	-4

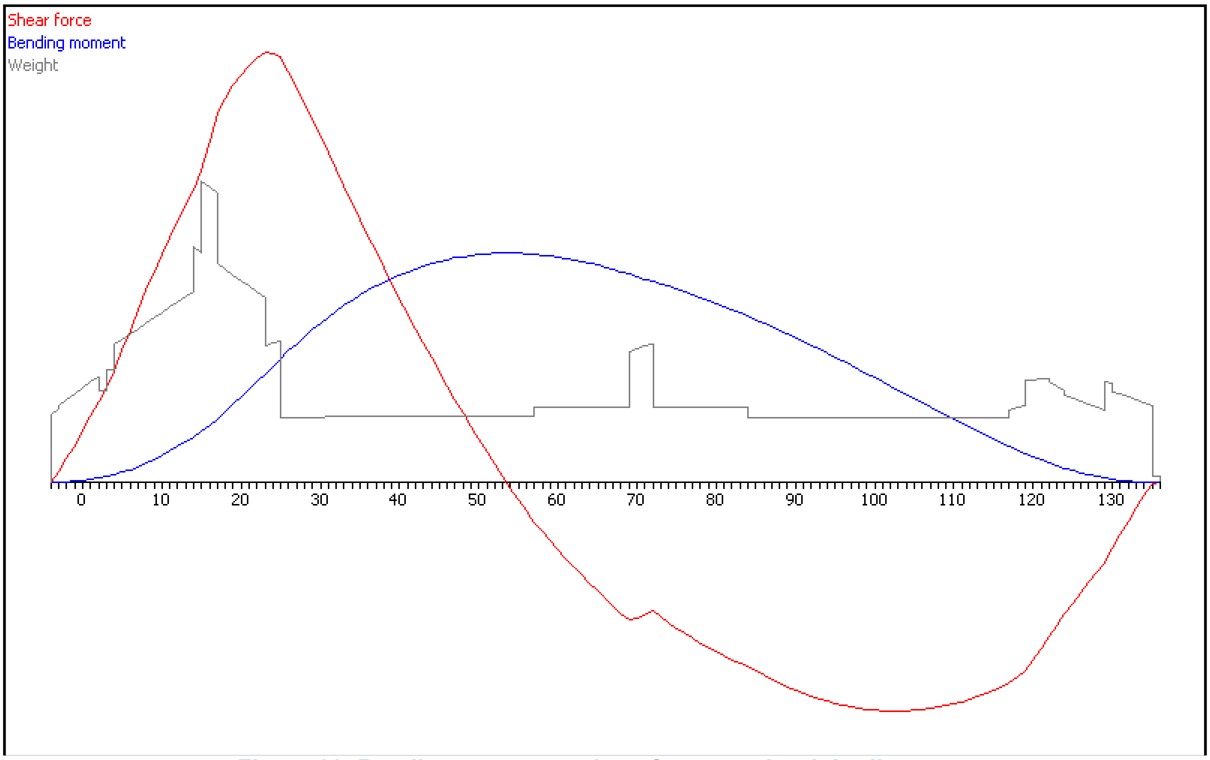

Figure 38. Bending moments, shear forces and weight diagrams

Results of scantling

For scantling formulas see Annex 7.3.

Table 64. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Navigation	6664.4	0.0	1138.2	1138.2	7802.5	1138.2
Harbour 2R	0.0	0.0	0.0	0.0	0.0	0.0

Table 65. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging
	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	87.5	12.8	0.0	0.0
Upper edge of horizontal stiffeners of hatch coaming	78.9	11.5	0.0	0.0

Upper edge of deck plating	56.5	8.2	0.0	0.0
Lower edge of bottom plaiting	57.7	8.4	0.0	0.0

Table 66. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1	t_2	t_3	t_{MAX}	$t_{ALLOW.}$
	[mm]	[mm]	[mm]	[mm]	[mm]
Bottom plate	5.720	2.644	7.342	7.342	6.240
Bilge plate				8.444	8.240
Side plate	5.205	2.389	5.014	5.205	6.240
Shearstrake doubling plate	12.990	0.000	1.356	12.990	15.240
Deck plate	5.180	1.295	2.128	5.180	8.240
Hatch coaming	6.160	1.098	2.983	6.160	7.240
Transversal wall	3.594	0.000		3.594	4.240

Table 67. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]		Modulus [cm^3]	
	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.16	5.74	12.80	33.90
Vertical wall stiffeners	3.83	5.74	0.00	33.90
Web frames	4.90	4.24	-	-

7.5.3.3. Case 2 - Ship with full cargo

Weights

```
--------------------------------------------------------------------
Weight group                  Weight[t]    LCG[m]     TCG[m]     VCG[m]
--------------------------------------------------------------------
Light ship                     196.190     29.753      0.000      1.800
Constant                         4.000     14.200      0.000      1.900
100% store                      12.900      6.743      0.000      1.784
100% homog. cargo              690.000     36.078      0.000      1.500
--------------------------------------------------------------------
TOTAL                          903.090     34.188      0.000      1.571
   Draughts [m]
      at LBP/2                     2.420
      at LCF                       2.420
```

```
      at fore perpendicular      2.424
      at aft perpendicular       2.416
   Trim at perpendiculars [m]    0.008
```

Longitudinal strength

```
   Maximum values
       SF+        293.68    at FR    122
       SF-       -320.75    at FR     23
       BM+        125.58    at FR      8
       BM-      -3746.38    at FR     66
```

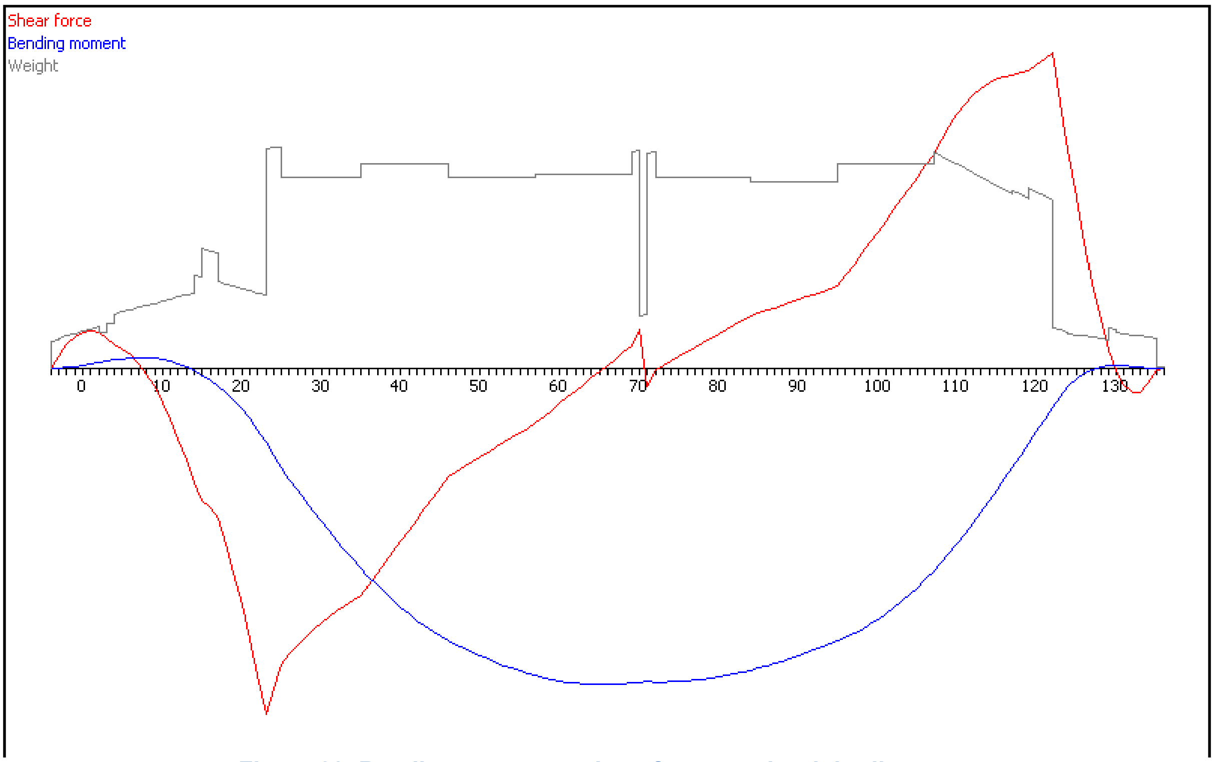

Figure 39. Bending moments, shear forces and weight diagrams

Results of scantling

For scantling formulas see Annex 7.3.

Table 68. Bending moments

Load case	BENDING MOMENT [kNm]					
	Still water		Wave		Total	
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
Navigation	125.6	3746.4	1138.2	1138.2	1263.8	4884.6
Harbour 2R	0.0	0.0	0.0	0.0	0.0	0.0

Table 69. Normal stresses

HULL GIRDER NORMAL STRESSES (MIDSHIP AREA)				
Zone	Hogging	Sagging	Hogging	Sagging

	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]	σ_1 [N/mm^2]
Upper edge of hatch coaming	14.2	54.8	14.2	54.8
Upper edge of horizontal stiffeners of hatch coaming	12.8	49.4	12.8	49.4
Upper edge of deck plating	9.2	35.4	9.2	35.4
Lower edge of bottom plaiting	9.3	36.1	9.3	36.1

Table 70. Plate thicknesses

PLATE THICKNESS (MIDSHIP AREA)					
Element	t_1 [mm]	t_2 [mm]	t_3 [mm]	t_{MAX} [mm]	$t_{ALLOW.}$ [mm]
Bottom plate	5.720	3.407	2.955	5.720	6.240
Bilge plate				6.578	8.240
Side plate	5.205	3.222	1.652	5.205	6.240
Shear strake doubling plate	12.990	0.000	2.810	12.990	15.240
Deck plate	5.180	1.234	4.409	5.180	8.240
Hatch coaming	6.160	1.008	6.181	6.181	7.240
Transversal wall	3.594	2.727		3.594	4.240

Table 71. Ordinary stiffeners and primary supporting members (midship area)

Element	Thickness [mm]		Modulus [cm^3]	
	t_1	$t_{ALLOW.}$	w_N	$w_{ALLOW.}$
Side frames	4.16	5.74	28.98	33.90
Vertical wall stiffeners	3.83	5.74	12.20	33.90
Web frames	4.90	4.24	-	-

7.6. FEM Calculation of the Original Ship - Length 57.5 m

7.6.1. General

In the process of generating the FEM model of the ship, BV Rules recommendations (relating to direct calculation of the structure) have been followed, as follows: BV Inland Navigation Rules Pt.B, Ch.5, Sec.1.
In the assessment of the FEM analysis, the following stages have been established:

Analysis criteria

- Structural modelling
- Boundary condition
- Load modelling
- Stress calculation

Checking criteria

- Yielding check

The software used for the FEM calculation is COSMOS/M.

7.6.1.1. Brief description of the FEM model

To be able to verify the structural adequacy of the self-propelled inland navigation vessel, a FEM analysis has been performed on half of the ship’s breadth. The extent of the model was so decided, in order to be able to cover all loading situations possible and to verify the response of the structure at the combination of local and global loads.
The FEM model consists in bended shell elements with 6 degrees of freedom per node. A coarse mesh approach has been preferred for the analyzed model.
The model includes all structural elements, so constructed to lead to results as realistic as possible.
Steel outfitting on main deck (anchoring and mooring elements) are not included in the FEM model.
Characteristics of FEM model:

Number of Nodes:.. 19184
Number of shell Elements: 40055
Mesh size:.. ~0.4 m
Number of equations 111084

7.6.1.2. Coordinate system

The coordinate system used in this document is right system, with reference point in:

Frame 0 / Center Line / BL

Positive directions:

X forward / Y portside / Z up.

7.6.1.3. Measure unit system

SI: International (Meter, Kilogram, Second)

7.6.1.4. Material and allowable stress limits

The material used in FEM calculation is steel grade A with the following mechanical characteristics:

- Young's modulus:............... $E=2.1 \cdot 10^5$ N/mm^2;
- Poisson’s ratio:....................$\nu = 0.28$;
- Minimum yielding stress...R_{eH}=235 N/mm^2.

For all elements of the models, it is to be checked that the normal stresses σ_1 and σ_2 and the shear stress τ_{12}, calculated according to BV Rules Ch 5, App 1, are in compliance with the following formulae:

$$\frac{0,98R_{eH}}{\gamma_R} \geq \max(\sigma_1, \sigma_2)$$

$$0,49\frac{R_{eH}}{\gamma_R} \geq \tau_{12} \qquad \frac{0,98R_{eH}}{\gamma_R} \geq \sigma_{VM},$$

where:

γ_R = 1.20 - Partial safety factor covering uncertainties regarding resistance.

σ_1, σ_2 (max) = 191.9 N/mm^2.

τ_{12} (max) = 95.9 N/mm^2.

