SMAIC
STATE MARINE ACCIDENT INVESTIGATION COMMISSION

FINAL REPORT

24/17

Very serious marine casualty

of the towing unit: the tugboat "IKAR" and the passenger and car river ferry „SIEBENGEBIRGE"

Sinking of the ferry under tow in the North Sea on 30 April 2017

February 2019

The investigation of a very serious marine casualty of sinking of a river car and passenger ferry „SIEBENGEBIRGE" was conducted under the Condition Marine Accident Investigation Commission Act of 31 August 2012 (The Journal of Laws item 1068 as amended) as well as norms, standards and recommended procedures agreed within the International Maritime Organisation (IMO) and binding the Republic of Poland.

The objective of the investigation of a marine casualty or incident under the above-mentioned Act is to ascertain its causes and circumstances to prevent future casualties and incidents and improve the Condition of marine safety.

The Condition Marine Accident Investigation Commission does not determine liability nor apportion blame to persons involved in the marine casualty or incident.

This report shall be inadmissible in any judicial or other proceedings whose purpose is to attribute blame or liability for the accident referred to in the report (Art. 40.2 of the Condition Marine Accident Investigation Commission Act).

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1. The Contents

2. Facts

On 29 April 2017 at 15:55 a towing unit consisting of the tugboat, *Ikar* and the car and passenger river ferry, *Siebengebirge* under tow with a pilot on board the tugboat unberthed from the wharf in the port of Rotterdam. Once the pilot had left the tugboat the towing unit continued its planned voyage to the port of Hanko (Finland).

On 30 April 2017, at 4:45, the tugboat crew noticed that the vessel under tow was heeling on starboard side and that the trim was deepening on the bow of the vessel under tow. The master immediately informed the Netherlands Coast Guard of the situation and upon receiving the consent he directed the towing unit to the port of Den Helder in the province of North Holland (over the Marsdiep Strait).

On 30 April 2017 at 06:25 am, the towed object turned the keel up, at 07:40 it completely submerged in water.

At 08:30 the towline was cut off and on the order of the Border Guard the tugboat remained in the region of the sinking of the vessel under tow. According to the instruction received at 08.55 the anchor was cast and further instructions were being awaited.

At 10:50, the Border Guard came aboard the tugboat and conducted an interrogation of the tugboat crew and checked the vessel’s documents.

At 17:50 the tugboat was allowed to raise the anchor and continue the journey. On 4 May 2017 at 11:35 the tugboat berthed in the port of Gdynia.

3. General Information

3.1. Vessels' Particulars

3.1.1. The *Ikar* Tugboat

Photograph 1: The „Ikar" tugboat

Flag:	Polish
Home port:	Gdynia
IMO number:	6519302
Register number:	ROG2568
Call sign:	SPG 2521
Keel laid:	12 March 1965
Built:	1966, the shipyard: Appledore Shipbuilders Ltd.
Devon,	United Kingdom, construction numer AS11
Classifier:	Polish Register of Shipping (PRS)
PRS register number:	PRS-210044
Class notation:	KM TUG I
Length overall:	29.97 m

Length between perpendiculars:	26.82 m
Width:	7.54 m
Freeboard depth:	3.81 m
Gross tonnage:	171
Net tonnage:	51
Deadweight:	101 metric tons
Propulsion:	internal combustion engine MWM, power 882 kW 375 r/min
Bollard pull:	150.76 kN according to certification No 190/GDY/11
Owner/operator:	Jan Stępniewski i Ska Sp. z o.o. Gdynia
Class certificate:	PRS No M-38642/17 of 28 Feb. 2017 valid until 17 July 2021
Safety information card:	UM Gdynia No 5274/GDY/2016 of 30 Sept. 2016 valid until 18 July 2021

3.1.2. The *Siebengebirge* Car and passenger river ferry

Photograph 2: The „Siebengebirge" ferry (Marine Traffic.com)

Flag:	German
Home port:	Bad Honnef
EU number:	04808160
Type:	passenger and car ferry
Built:	Schiffswerft Oberwinter GmbH, Oberwinter,
Niemcy	1969; construction number 167
Water region of navigation:	the Rhine (640.2 km) between Bad Honnef and Rolandseck harbours
Length overall:	39.65 m
Waterline length:	27.60 m
Maximum width:	9.50 m
Freeboard depth:	1.85 m
Maximum draught:	1.10 m
Freeboard:	750 mm
Number of waterproof divisions:	10
Maximum number of cars:	12
Maximum number of passengers:	250
Engines:	2 x MAN D2866E: power of 178 kW each, one spare engine: MAN D2866E
Propellers:	2 x Schottel SRP100
Maximum speed:	5.36 knots
Anchor:	1 anchor chain of the length of 48 m
Owner (before the sale):	Fahrgesellschaft Honnef Pool GmbH u. Co. KG, Bad Honnef DE-53604, Hauptstrasse 11D
Purchaser:	JS Ferryway Ltd. Oy, Finland
Parameters of an empty ferry:	
Developed under the documentation:	Stabilitats und Leckrechnung fur Fahrschiff „Siebengebirge" of 19.06.1970
Light weight of an empty ferry:	D_{LS} = 78.00 t,
Height of the centre of gravity:	z_{GLS} = 1.78 m,
Transverse metacentric height:	GM_{LS} = 15.53 m
Windage area for the draught T=1.05 m:	A_W = 100.4 m^2
Height of the centre of the windage area above the waterline:	1.83 m