σ_{VM} = 191.9 N/mm^2.

It has to be mentioned that as a result of introducing the loads in FEM model disregarding the dynamic component (as can be seen in “Loads” chapter), the allowable stress limits have been diminished by 10%. From the calculations presented in annex 7.1 and from the detailed calculations presented in annex 7.3, it results that the value of the dynamic loads disregarded from the present calculation represents max.10% from total loads. Also, the wave component has its stress values below 10 N/mm^2 and has been deducted from the allowable values.

In conclusion:

σ_1, σ_2 (max) = 162.7 N/mm^2.

τ_{12} (max) = 86.3 N/mm^2.

σ_{VM} = 162.7 N/mm^2.

7.6.1.5. FEM Model

The FEM model has been created in ACAD with 3D Face elements and then imported in COSMOS. The layout of the real constants from COSMOS together with the description of the structure is presented in Table 72. The colour legend of the ACAD model is presented in Figure 40 and the corresponding images can be found in Figure 41 to Figure 44.

The present calculation has been performed utilizing the net thicknesses of the elements. The net thickness is obtained by deducing the corrosion addition from the initial thickness (see Annex 7.3/Table 38).

The model is divided in three distinct areas for which different material properties have been associated for being able to adjust the weights i.w.o. equilibrating the model as presented in the “Loads” chapter.

The model is divided as follows:

M1 - AFT PART: Transom aft – Frame 23
M2 - MIDDLE PART: Frame 23 – Frame 98
M3 - FORE PART: Frame 98 – Fore

The mechanical characteristics of the materials M1, M2, and M3 are the same excepting the density which needs to be adjusted in such way to equilibrate the model and to obtain the lightship weight.

Table 72. Plate thicknesses of the FEM model

RC no.	Denomination	Gross thk. [mm]	Corrosion add. [mm]	Net thk. [mm]
201	Bottom plates	7.0	1.0	6.0
202	Bilge plates	9.0	1.0	8.0
203	Floors central part (web)	5.0	1.0	4.0
204	Floors central part FP90x10	10.0	1.0	9.0
205	Side girders central part (web)	5.0	1.0	4.0
206	UNP profiles central part	5.0	0.0	5.0
207	Floors (web aft & fore)	6.0	1.0	5.0
208	CL girder in fore peak (t/2)	5.0	0.5	4.5
209	Floors (web Aft-Fr.22)	7.0	1.0	6.0
210	Floors FP100x10 (Aft-Fr.22)	10.0	1.0	9.0
211	ME seatings (web)	10.0	1.0	9.0
212	ME seatings (FP300x12 bed plate)	12.0	1.0	11.0
213	Floors and girders (web Aft)	6.0	1.0	5.0
214	Floors and girders FP80x8 (Aft)	8.0	1.0	7.0
215	CL girder central part (web t/2)	2.5	0.5	2.0
216	CL girder (web Aft t/2)	4.5	0.5	4.0
217	CL girder (web Fore t/2)	3.0	0.5	2.5
218	Floors (web Aft)	9.0	1.0	8.0
219	Stern tube	30.0	0.0	30.0
221	Side plates	7.0	1.0	6.0
222	Sheer strake	16.0	1.0	15.0
223	Side frames T80x6.5	6.5	1.0	5.5
224	Side horizontal stiffeners L100x50x6	6.0	1.0	5.0
225	Side web frames 210x5	5.0	1.0	4.0

RC no.	Denomination	Gross thk. [mm]	Corrosion add. [mm]	Net thk. [mm]
226	Side web frames FP90x10	10.0	1.0	9.0
227	Side stringers T140x7	7.0	1.0	6.0
228	Side stringers fore part (web)	6.0	1.0	5.0
229	Side stringers fore part FP80x8	8.0	1.0	7.0
230	Side web frame aft part (web)	8.0	1.0	7.0
231	Side web frame aft part FP120x10	10.0	1.0	9.0
241	Deck plates	9.0	1.0	8.0
242	Deck brackets	5.0	0.0	5.0
243	Deck brackets FP50x6	6.0	1.0	5.0
244	Deck web beams (web)	5.0	1.0	4.0
245	Deck girders (web Fore)	8.0	1.0	7.0
246	Deck girders FP120x10 (Fore)	10.0	1.0	9.0
247	Deck beams fore part L100x50x6	6.0	1.0	5.0
248	Deck girder FP200x8 (Aft)	8.0	1.0	7.0
249	Deck beams FP80x8 (Aft)	8.0	1.0	7.0
250	Deck beams (Aft) L100x50x6	6.0	1.0	5.0
251	Hatch coaming plates	8.0	1.0	7.0
252	Hatch coaming plates	16.0	1.0	15.0
253	Hatch horizontal stiff. T160x8	8.0	1.0	7.0
254	Hatch stays T140x7	7.0	1.0	6.0
261	BHD plates	5.0	1.0	4.0
262	BHD stiffeners T80x6.5	6.5	1.0	5.5
263	BHD UNP8	4.0	0.0	4.0
264	BHD stiffeners FP60x5	5.0	1.0	4.0
265	BHD beams and stiffeners L65x50x7	7.0	1.0	6.0
266	BHD plates	7.0	1.0	6.0
267	BHD and deckhouse top plates	4.0	0.0	4.0
268	BHD plates	6.0	1.0	5.0

RC no.	Denomination	Gross thk.	Corrosion add.	Net thk.
		[mm]	[mm]	[mm]
269	BHD plates	8.0	1.0	7.0
281	Funnel and WH plates	4.0	0.0	4.0
282	Bulwark plates	5.0	1.0	4.0

Note: All elements in CL have been modelled with half of the thickness.

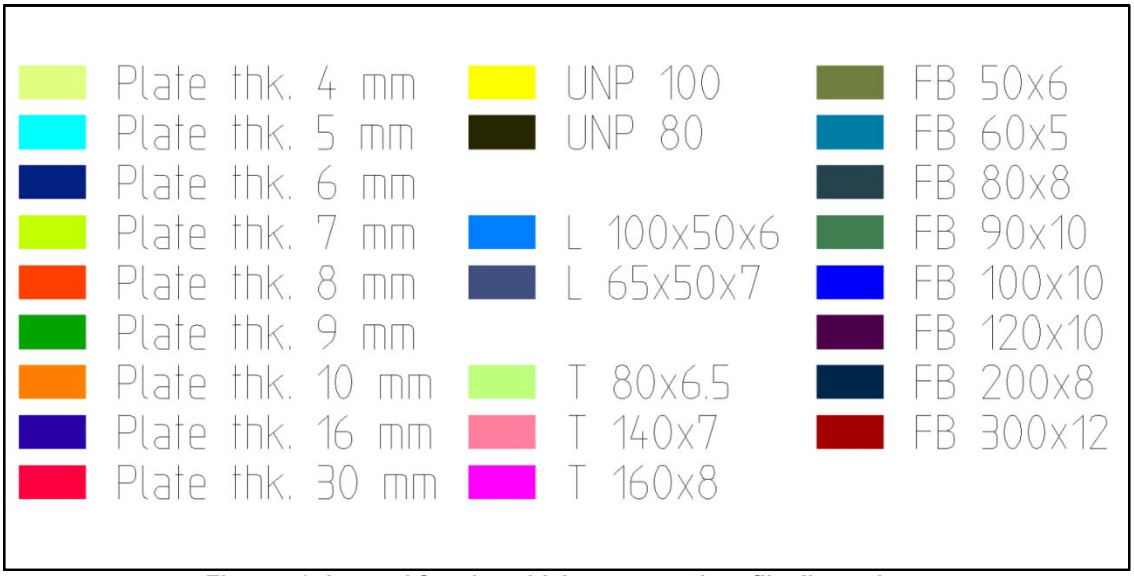

Figure 40. Legend for plate thicknesses and profile dimensions

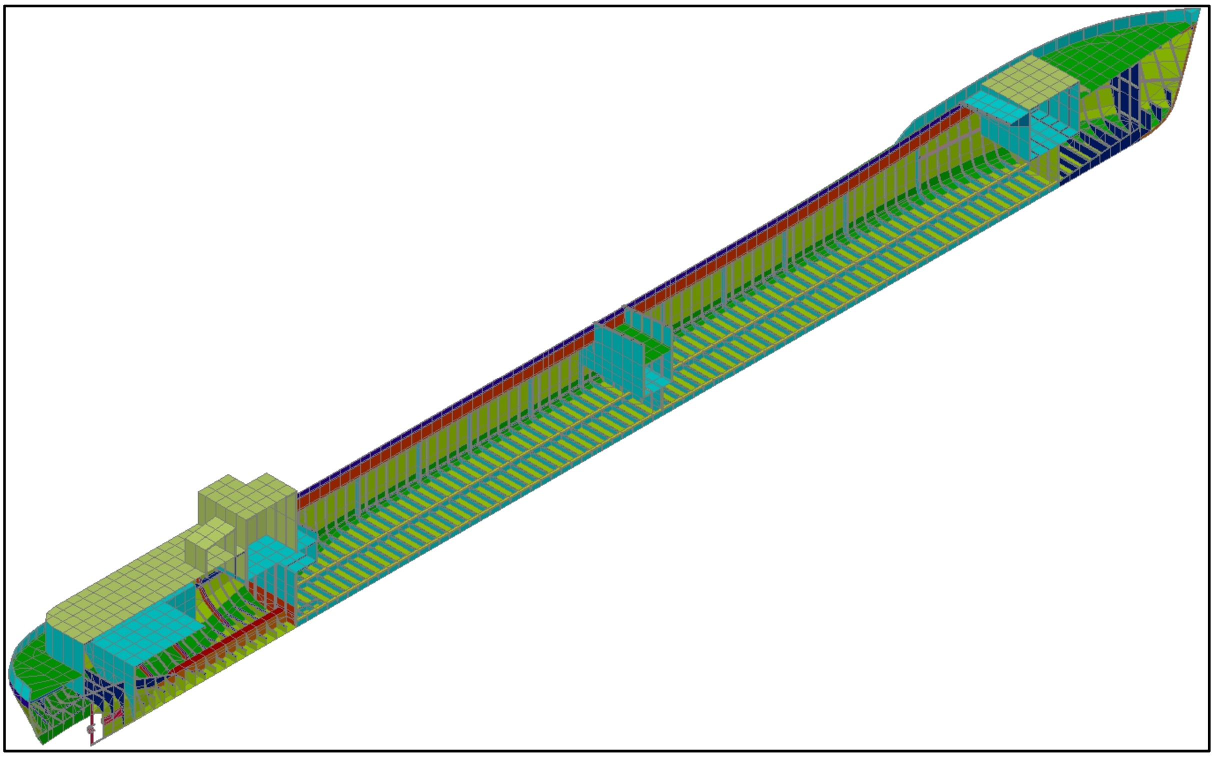

Figure 41. Complete model of the barge

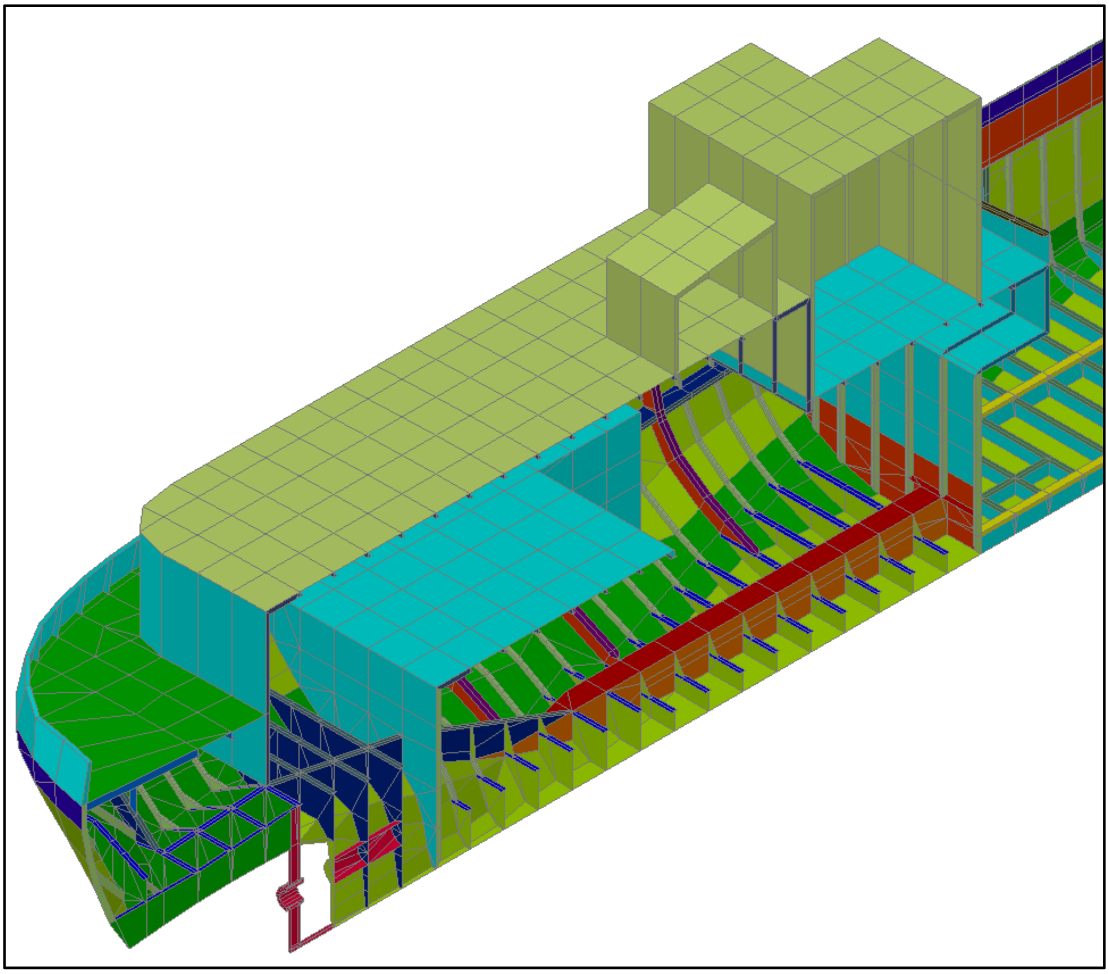

Figure 42. Aft part of the barge

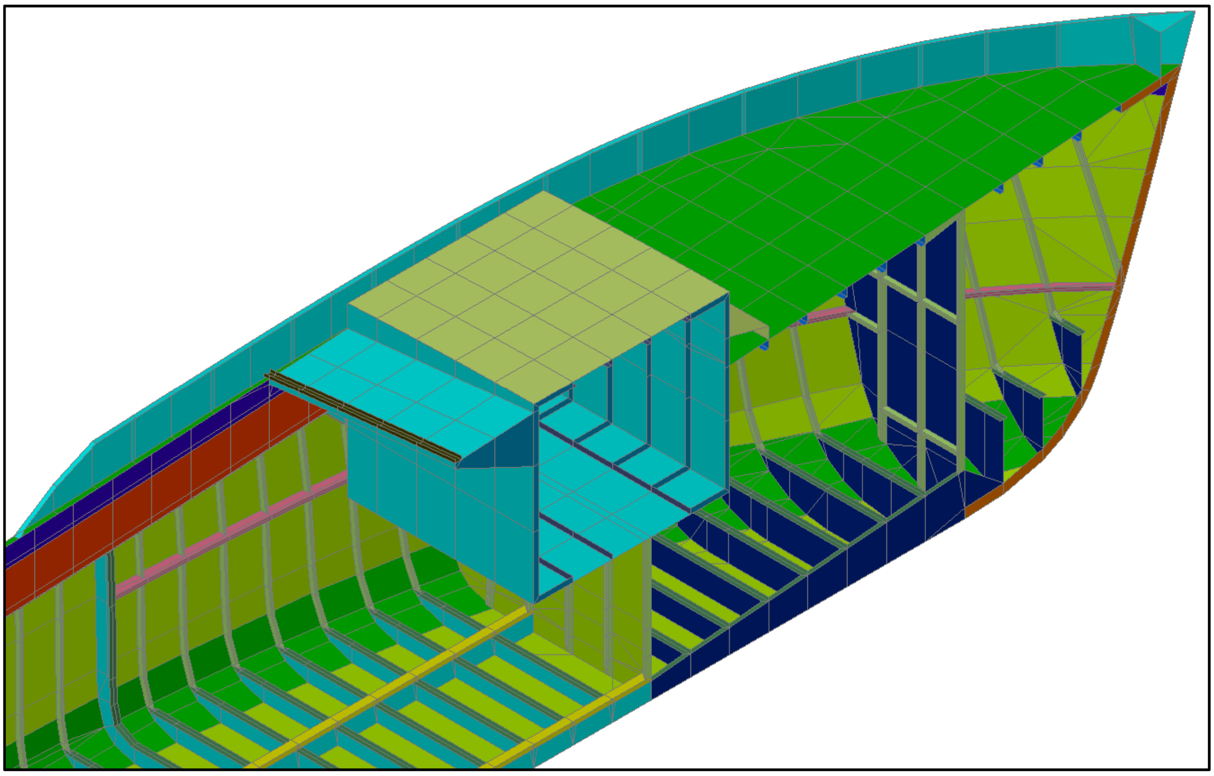

Figure 43. Fore part of the barge

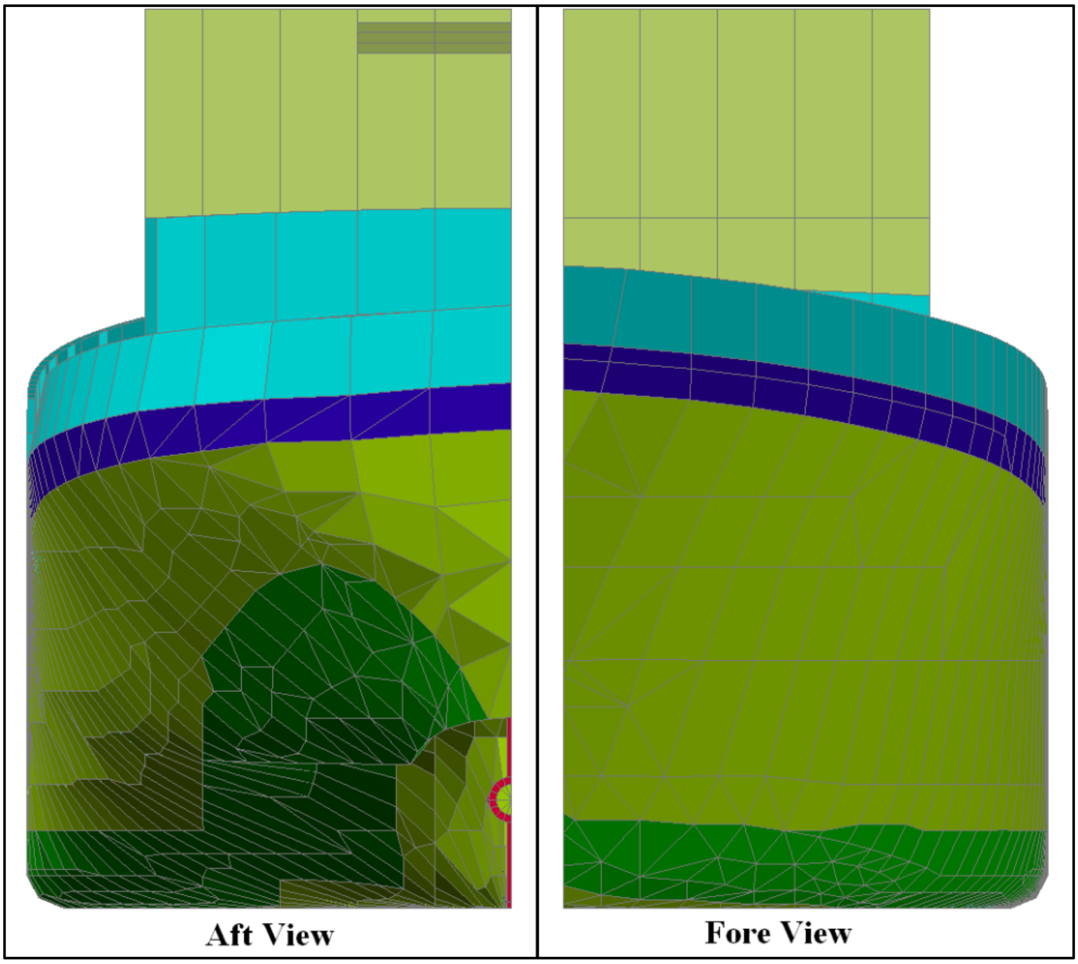

Figure 44. Aft and fore view of the model

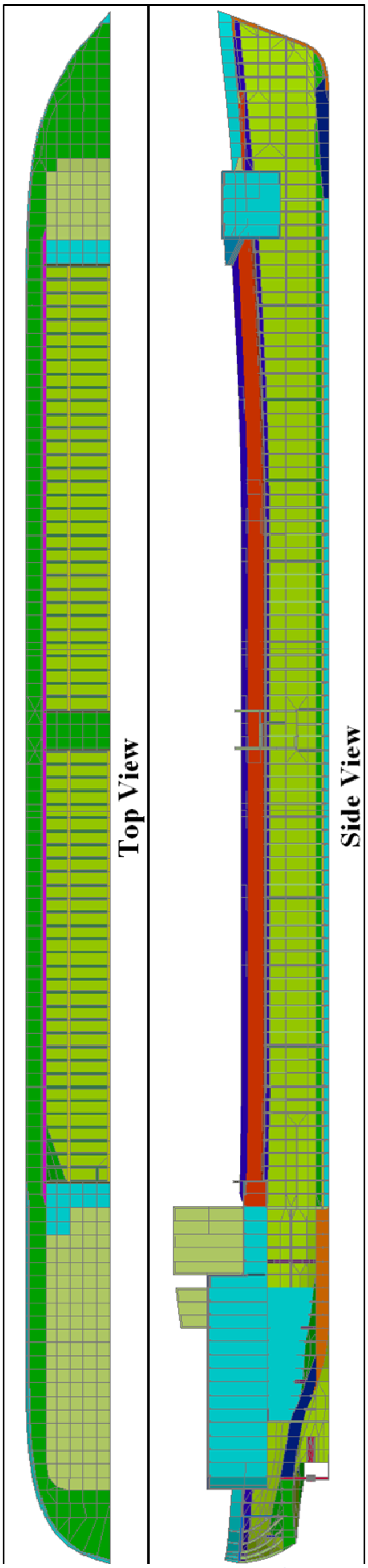

Figure 45. Top and side view of the model

7.6.2. Boundary Conditions

The boundary conditions regarding the symmetry in way of the barge’s centre line longitudinal plane are presented in the tables below (According to BV Inland Rules Pt B, Ch 5, App 1.)

Boundary conditions	DISPLACEMENTS in directions (1)		
	X	Y	Z
Symmetry	free	fixed	free
Anti-symmetry	fixed	free	fixed

Boundary conditions	ROTATION around axes (1)		
	X	Y	Z
Symmetry	fixed	free	fixed
Anti-symmetry	free	fixed	free

Figure 46. Boundary conditions stated by BV

To prevent the rigid body motion of the model, two nodes have been chosen for additional boundary conditions as follows:

Table 73. Boundary conditions utilised in the FEM model

Boundary condition	Displacement			Rotation		
	X	Y	Z	X	Y	Z
Fore end node (X=53.000; Y=0.000; Z=0.000)	free	**fixed**	**fixed**	free	free	free
Aft end node (X=3.500; Y=2.000; Z=1.315)	**fixed**	free	**fixed**	free	free	free

Notes: (1) - X, Y and Z directions and axes are defined with respect to the reference co-ordinate system;

7.6.3. Loads

7.6.3.1. Loads generated by the own weight of the structure

In FEM model, the lightship weight is achieved by modifying the density of the material. This approach was preferred also for being able to easily adjust the weight distribution in order to equilibrate the model (trim of the barge = 0). The weight is calculated automatically by applying the gravity acceleration to the model.

7.6.3.2. External loads

The external pressure has been applied to the model as hydrostatic pressure simulating different loading cases. The loading situations are:

- Lightship (no cargo in the hold);
- Full load situation;

For these cases the dynamic pressure component, p_w, has been disregarded. Also, the deck load and wave pressure component have been disregarded.

7.6.3.3. Cargo loads

The cargo load pressure has been introduced in FEM model as uniform pressure on floors face plates in cargo hold (only vertical component of the cargo load has been considered).
Also for this case, the dynamic pressure component, p_w, has been disregarded.

7.6.3.4. Load cases in FEM model

LC1 – Own weight of the structure;
LC2 – Lightship situation external pressure;
LC3 – Full load situation external pressure;
LC4 – Full load situation cargo pressure;

Combined loading situation:

LC51 – LC1+LC2;
LC52 – LC1+LC3+LC4.

The equilibration of the model consists in obtaining the total reaction force on the model equal to zero. Reaction forces on both combined cases are presented in Table 74 and Table 75.

7.6.4. Results

7.6.4.1. Reaction forces

The reaction forces in Z axis direction are presented on the two nodes in which boundary conditions to prevent rigid body motion have been imposed.
The nodes are as follows:

- 2135 – Aft ;
- 829 – Fore .

Table 74. LC51 reaction forces

Node	RFZ
829	2.50E+03
2135	4.99E+04
Sum:	1.61E+05

Table 75. LC52 reaction forces

Node	RFZ
829	-1.21E+05
2135	1.22E+05

Sum:	6.13E+02

7.6.4.2. *Stress results*

Stress results for all situations analysed are presented in Table 76 and Table 77 for all structural elements. Graphical results are presented in Figure 47 to Figure 58.