3.1.3. Model of the *Siebengebirge* ferry

In order to analyze the stability a 3D model of the *Siebengebirge* ferry has been developed. The parameters of the model are presented in Figures 1 to 5.

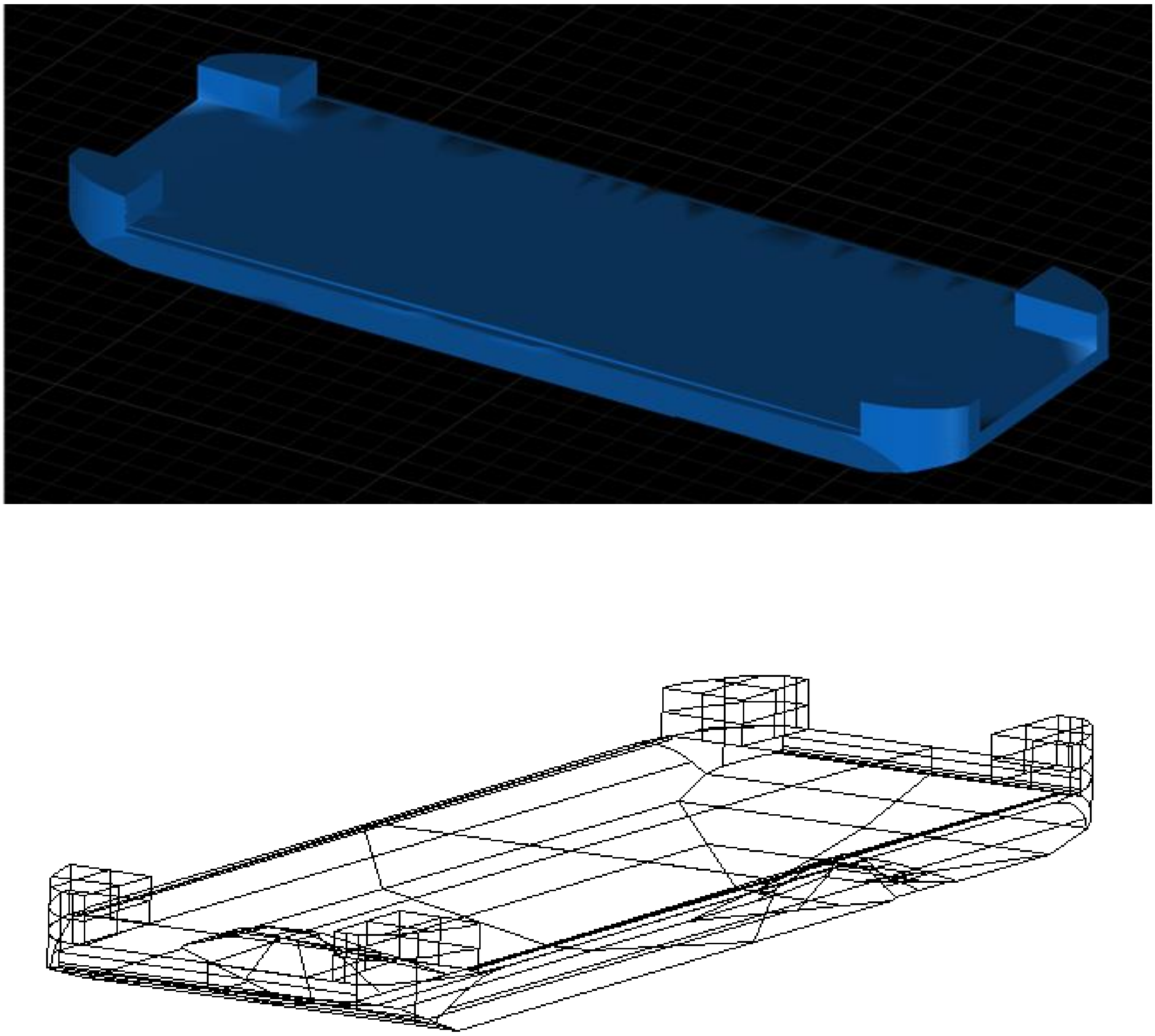