Table 76. FEM calculation - stress result [N/mm2] – LC51

RC	Denomination	σ_{VM}	σ_{Xmin}	σ_{Xmax}	σ_{Ymin}	σ_{Ymax}	σ_{Zmin}	σ_{Zmax}	τ_{XYmin}	τ_{XYmax}	τ_{XZmin}	τ_{XZmax}	τ_{YZmin}	τ_{YZmax}
201	Bottom plates	39.9	-45.8	0.2	-18.6	13.8	-8.0	3.9	-5.9	4.2	-8.7	8.6	-6.6	2.2
202	Bilge plates	38.9	-40.3	0.8	-6.7	12.3	-8.0	11.7	-5.9	6.9	-7.5	8.8	-4.3	11.7
203	Floors central part (web)	65.4	-68.8	3.0	-23.5	42.4	-43.5	6.7	-4.0	3.7	-8.7	8.8	-12.4	11.7
204	Floors central part FP90x10	79.5	-82.3	3.0	-25.1	46.7	-43.5	6.7	-9.3	11.5	-11.8	9.3	-12.4	5.2
205	Side girders central part (web)	57.4	-60.8	-0.5	-10.0	24.7	-12.3	3.4	-2.3	1.9	-8.2	9.3	-3.8	2.2
206	UNP profiles central part	69.9	-72.4	0.0	-2.3	34.8	-16.0	3.8	-2.6	1.7	-11.8	12.5	-5.9	1.0
207	Floors (web aft & fore)	5.9	-5.7	0.2	-1.5	2.3	-0.5	0.8	-1.9	0.2	-1.5	0.6	-0.1	0.6
208	CL girder in fore peak (t/2)	4.1	-4.3	0.6	-0.1	1.6	-1.7	0.8	-0.3	0.1	-0.6	0.5	-0.1	0.2
209	Floors (web Aft-Fr.22)	16.2	-16.2	0.3	-4.2	8.5	-1.6	6.2	-1.0	2.4	-0.8	3.1	-1.5	3.9
210	Floors FP100x10 (Aft-Fr.22)	12.2	-10.2	1.3	-5.8	9.2	-1.8	1.6	-1.0	2.1	-0.5	2.7	-1.0	2.2
211	ME seatings (web)	29.0	-26.8	0.4	-3.5	2.4	-2.8	3.3	-1.0	1.8	-2.9	4.7	-0.9	0.7
212	ME seatings (FP300x12 bed plate)	21.6	-11.6	2.5	-3.3	14.3	-3.0	18.0	-2.4	11.2	-0.5	4.1	-1.3	1.1
213	Floors and girders (web Aft)	10.5	-10.0	1.1	-2.9	7.2	-2.2	1.3	-1.0	2.0	-0.6	2.9	-1.3	1.7
214	Floors and girders FP80x8 (Aft)	9.1	-7.7	1.1	-2.2	6.6	-2.1	1.4	-0.8	2.0	-0.2	2.9	-0.5	1.6
215	CL girder central part (web t/2)	60.9	-64.2	-2.4	-10.0	23.6	-16.0	2.8	-2.2	1.7	-11.8	12.5	-1.3	1.4
216	CL girder (web Aft t/2)	4.3	-4.1	-0.6	-0.9	2.1	-1.8	0.4	-0.4	0.3	-0.6	1.2	-0.3	0.2
217	CL girder (web Fore t/2)	9.4	-9.7	0.2	-1.0	1.5	-0.9	0.6	-0.5	0.1	-0.9	1.4	-0.1	0.3
218	Floors (web Aft)	5.2	-3.9	0.3	-1.5	5.4	-0.6	0.8	-0.7	1.2	-1.1	1.1	-0.9	1.2
219	Stern tube	3.5	-2.6	0.3	-2.5	0.7	-1.0	1.4	-0.4	0.4	-0.4	1.3	-0.2	0.4
221	Side plates	29.8	-21.3	30.1	-3.6	5.7	-8.1	6.1	-1.8	6.8	-8.9	13.1	-2.6	3.9
222	Sheerstrake	39.6	-0.5	39.8	-1.4	1.5	-2.7	2.9	-3.1	2.9	-5.5	8.0	-2.8	1.6
223	Side frames T80x6.5	63.0	-22.9	29.3	-33.4	12.7	-59.1	8.7	-4.0	4.4	-7.1	8.9	-25.9	6.0
224	Side horizontal stiffeners L100x50x6	35.5	-36.4	-0.4	-14.0	4.4	-33.3	6.7	-3.1	2.9	-4.3	4.0	-5.3	4.8
225	Side web frames 210x5	61.4	-24.4	29.8	-22.6	2.1	-67.3	11.7	-3.0	3.7	-6.3	5.7	-11.7	5.2
226	Side web frames FP90x10	78.4	-4.5	26.2	-24.4	4.5	-78.9	0.5	-2.0	3.3	-7.9	5.8	-19.0	3.4

RC	Denomination	σ_{VM}	σ_{Xmin}	σ_{Xmax}	σ_{Ymin}	σ_{Ymax}	σ_{Zmin}	σ_{Zmax}	τ_{XYmin}	τ_{XYmax}	τ_{XZmin}	τ_{XZmax}	τ_{YZmin}	τ_{YZmax}
227	Side stringers T140x7	10.7	-9.2	5.5	-4.5	0.9	-1.8	3.7	-1.7	3.0	-6.1	0.4	-0.4	0.8
228	Side stringers fore part (web)	15.9	-1.9	2.8	-4.9	3.9	-2.5	0.9	-1.5	3.2	-0.4	8.5	-0.8	1.6
229	Side stringers fore part FP80x8	4.5	-2.0	4.4	-0.6	1.1	-2.2	0.6	-0.6	0.6	-1.0	1.1	-0.8	1.1
230	Side web frame aft part (web)	16.0	-9.0	14.6	-3.9	3.8	-7.2	1.1	-2.2	4.9	-0.4	8.4	-2.6	2.6
231	Side web frame aft part FP120x10	16.3	-4.4	16.8	-5.5	3.8	-7.5	1.3	-1.7	0.5	-0.5	1.8	-2.6	2.2
241	Deck plates	41.4	-5.7	43.6	-7.1	5.2	-11.1	4.4	-9.2	6.1	-3.5	5.9	-2.9	6.1
242	Deck brackets	37.7	-1.4	36.4	-7.1	9.5	-9.1	1.9	-5.0	4.0	-3.3	3.5	-2.1	6.1
243	Deck brackets FP50x6	22.0	-4.4	23.2	-7.0	8.0	-9.1	2.3	-2.1	1.8	-0.6	1.2	-1.8	1.6
244	Deck web beams (web)	31.2	-2.4	28.6	-9.8	3.6	-11.1	2.6	-3.4	4.1	-0.8	1.7	-4.2	5.4
245	Deck girders (web Fore)	8.1	-1.4	8.1	-0.9	0.4	-1.4	1.8	0.0	0.1	-1.4	1.5	-0.1	0.2
246	Deck girders FP120x10 (Fore)	8.9	-0.3	8.9	-0.5	0.7	-1.4	0.4	-0.5	0.7	-1.4	1.2	0.0	0.2
247	Deck beams fore part L100x50x6	9.2	-1.9	4.5	-9.0	7.6	-1.8	1.9	-0.6	2.0	-0.7	1.3	-0.9	1.9
248	Deck girder FP200x8 (Aft)	29.3	-2.6	29.4	-4.8	4.8	-3.7	1.1	-2.3	3.3	-0.3	1.6	-2.0	1.1
249	Deck beams FP80x8 (Aft)	11.9	-0.9	2.0	-11.8	5.4	-4.8	2.6	-2.4	0.4	-1.5	1.1	-1.0	5.4
250	Deck beams (Aft) L100x50x6	11.8	-5.7	1.7	-11.0	9.5	-9.0	0.7	-1.0	1.4	-0.5	0.8	-0.9	1.6
251	Hatch coaming plates	51.7	-0.1	51.7	-7.1	9.5	-7.9	4.4	-2.3	6.9	-7.0	4.4	-4.2	3.8
252	Hatch coaming plates	59.9	3.2	60.6	-3.4	5.2	-3.8	2.3	-1.3	6.9	-2.4	7.0	-1.7	2.4
253	Hatch horizontal stiff. T160x8	59.1	2.6	59.0	-3.1	5.2	-3.6	1.5	-1.8	10.0	-1.6	1.9	-0.6	1.1
254	Hatch stays T140x7	44.9	-0.7	43.2	-6.3	0.8	-25.4	3.0	-1.6	1.9	-1.9	2.0	-1.0	2.9
261	BHD plates	60.8	-43.2	65.2	-16.1	15.0	-12.0	12.0	-10.2	11.0	-4.2	8.0	-10.1	5.3
262	BHD stiffeners T80x6.5	43.1	-45.5	20.0	-6.2	14.3	-22.8	39.9	-2.3	4.0	-13.4	4.1	-6.8	3.7
263	BHD UNP8	28.8	-4.0	29.0	-13.2	6.0	-2.7	1.5	-2.3	3.2	-0.4	0.5	-1.9	2.0
264	BHD stiffeners FP60x5	18.4	-10.5	9.2	-8.6	3.4	-11.8	8.2	-0.9	9.0	-2.4	4.0	-2.4	2.6
265	BHD beams and stiffeners L65x50x7	54.7	-9.3	38.2	-26.0	56.4	-56.2	15.1	-4.9	6.9	-2.4	6.4	-17.5	12.1
266	BHD plates	6.4	-5.8	0.5	-1.9	2.3	-1.4	1.3	-2.2	0.6	-3.4	1.9	-0.2	1.7
267	BHD and deckhouse top plates	17.1	-7.6	13.3	-14.7	15.0	-9.9	12.0	-2.8	4.9	-3.4	4.0	-4.0	4.9
268	BHD plates	2.4	-1.5	1.9	0.0	1.0	-1.0	0.4	-0.7	0.2	-1.0	0.3	-0.2	0.8
269	BHD plates	22.5	-23.7	1.1	-3.6	5.2	-8.6	1.7	-1.3	3.9	-8.6	8.0	-1.8	1.4
281	Funnel and WH plates	63.7	-21.6	26.6	-25.9	61.4	-20.0	15.4	-4.7	3.7	-7.5	4.6	-4.2	7.1
282	Bulwark plates	40.1	-1.6	28.1	-1.9	2.4	-5.7	11.1	-4.0	3.4	-17.6	3.8	-2.2	0.9

RC	Denomination	σ_{VM}	σ_{Xmin}	σ_{Xmax}	σ_{Ymin}	σ_{Ymax}	σ_{Zmin}	σ_{Zmax}	τ_{XYmin}	τ_{XYmax}	τ_{XZmin}	τ_{XZmax}	τ_{YZmin}	τ_{YZmax}
	Min./Max.	**79.5**	**-82.3**	**65.2**	**-33.4**	**61.4**	**-78.9**	**39.9**	**-10.2**	**11.5**	**-17.6**	**13.1**	**-25.9**	**12.1**