Figure 1: Model of „Siebengebirge". Top view

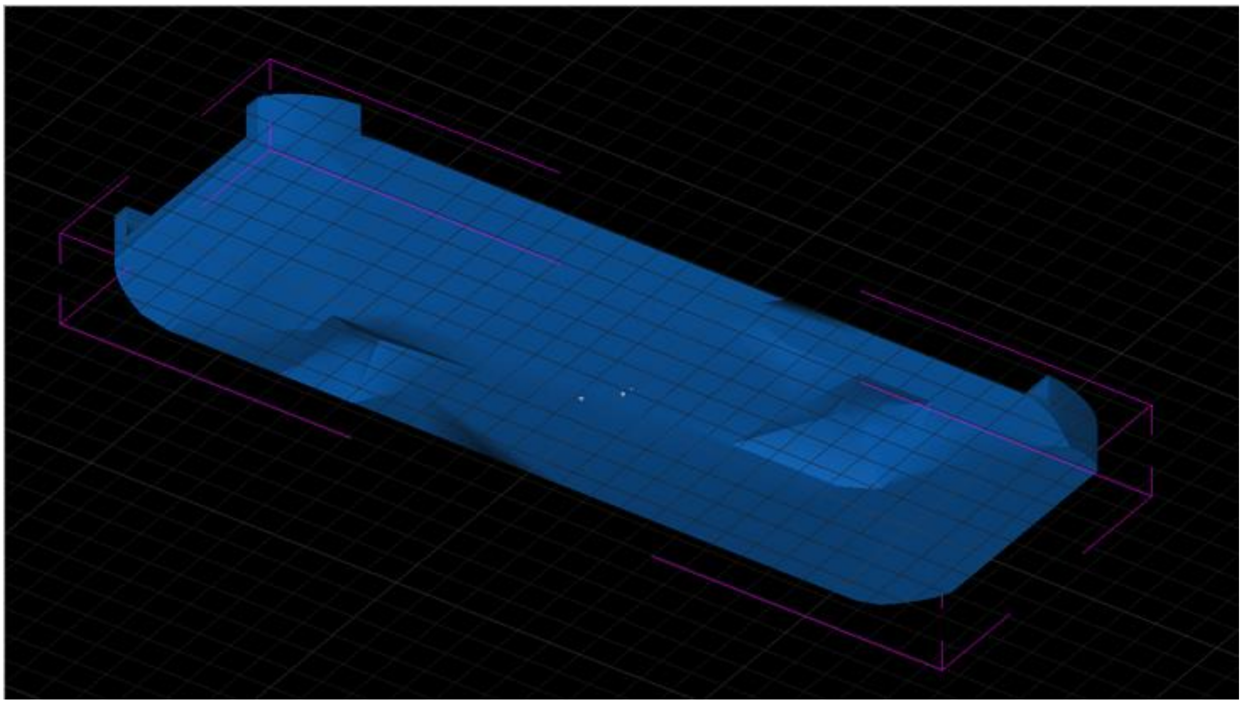


Figure 2: Model of „Siebengebirge''. Bottom view

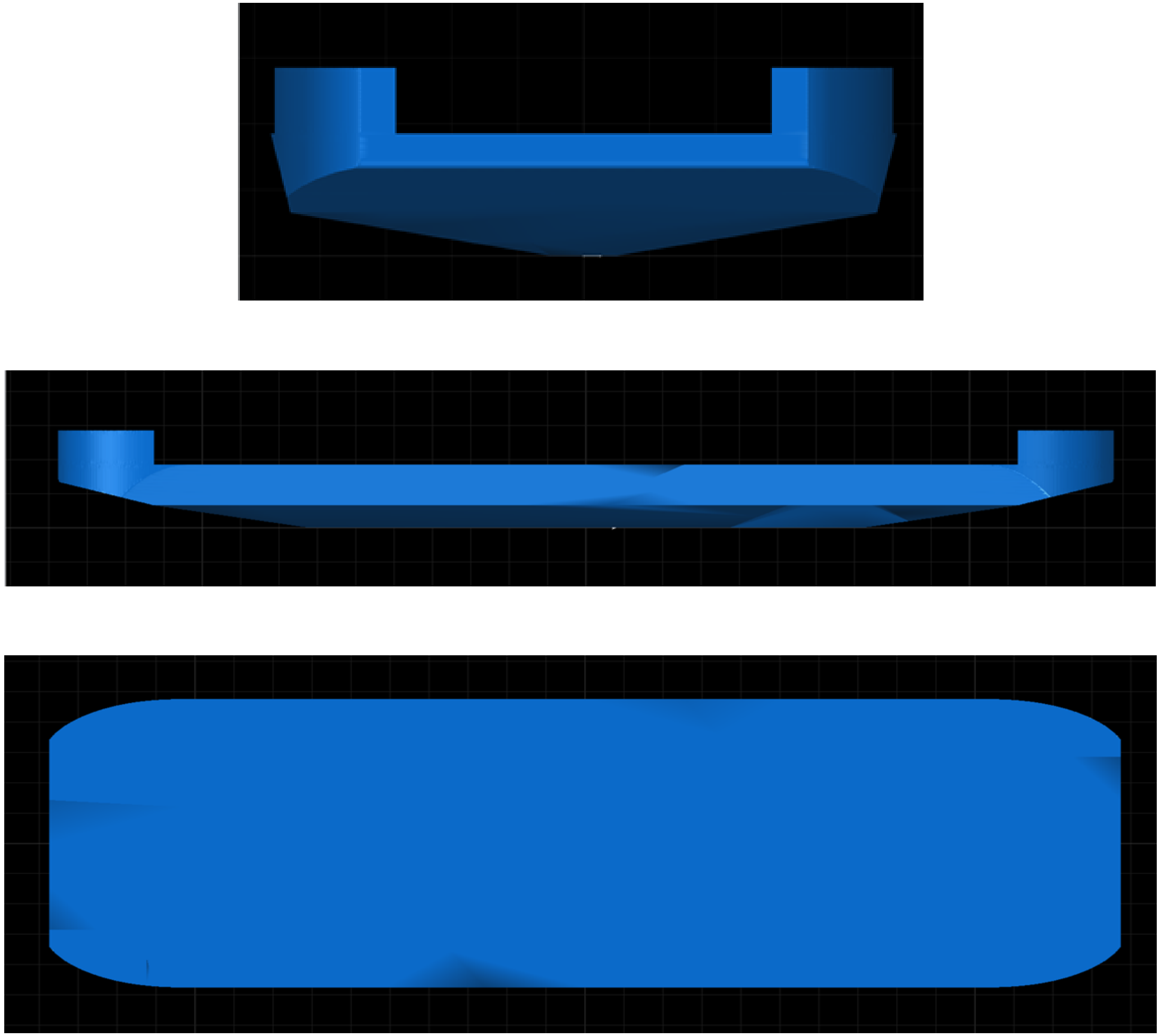


Figure 3: Model of the ferry (planes)