Table 77. FEM calculation - stress result [N/mm2] – LC52

RC	Denomination	σ_{VM}	σ_{Xmin}	σ_{Xmax}	σ_{Ymin}	σ_{Ymax}	σ_{Zmin}	σ_{Zmax}	τ_{XYmin}	τ_{XYmax}	τ_{XZmin}	τ_{XZmax}	τ_{YZmin}	τ_{YZmax}
201	Bottom plates	34.7	-19.4	19.0	-22.4	22.2	-6.9	30.2	-6.5	4.3	-13.6	19.9	-4.1	8.9
202	Bilge plates	47.1	-12.8	19.0	-22.4	12.2	-18.0	14.5	-6.8	4.6	-7.9	5.1	-22.5	4.8
203	Floors central part (web)	82.3	-23.3	15.6	-82.4	41.3	-35.0	81.0	-4.9	3.0	-13.6	12.8	-22.5	8.9
204	Floors central part FP90x10	93.7	-39.1	39.0	-91.2	48.9	-35.0	81.0	-6.9	6.3	-16.5	15.8	-12.4	7.5
205	Side girders central part (web)	39.4	-26.4	14.7	-42.9	12.9	-2.5	3.4	-3.6	1.9	-9.1	8.5	-1.7	6.2
206	UNP profiles central part	71.9	-75.3	28.3	-69.0	1.1	-17.4	10.1	-3.3	2.9	-16.5	14.8	-3.6	6.9
207	Floors (web aft & fore)	23.9	-7.9	24.3	-18.1	20.1	-21.1	5.1	-2.2	2.6	-4.6	9.9	-8.9	4.7
208	CL girder in fore peak (t/2)	50.0	-15.1	14.8	-1.4	10.6	-4.5	43.7	-1.5	1.4	-6.4	22.2	-0.4	8.5
209	Floors (web Aft-Fr.22)	12.4	-11.3	7.3	-13.1	11.5	-3.4	4.6	-3.6	1.7	-1.8	2.7	-4.2	3.7
210	Floors FP100x10 (Aft-Fr.22)	16.7	-7.5	2.4	-16.4	11.5	-3.3	2.0	-3.5	5.0	-1.8	1.5	-4.2	3.3
211	ME seatings (web)	11.1	-13.2	7.8	-7.7	1.7	-6.5	1.1	-1.2	2.1	-5.3	2.9	-2.4	1.4
212	ME seatings (FP300x12 bed plate)	11.5	-7.8	9.8	-13.1	10.0	-8.8	3.1	-2.1	3.7	-2.5	1.2	-2.5	3.7
213	Floors and girders (web Aft)	15.6	-10.1	2.2	-6.0	16.6	-3.4	2.6	-0.6	2.4	-0.9	2.8	-1.9	0.9
214	Floors and girders FP80x8 (Aft)	10.4	-10.1	1.0	-2.7	6.6	-3.4	0.8	-0.7	2.1	-0.2	2.7	-0.8	0.5
215	CL girder central part (web t/2)	38.5	-39.1	17.9	-46.6	16.0	-9.9	6.9	-2.9	2.8	-16.5	14.8	-3.7	0.5
216	CL girder (web Aft t/2)	3.0	-3.2	0.0	-0.8	1.4	-1.7	1.7	-0.3	0.3	-0.5	0.8	-0.2	0.2
217	CL girder (web Fore t/2)	60.4	-48.6	39.0	-7.6	10.6	-10.7	43.7	-2.2	2.6	-18.7	23.7	-2.4	8.5
218	Floors (web Aft)	6.1	-5.5	0.6	-1.6	3.8	-1.0	0.9	-0.6	1.0	-1.5	0.8	-0.8	1.1
219	Stern tube	6.0	-1.7	1.8	-4.5	1.9	-1.8	3.6	-0.3	0.4	-1.1	1.1	-0.8	0.3
221	Side plates	22.6	-13.9	6.8	-10.8	4.1	-20.2	5.2	-5.6	4.6	-8.9	5.4	-6.9	8.0
222	Sheerstrake	21.0	-20.8	6.9	-3.7	2.8	-2.7	4.0	-2.2	3.6	-6.0	2.9	-3.8	8.0
223	Side frames T80x6.5	85.5	-13.7	6.4	-29.9	20.1	-60.0	84.9	-4.2	4.0	-6.1	5.5	-25.7	10.1
224	Side horizontal stiffeners L100x50x6	38.0	-1.6	13.7	-14.1	22.0	-35.4	38.5	-3.9	3.7	-5.4	5.9	-9.1	2.8
225	Side web frames 210x5	117.7	-16.5	11.4	-7.4	41.3	-19.6	129.0	-2.4	2.9	-6.5	2.6	-11.0	17.6
226	Side web frames FP90x10	148.7	-11.3	8.0	-10.8	41.3	-3.2	149.3	-4.6	3.5	-11.3	15.7	-6.8	5.4
227	Side stringers T140x7	42.2	-40.9	13.8	-7.3	2.2	-5.8	13.5	-4.6	12.9	-4.0	4.1	-1.9	2.6

RC	Denomination	σ_{VM}	σ_{Xmin}	σ_{Xmax}	σ_{Ymin}	σ_{Ymax}	σ_{Zmin}	σ_{Zmax}	τ_{XYmin}	τ_{XYmax}	τ_{XZmin}	τ_{XZmax}	τ_{YZmin}	τ_{YZmax}
228	Side stringers fore part (web)	9.0	-5.4	3.9	-4.9	1.5	-5.4	2.0	-1.4	2.0	-3.3	0.8	-4.2	0.8
229	Side stringers fore part FP80x8	9.0	-7.2	3.5	-4.9	1.5	-5.4	0.7	-0.6	0.5	-1.3	1.4	-4.2	0.1
230	Side web frame aft part (web)	21.2	-4.8	5.7	-13.1	10.0	-16.0	3.1	-2.1	2.9	-1.4	2.3	-8.6	3.7
231	Side web frame aft part FP120x10	25.7	-2.7	6.8	-21.6	10.0	-16.0	3.1	-1.6	1.8	-1.2	1.6	-10.0	4.9
241	Deck plates	31.8	-20.8	6.9	-12.1	6.7	-5.1	20.8	-4.7	6.6	-3.1	2.5	-11.1	5.3
242	Deck brackets	31.8	-17.7	4.2	-30.0	3.6	-15.9	15.6	-3.2	4.7	-2.1	1.8	-11.1	5.2
243	Deck brackets FP50x6	33.3	-11.9	4.9	-33.7	5.4	-15.9	3.3	-3.7	3.6	-0.8	0.8	-1.7	7.8
244	Deck web beams (web)	21.6	-12.9	2.3	-10.8	17.4	-2.6	20.8	-1.5	3.0	-2.6	0.6	-6.8	7.9
245	Deck girders (web Fore)	6.5	-0.9	6.5	-0.7	2.8	-1.0	1.6	-0.3	0.1	-1.2	1.2	-0.1	1.0
246	Deck girders FP120x10 (Fore)	7.1	0.0	7.0	-0.6	0.7	-0.3	0.3	-0.4	0.5	-1.2	1.1	-0.1	1.0
247	Deck beams fore part L100x50x6	23.9	-2.4	4.8	-23.9	7.1	-4.6	1.5	-1.0	0.7	-0.7	1.0	-2.6	3.9
248	Deck girder FP200x8 (Aft)	7.6	-5.8	5.6	-3.9	3.4	-6.8	2.1	-2.1	1.1	-1.5	1.7	-4.0	1.7
249	Deck beams FP80x8 (Aft)	19.4	-0.7	0.5	-1.0	19.4	-2.7	1.0	-1.9	0.5	-0.7	0.7	-3.2	1.3
250	Deck beams (Aft) L100x50x6	11.5	-5.8	1.8	-10.7	10.3	-9.5	0.9	-1.0	1.3	-0.5	1.0	-1.2	1.6
251	Hatch coaming plates	26.4	-18.7	4.9	-28.4	3.9	-6.8	9.3	-4.6	4.0	-3.4	3.2	-8.6	7.9
252	Hatch coaming plates	19.6	-19.9	3.7	-0.8	1.5	-1.5	1.2	-1.4	2.0	-2.6	2.3	-4.3	0.7
253	Hatch horizontal stiff. T160x8	26.2	-26.1	4.0	-0.8	1.5	-0.8	1.2	-2.4	2.0	-0.9	1.2	-2.0	0.4
254	Hatch stays T140x7	48.7	-13.3	2.6	-1.9	6.7	-2.6	48.1	-1.2	1.3	-3.1	3.6	-5.2	3.2
261	BHD plates	31.5	-17.6	10.9	-24.9	17.4	-34.5	12.0	-3.7	3.7	-12.6	5.9	-11.0	10.9
262	BHD stiffeners T80x6.5	31.9	-31.0	8.4	-12.2	6.9	-18.7	22.0	-3.9	9.2	-2.1	4.8	-3.7	6.8
263	BHD UNP8	9.2	-9.4	1.3	-3.4	1.9	-0.5	0.9	-1.0	0.8	-0.2	0.2	-0.8	0.5
264	BHD stiffeners FP60x5	12.1	-6.8	6.4	-4.5	4.8	-12.3	5.8	-0.8	0.9	-1.8	4.1	-1.7	1.9
265	BHD beams and stiffeners L65x50x7	55.7	-9.9	8.0	-17.3	57.5	-54.9	12.2	-3.2	4.4	-3.0	3.7	-15.2	11.7
266	BHD plates	19.1	-17.6	2.3	-7.8	3.0	-17.4	0.2	-2.2	3.0	-0.4	10.0	-5.8	0.2
267	BHD and deckhouse top plates	14.3	-7.5	10.9	-15.2	14.6	-9.6	12.0	-2.2	4.9	-3.1	4.1	-4.1	5.0
268	BHD plates	54.1	-23.5	14.8	-2.0	12.3	-3.4	43.7	-1.1	5.0	-6.4	9.9	0.1	17.4
269	BHD plates	11.7	-6.3	1.1	-6.1	3.2	-3.9	0.6	-3.9	0.5	-4.6	0.9	-2.8	1.1
281	Funnel and WH plates	63.4	-21.7	8.8	-26.5	61.2	-21.0	15.4	-3.2	3.3	-6.6	4.5	-4.3	7.1
282	Bulwark plates	8.2	-3.1	8.3	-1.8	1.6	-5.0	2.6	-1.2	1.5	-2.7	0.8	-2.2	1.5
Min./Max.		**148.7**	**-75.3**	**39.0**	**-91.2**	**61.2**	**-60.0**	**149.3**	**-6.9**	**12.9**	**-18.7**	**23.7**	**-25.7**	**17.6**