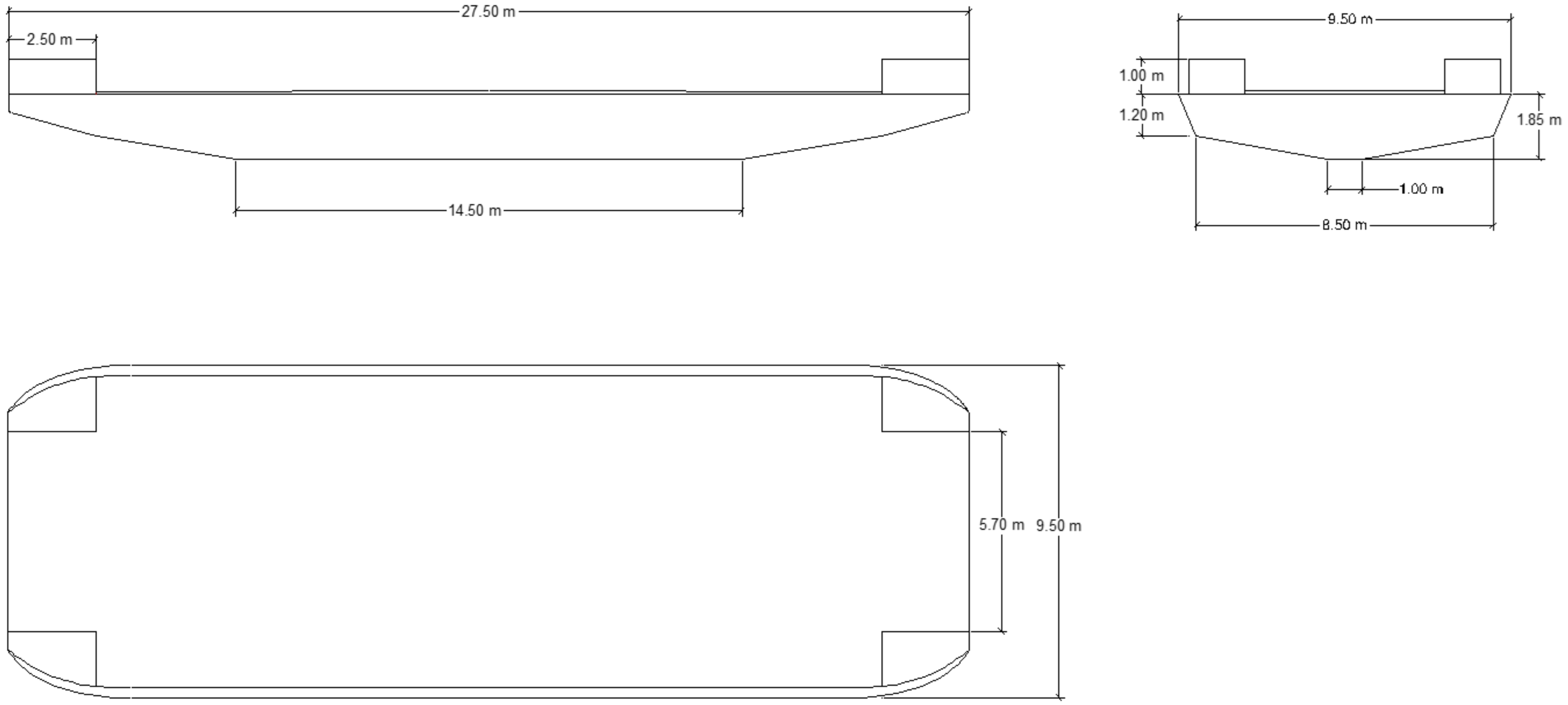