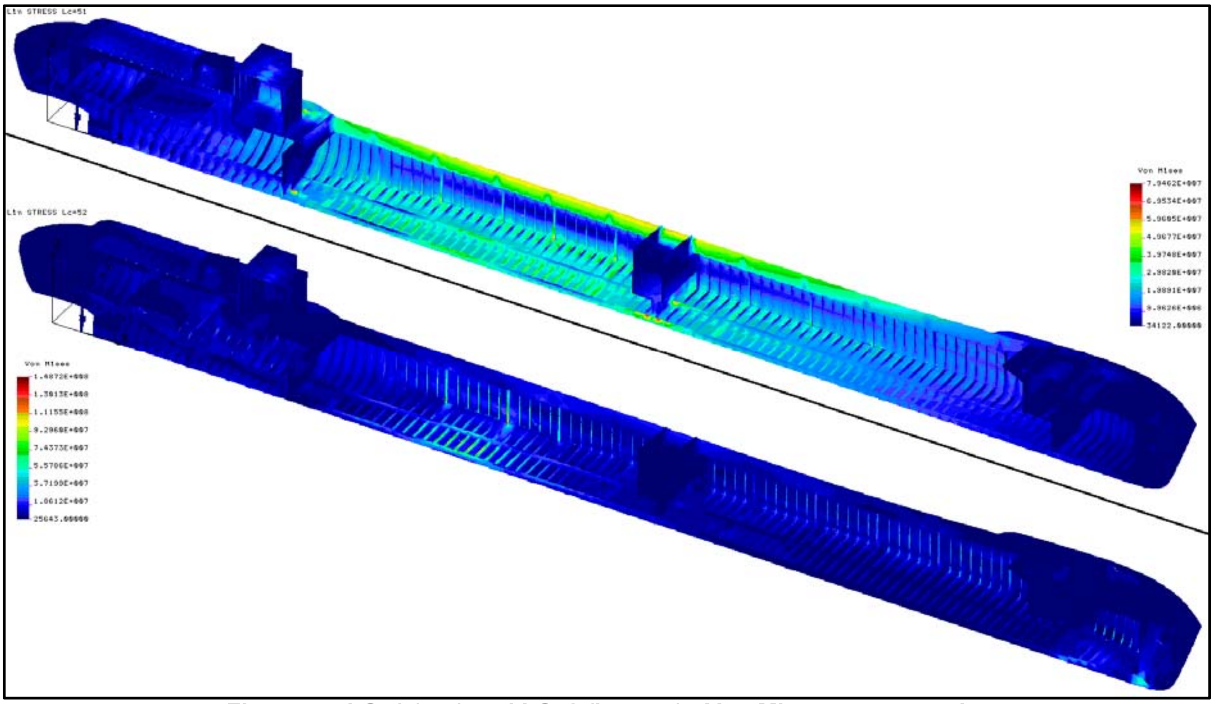

Figure 47. LC51 (top) and LC52 (bottom) - Von Mises stress results

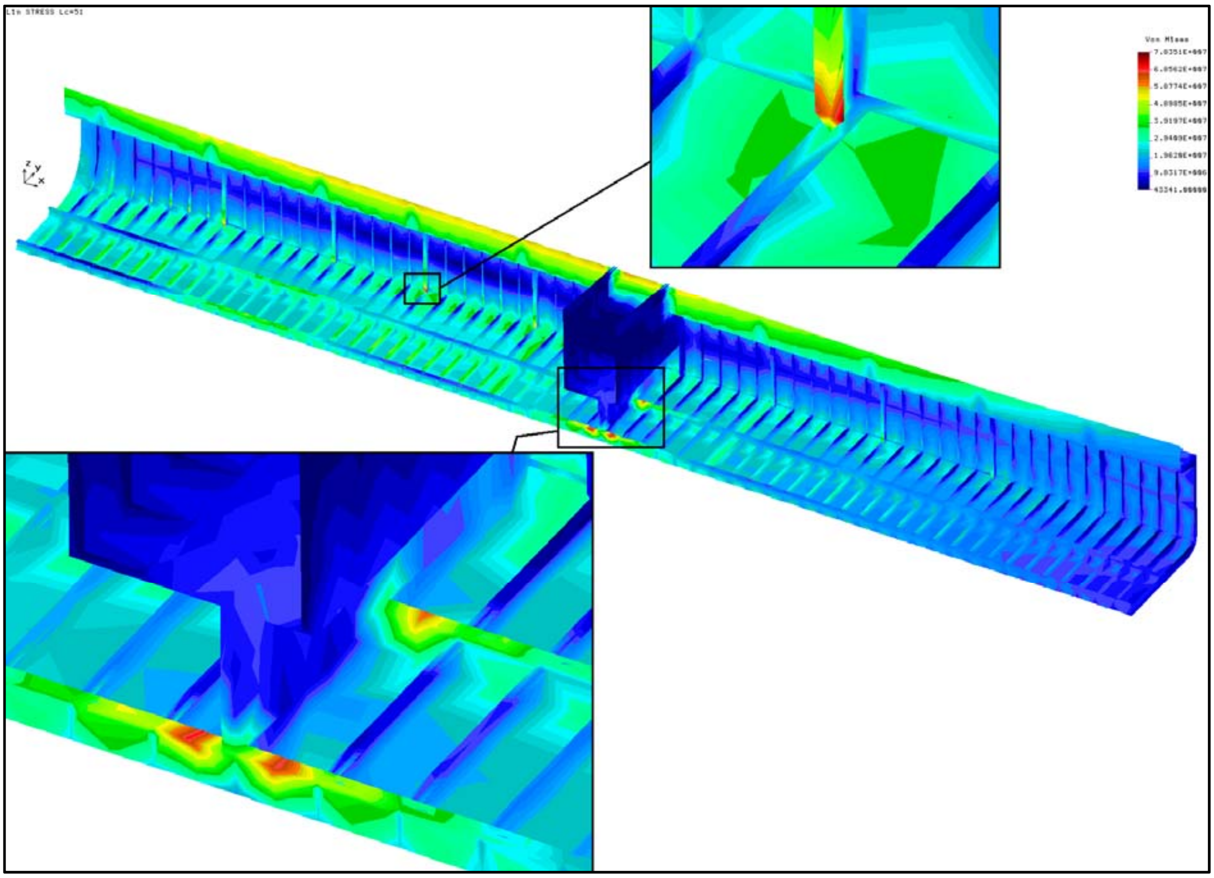

Figure 48. LC51 - Von Mises stress results for cargo area

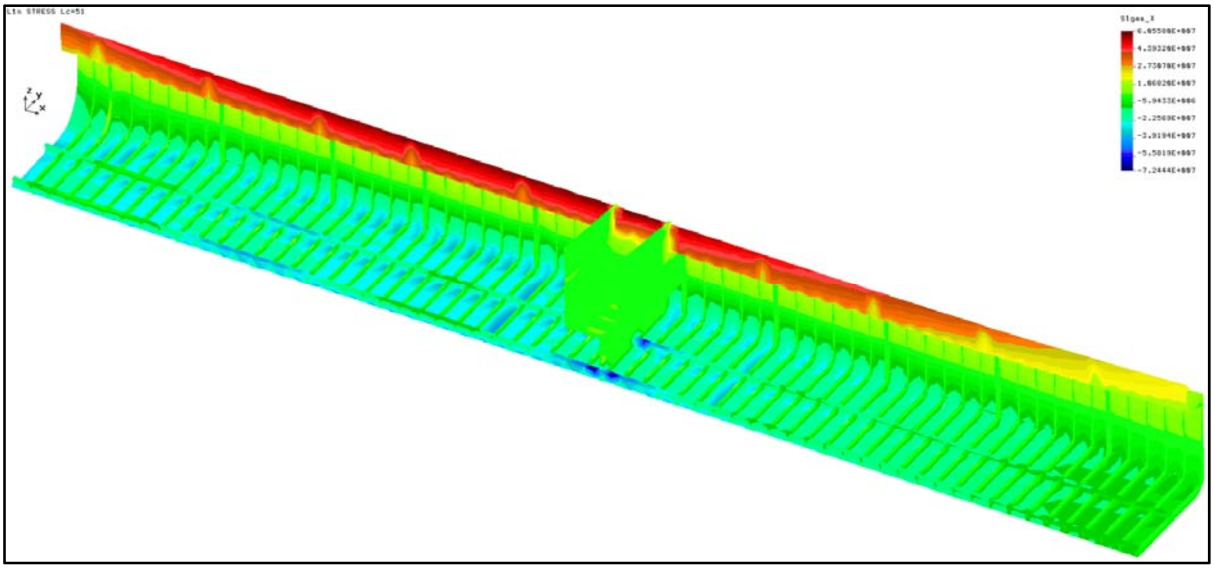

Figure 49. LC51 - σx stress results for cargo area

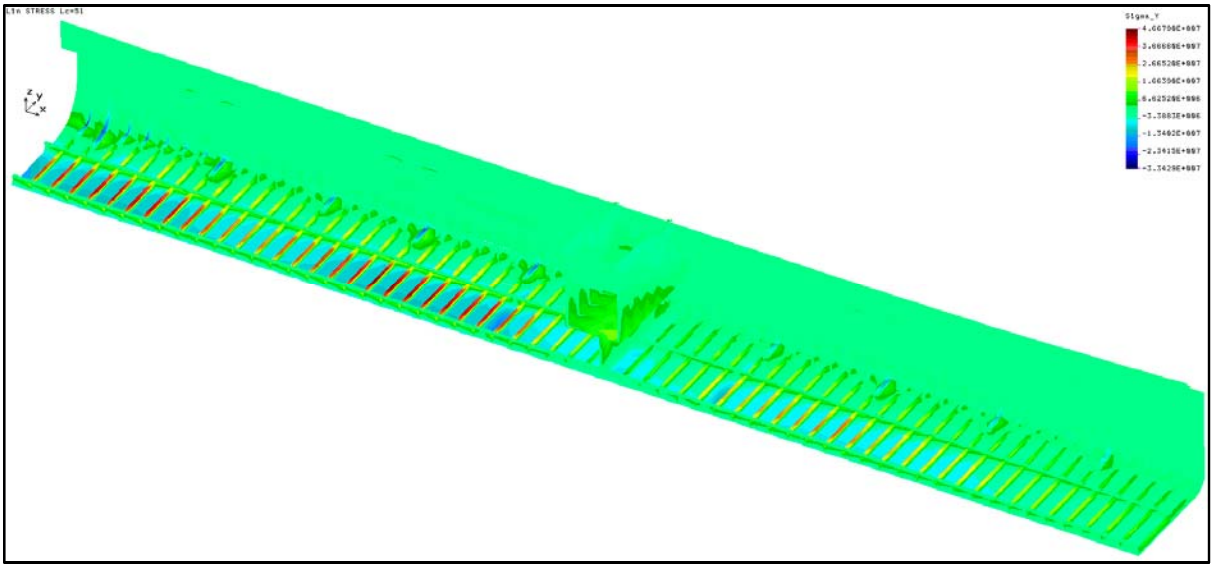

Figure 50. σy stress results for cargo area

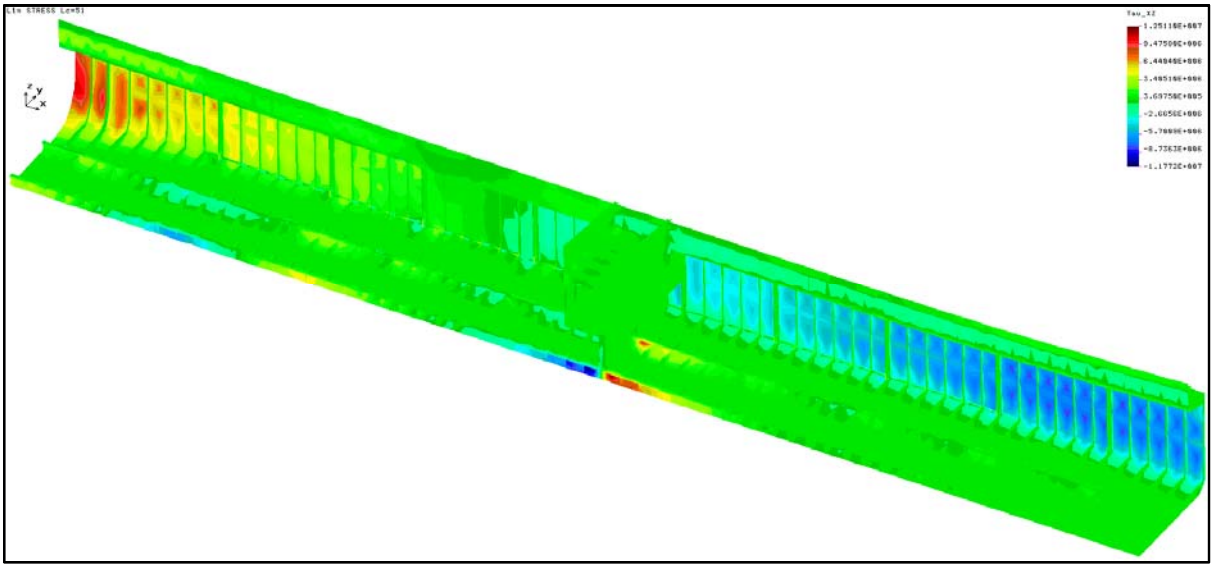

Figure 51. LC51 - τxz stress results for cargo area

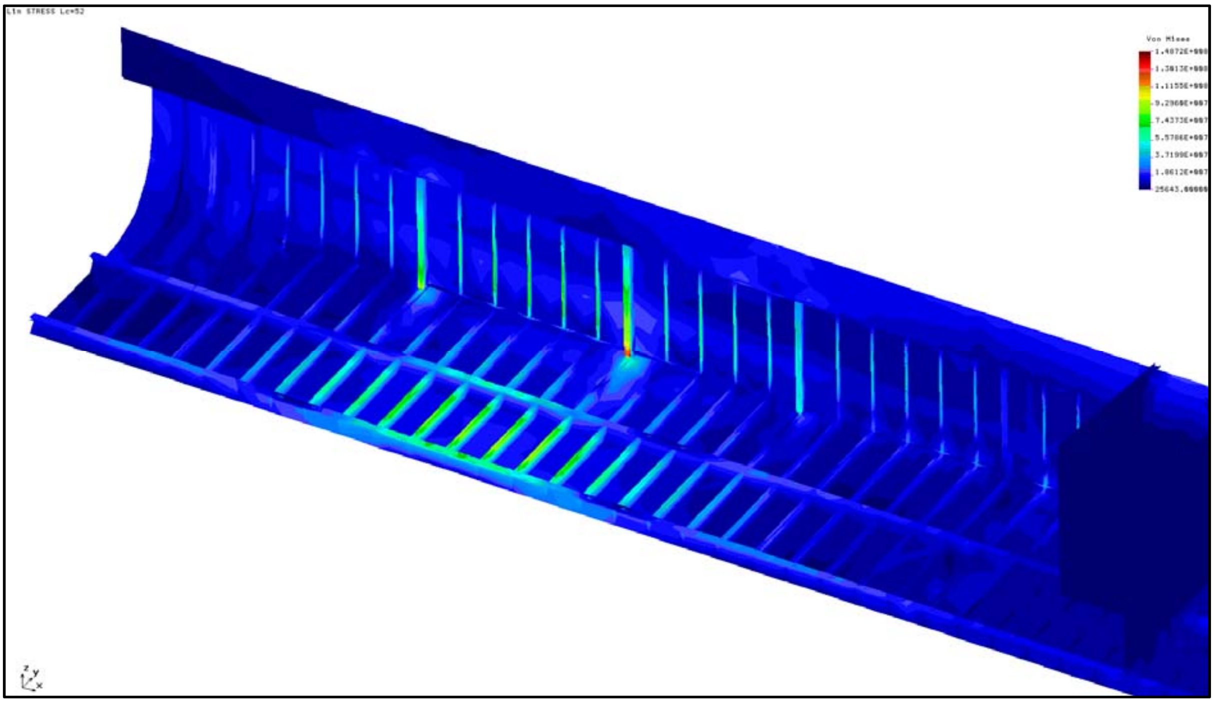

Figure 52. LC52 - Von Mises stress results for cargo area

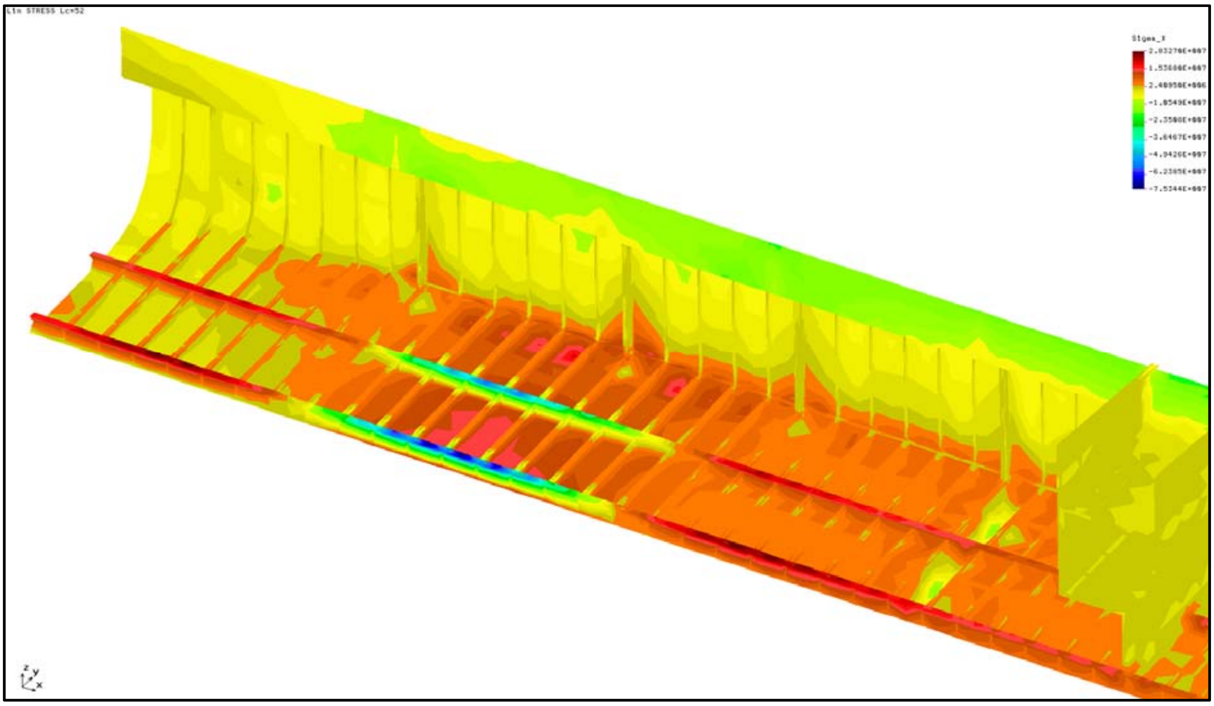

Figure 53. LC52 - σx stress results for cargo area

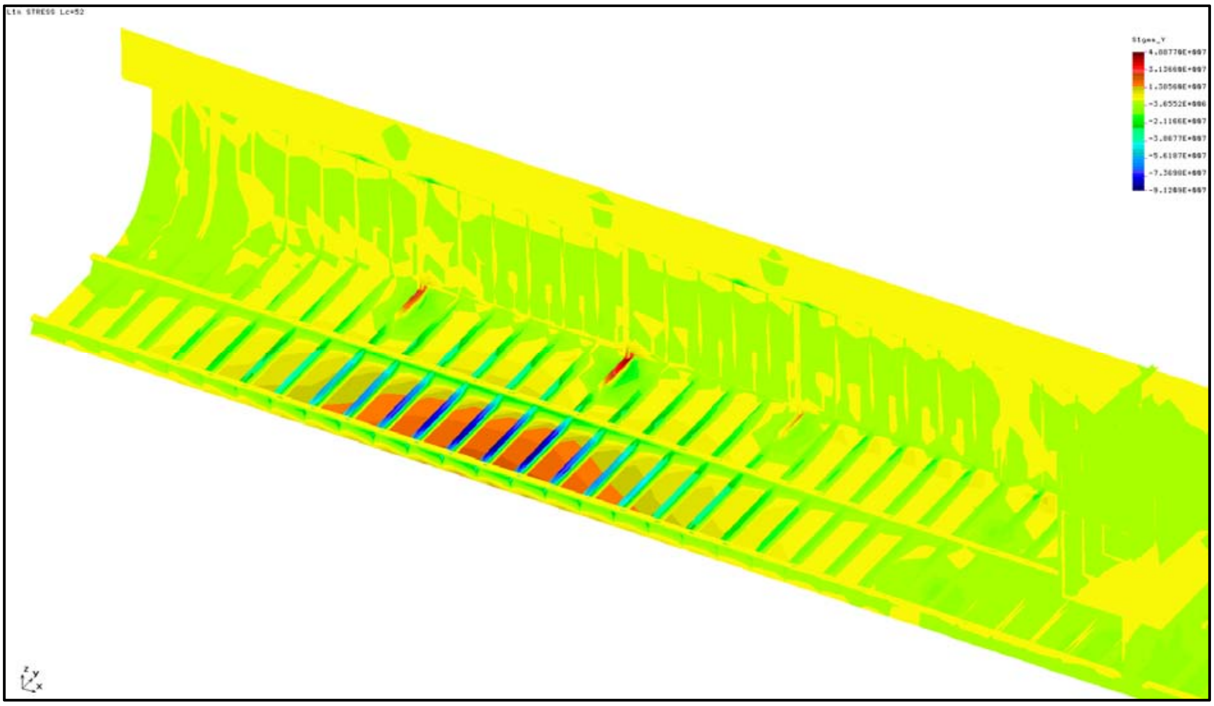

Figure 54. σy stress results for cargo area

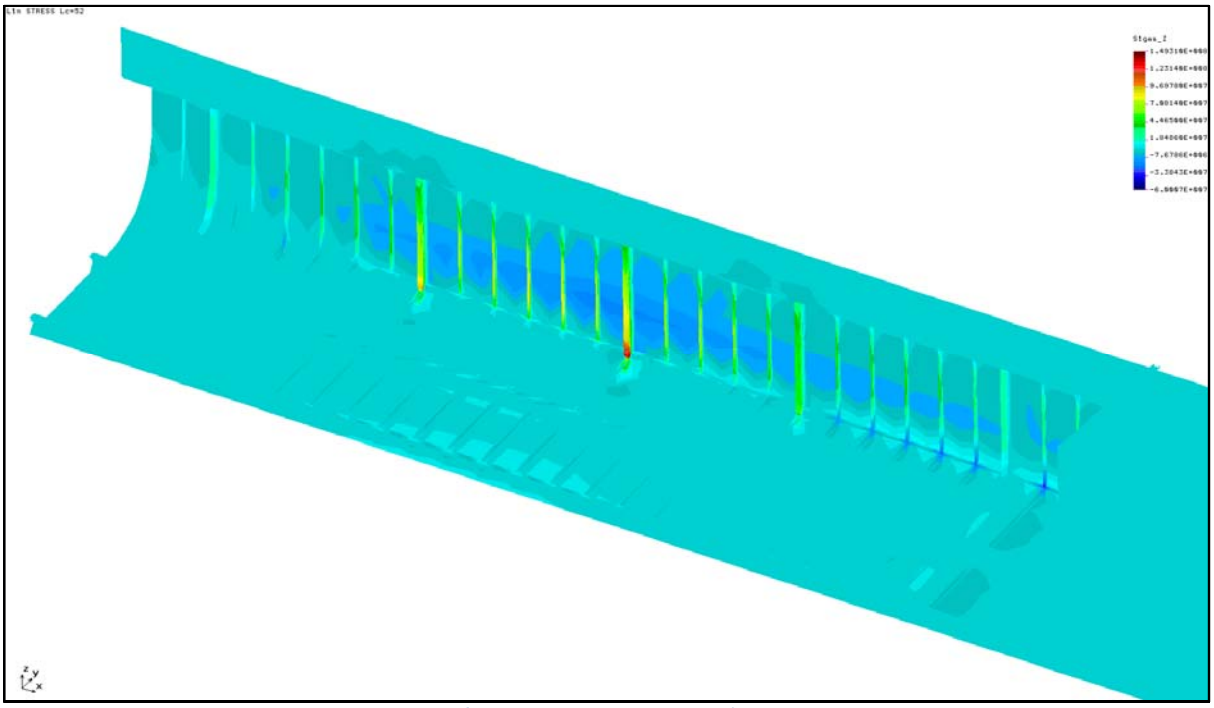

Figure 55. LC52 – σz stress results for cargo area

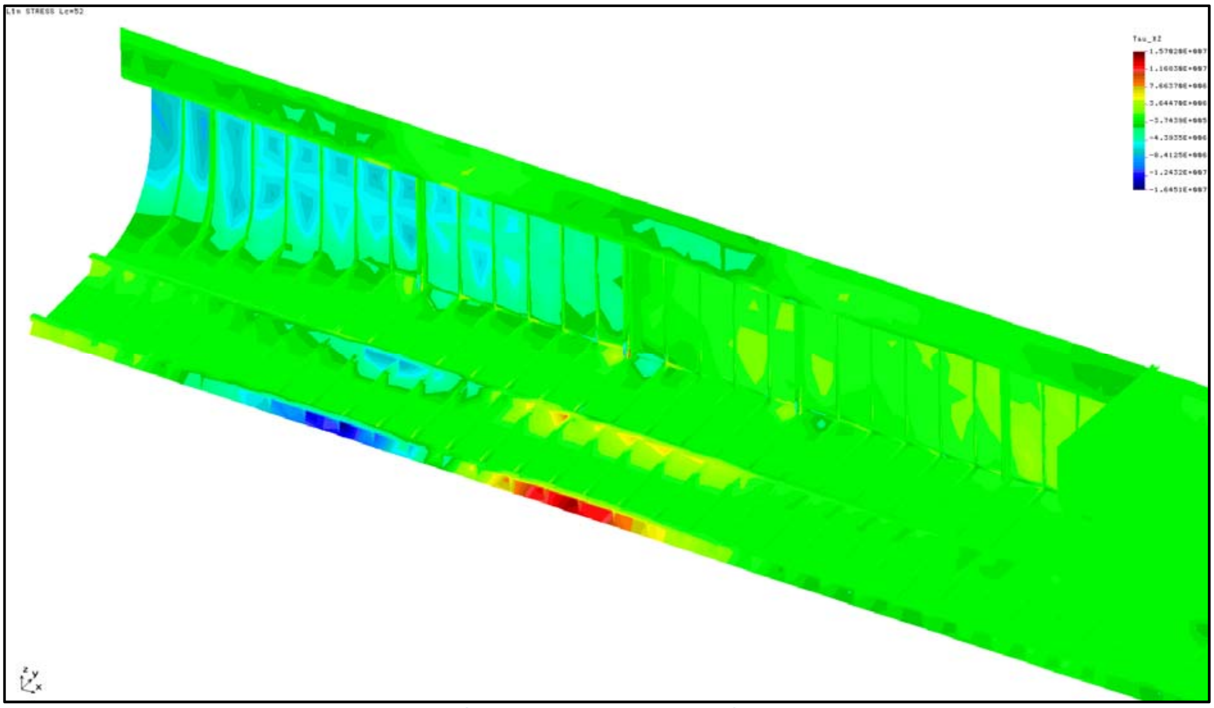

Figure 56. LC52 - τxz stress results for cargo area

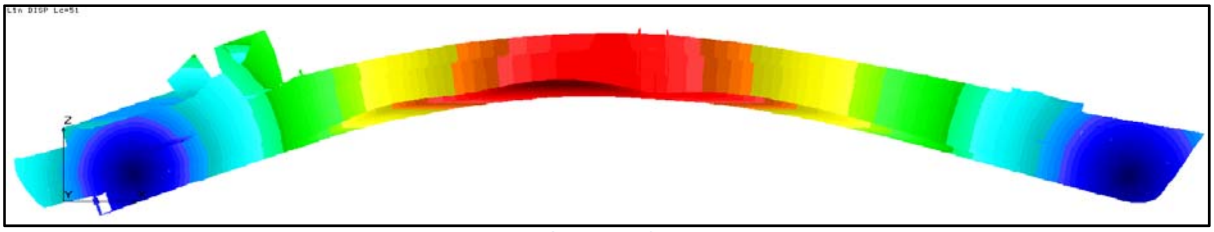

Figure 57. LC51 – Deformed shape

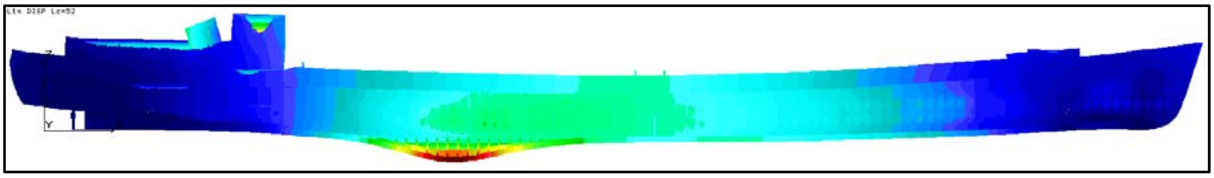

Figure 58. LC52 – Deformed shape

7.6.5. Conclusion

The FEM calculation results have proved that for the existing barge (L_{OA} = 57.5 m), the stress values for the representative structure analysed (cargo area) are within allowable limits.