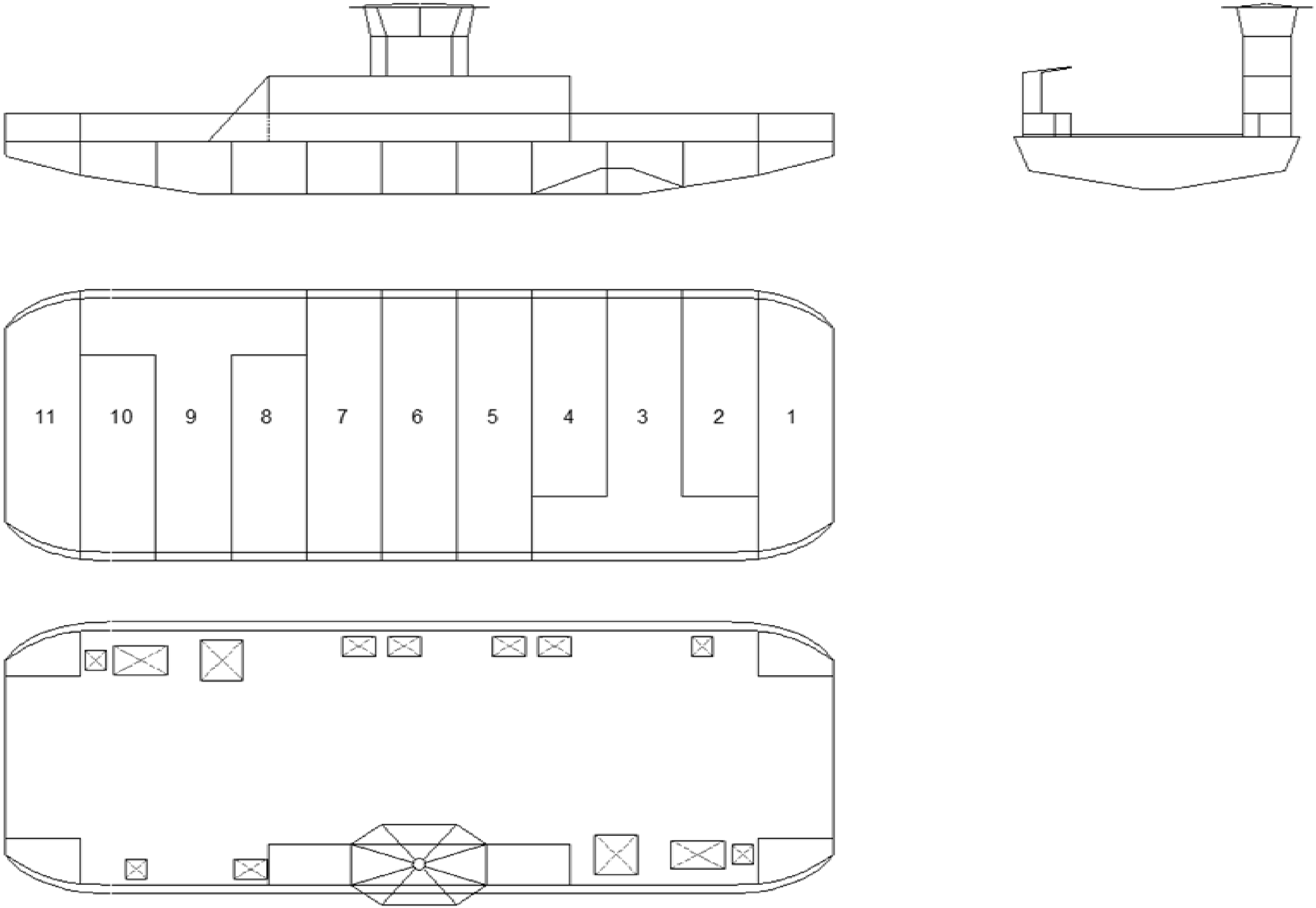


Figure 4: Main dimensions of the „Siebengebirge" hull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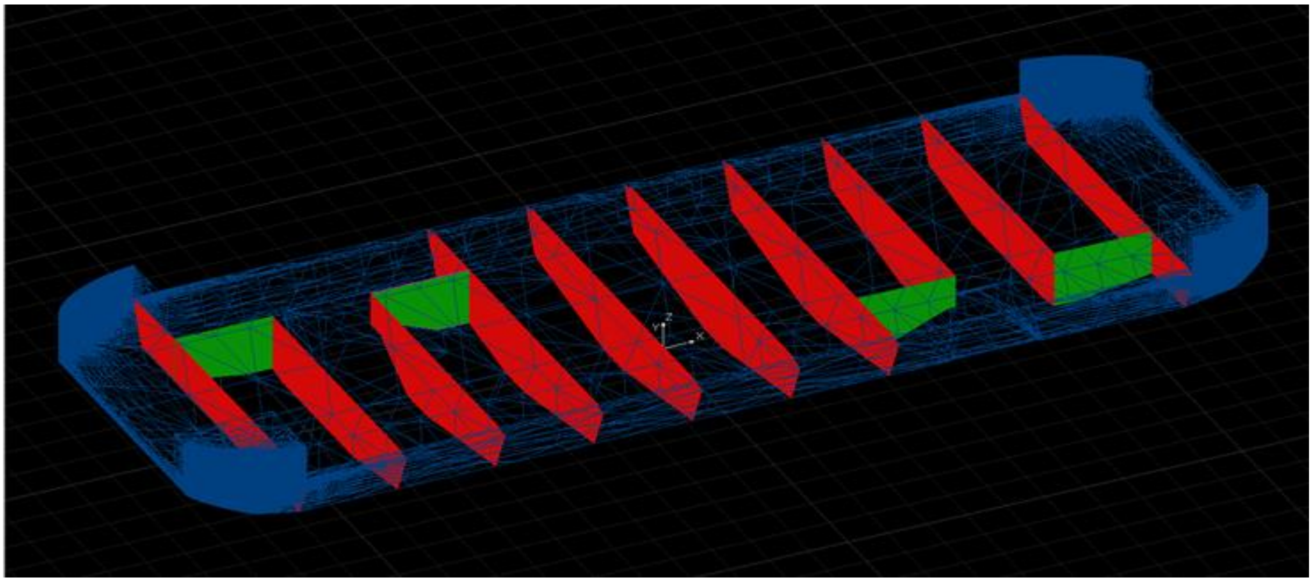


Figure 5: Hatchways on board and watertight compartments of the „Siebengebirge" ferry

- The ferry at the time of commencement of towing had the Community inland navigation certificate No DU229F of 20 April 2015, valid until 19 April 2020.
- The ferry was not manned during the sea voyage.
- About 1,200 liters of fuel was in the ferry's tanks.

Photograph 3:The point of flooding adopted for the purpose of estimating the stability

3.2. Voyage Particulars of the Towing Unit Composed of *Ikar* and *Siebengebirge*

Commencement of towing:	Rotterdam (the Netherlands)
Port of destination:	Hanko (Finland)
Type of navigation:	international
Manning:	6 persons
Passengers:	none

3.3. Information about the Accident

Kind:	very serious marine casualty
Date and time of the event:	30.04.2017 at 07:40 LT
Geographical position of the event:	φ = 53°06.85' N; λ = 004°33.76' E
Geographical area of the event:	North Sea – to the west of Texel
Nature of the water region:	coastal, beyond the fairway
Weather during the event:	wind NE 4˚B, very good visibility
Operational status of the tugboat, *Ikar*:	towage of the car and passenger ferry
Operational status of the ferry, *Siebengebirge*:	on tow, unmanned, excluded from operation
Consequences of the accident to *Ikar*:	no damage to the tugboat, loss of towline
Consequences of the accident to *Siebengebirge*:	the ferry sank

3.4. Shore Services and Rescue Action Information

The master of the *Ikar* tugboat notified the Dutch Coast Guard of the sinking of the ferry under tow. The tugboat did not tow the sinking ferry to the port indicated by the Coast Guard. No rescue operations were carried out, and the activities of the Coast Guard representatives were limited to the control of *Ikar*'s papers following the sinking of the ferry.

4. Circumstances of the Accident

On 26 April 2017 at 18:35 (LT) the *Ikar* tugboat came to the port of Rotterdam, the Netherlands and at 20:35 it berthed to the side of the vessel it was supposed to tow, i.e. the car and passenger river ferry, *Siebengebirge*.