7.7. Lines Plan of MV "Rheinland"

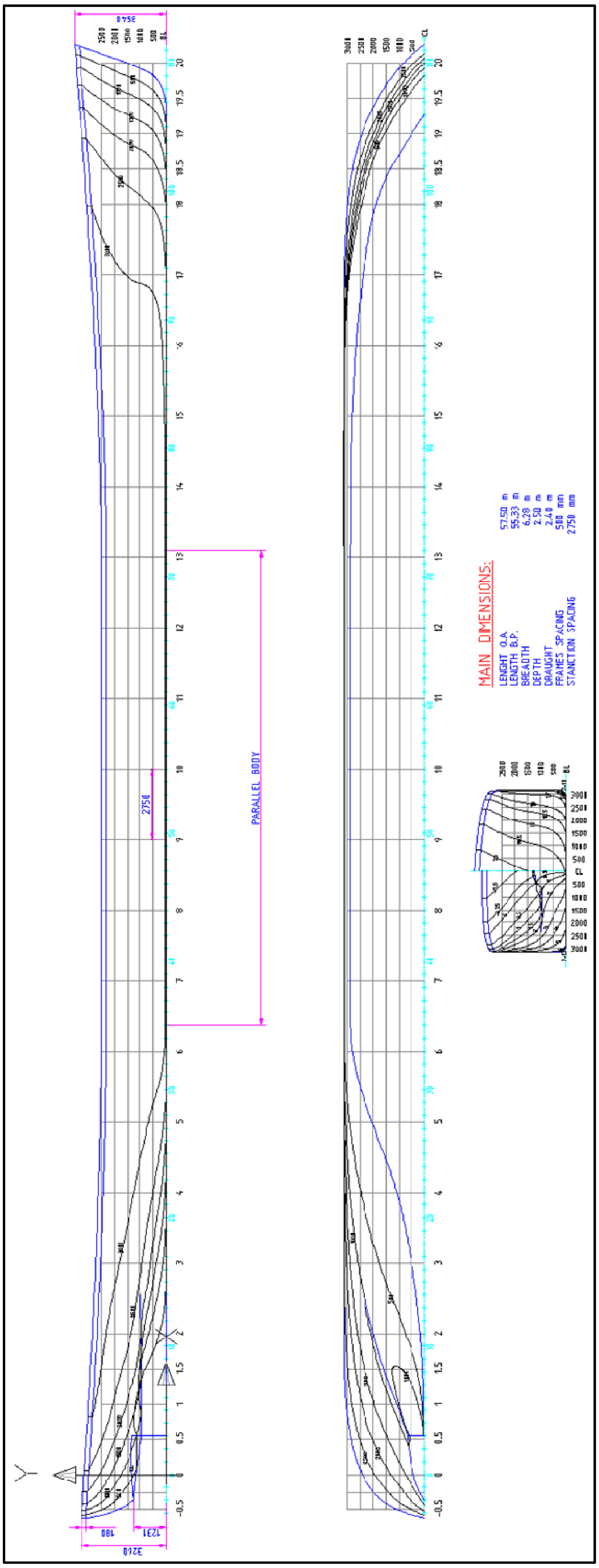

Figure 59. Lines plan of MV "Rheinland"

7.8. Midship Sections of MV “Rheinland”

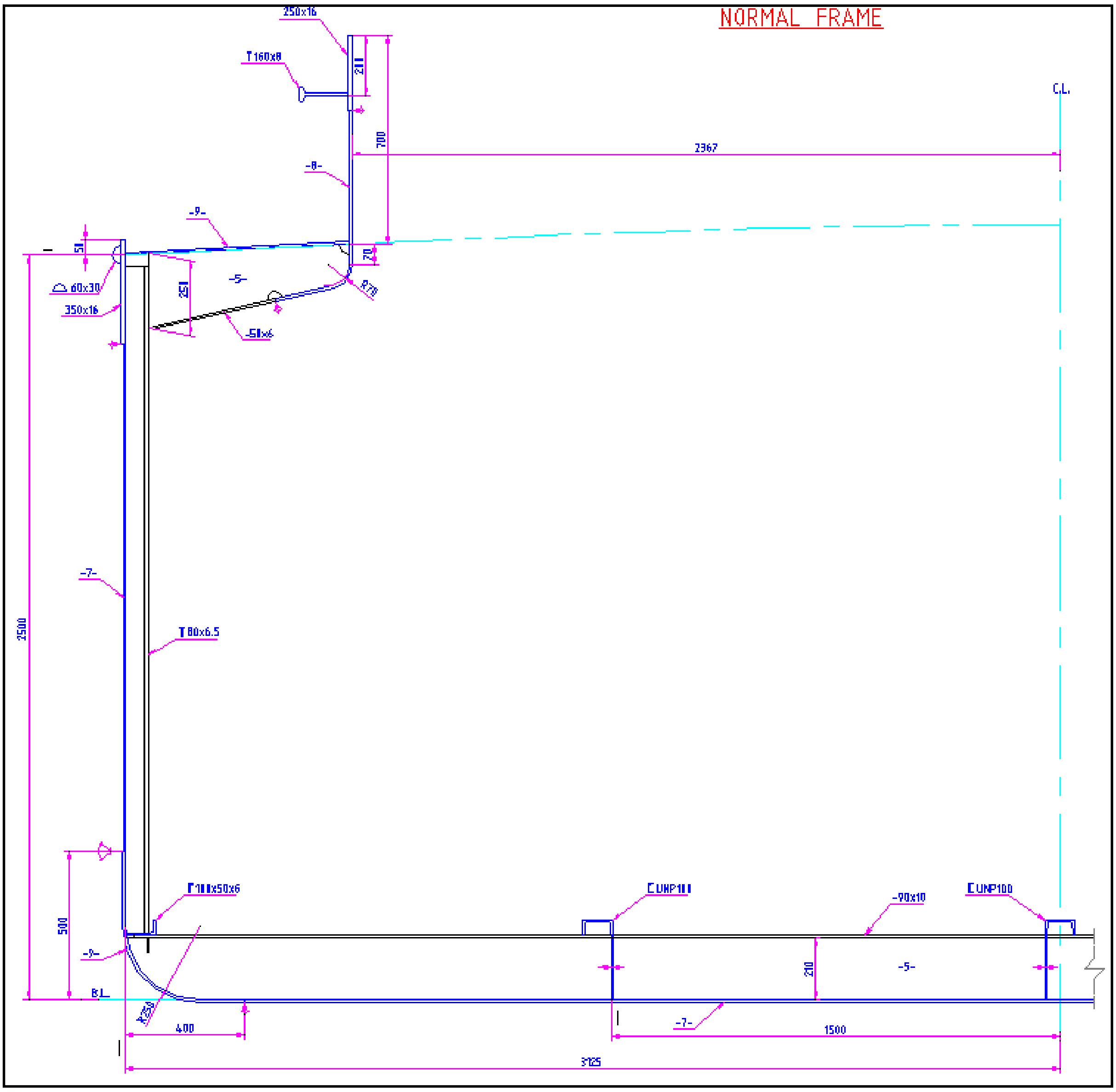

Figure 60. Normal frame midship section of MV “Rheinland”

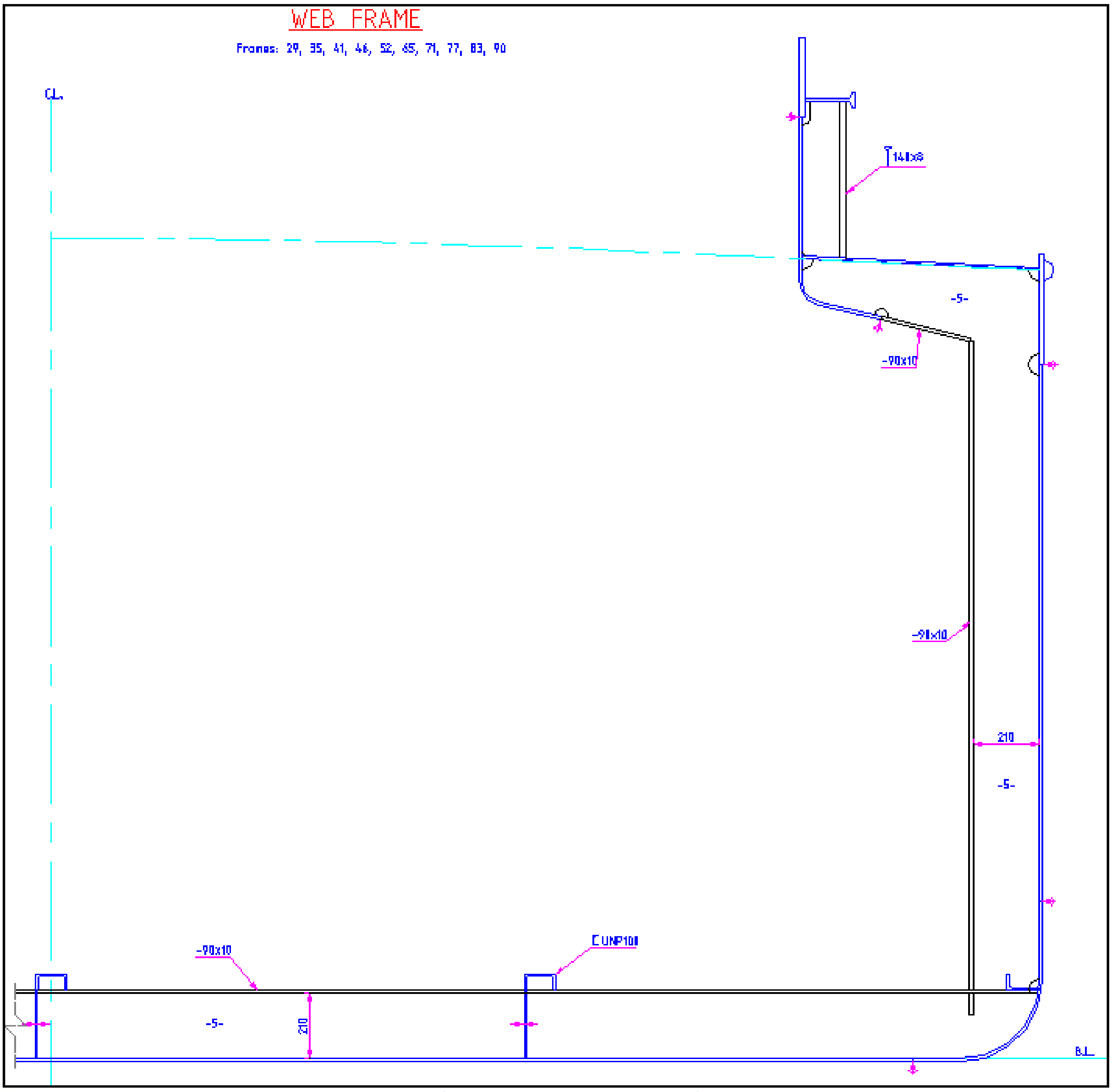

Figure 61. Web frame midship section of MV “Rheinland”

7.9. Public summary

This deliverable 6.1 “Ship Structure” presents the investigations on the lengthening possibilities of two existing inland navigation vessels for dry bulk cargo, MV “Hendrik” (L_{OA} 70.0 m) and MV “Rheinland” (L_{OA} 57.5 m), representing a share of the European fleet in need of retrofitting and modernisation in order to regain competitiveness on the market. Among other retrofitting procedures such as increasing the breadth of the hull or conversion for different types of purposes, lengthening the ship’s hull in the midship area by a prismatic section is the most effective and cost efficient way.

MV “Hendrik”, originally built in 1975, represents CEMT class III to IV (Conférence Européenne des Ministres de Transport) for inland navigation vessels and features a double bottom and single side platings. CEMT class II is represented by MV “Rheinland”, built in 1959, which is equipped with a single hull. Both vessels comprise transversally framed ordinary mild steel structures. Those two vessels serve as basis for exemplary investigation on the lengthening of the ship’s hull and its required strength.

After the determination of current plate thicknesses and stiffener dimensions according to GL (Germanischer Lloyd) rules for MV “Hendrik” and BV (Bureau Veritas) rules for MV “Rheinland” and comparison with the “as built” dimensions from the general arrangement drawings, investigations were made in order to define the maximum possible lengthening sections.

The limit turned out to be an additional section of 18.0 m, resulting in a L_{OA} 88.0 m, for MV “Hendrik” accompanied with a few modifications to the existing structural members such as upgrading ordinary side frames and replacing every fourth side frame by a side web girder. The maximum possible length for an additional section for MV “Rheinland” is 12.0 m. However, this procedure can only be executed if additional longitudinal stiffeners are fitted to the bottom plates to reduce the buckling length and if the classification society advisor accepts the direct calculations of the ship’s hull regarding the floors and web frames.

The results for the two different vessels show the general feasibility of retrofitting by lengthening of the ship’s hull at the midship area. Economical benefits can be obtained either by increasing the amount of cargo at equal draught or decreasing the draught at constant amount of cargo in order to enhance the operating time in low water periods.

For economic purposes, initial estimations regarding the cargo benefit and draught reduction per lengthening meter were made as well as an approximate cost calculation for the retrofitting procedures.