On 27 April 2017, at 08.30, the team of the Redwise Maritime Services B.V. company came on board *Siebengebirge* in order to get it ready for towage from Rotterdam to Hanko in Finland. Preparations for towing consisted, among other things, in dismantling loading platforms at the stern and bow, closing the holes in the hull (tank vents and holes created after disassembling the platforms), securing the windows of the wheelhouse with plywood, closing some holes in the ferry's bulwark, etc. Disassembled platforms were attached on board of the ferry. The Redwise company also made chain bridles for attaching the chain of the main towline.

On 28 April 2017, the Redwise company employees were continuing security works on board of *Siebengebirge*. At 14:30, the representatives of the insurer ("IF" company) from the Al Mare Consulting AB company came on board the *Ikar* tugboat to inspect the towing unit with regard to its preparedness for planned towing. They checked the tugboat's documents and the certificates of the equipment that was to be used during towing, as well as the plan of the towing route together with defined ports of rescue. The representatives of the insurer received copies of the documents which they had requested from the master of *MT Ikar*.

On 29 April 2017 at 07:00, the crew of *MT Ikar* began to furnish *Siebengebirge* with armature (installing the towing equipment). The insurers representatives turned to the master of *MT Ikar* with an instruction to carry out a load test of bridles installed by the Redwise company to fix the main towline. The test consisted in the fact that *Ikar* was fastening its main towline successively to both bridles and, resting its bow against *Siebengebirge*, was stretching the towline by means of the towing winch. Both bridles were subjected to a static load test of approximately 19 metric tons (towline force of *MT Ikar*). After the load test the insurer's representative made an external inspection of both bridles.

After the inspection, the representative of the insurer, Al Mare Consulting AB, issued a certificate of readiness for the towing unit (Towage Approval Certificate) and handed it over to the master of the tugboat. According to the certificate, the expert of the Al Mare Consulting AB company decided that the set was properly prepared for the planned towage from Rotterdam to Hanko by Skagerrak. The towing time was determined for about 8 days. The certificate was accompanied by a list of recommendations and restrictions. According to the recommendations, the border weather conditions for towing were the following: maximum wind speed of 12 m/s, and the significant wave height of no more than 1.5 meters.

The towing unit with the pilot on board and in the assistance of a port tugboat, *Buizero* left the wharf at 15:55.

Photograph 4: Towing unit at the exit from Rotterdam with the assistance of a port tugboat. One can see the resisting wave at the ferry's bow

At 18:10 the port tugboat was released, and after passing Hook van Holland at 19:10 the pilot left the tugboat. The towline was extended to 140 m and sea towing was started with the initial speed of 5 k.

The next day, i.e. 30 April 2017 at 4:00, the watch officer noticed that the side lights of the ferry under tow indicated that it was heeling on starboard side. The master of the tugboat who was notified about it, reduced the towing speed and immediately informed the Dutch Coast Guard about the situation.

He obtained permission to leave the fairway and direct the towing unit to the port of Den Helder. The towing unit went to the indicated port of refuge. At dawn it was found that the ferry, apart from the heel, had also a significant trim on the bow.

At 6:25, the ferry under tow capsized and then at 7:40 sank at the depth of 20 m.

The Coast Guard, notified about the sinking of the vessel, ordered the master of the tugboat to remain in the place of sinking of the ferry. When at 8:30 the towline connecting the vessels was cut off, the *Ikar* tugboat anchored near the place where the ferry had sunk.

At 10:50, the Coast Guard officers came on board to take the deposition of the master and to check the documents.

At 13:05 the master was allowed to leave the area where the vessel under tow had sunk.

The *Ikar* tugboat entered the port of Gdynia on 4 May 2017 at 11:35.

5. Analysis and Comments about Factors Causing the Accident with Regard to Examination Results and Expert Opinions

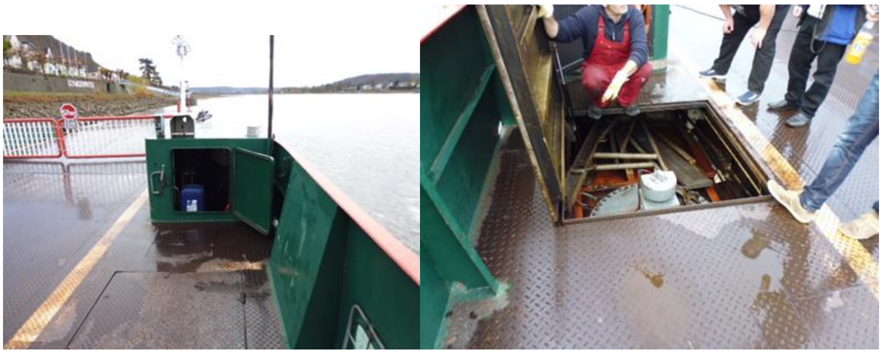
The *Siebengebirge* ferry was designed and built for navigation on closed waters and internal waters. Despite visible good technical condition there were noticeable spots of rust on that 46-year-old vessel. A part of the hull plating was made of 5 mm thick steel, which was adequate to operate the vessel on internal waters. It was not adapted to go out in the high sea.

The protection of external openings could only make them splash-proof but it did not prevent water from entering the internal spaces of the ferry through leaks.

The reason for capsizing and sinking of the ferry was flooding the watertight compartments at the bow and water coming to the deck in the forebody.

5.1. Mechanical Factors

Possible points of leakage of the ferry:



Photograph 5: Hatches to the engine compartment – on the starboard bow. Compartment No 3

Photograph 6: Hatches to the engine compartment – on the starboard bow. Compartment No 3

Photograph 7: Vents of the tanks/compartments

Photograph 8: Door to the superstructure – starboard. Sealing of the chain pipe. Compartment No 2

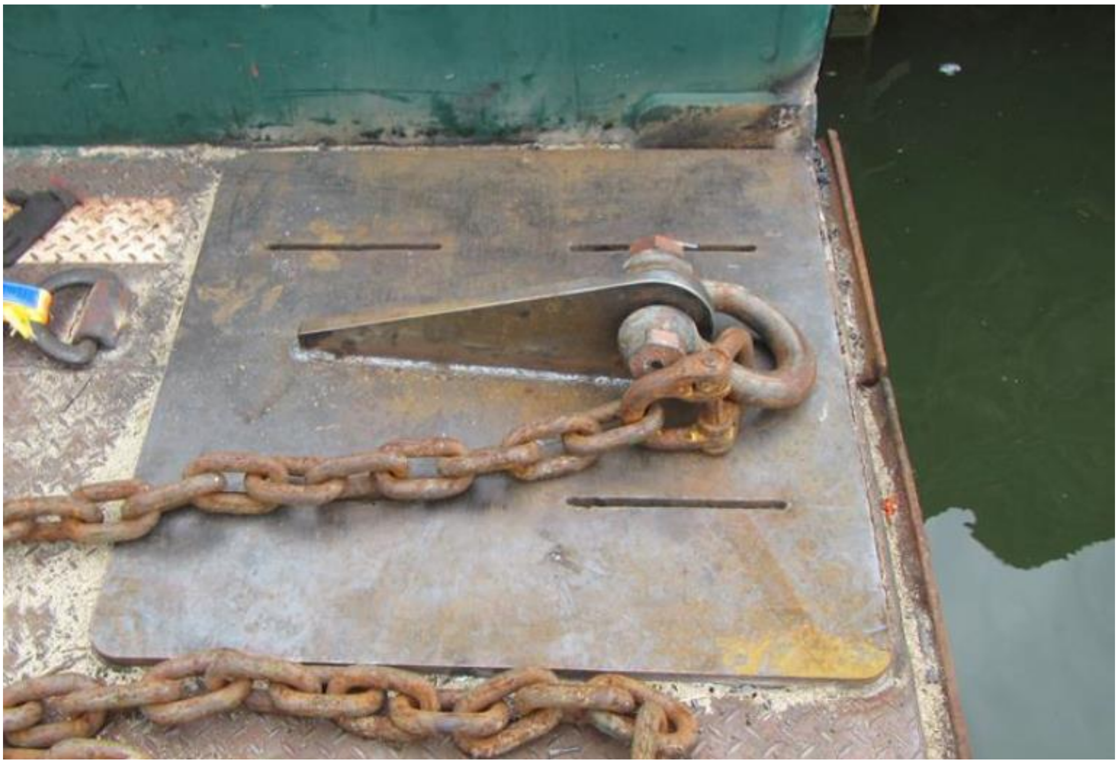
Photograph 9: Ferry's bow, front edge of the compartment No 1

The Commission reconstructed the scope of works performed by the Redwise company on the basis of a report prepared by the "IF" company for the insurer and information received from the tugboat's crew.

The presented documentation (mostly photographic) did not document work carried out inside the hull of the ferry and around its propellers. There is no information or photographs showing the condition of the watertight bulkheads of the ferry and the condition and preparation of Schottel propellers for planned towage. The maximum structural speed of the ferry was 5.36 knots, assuming that it was set by its own propulsion. In the case of towing at a higher speed, the force exerted on improperly secured propellers were greater than those assumed during the design of the vessel. This could damage the screws or columns of Schottel propellers and cause the loss of tightness of the hull.

According to the "Towage Approval Certificate" the recommended towing speed was set at 6 - 8 knots.

The chain bridles were made and installed by the Redwise company. Each of the bridles were constructed of a sheet approximately 20 mm thick and with approximate dimensions of 600 x 600 mm, to which an ear made of 20-25 mm thick steel was welded. All dimensions given above were estimated on the basis of photographic analysis.



Photograph 10: The chain bridle installed on the port side bow of „Siebengebirge" with the chain (the photograph taken by the representative of the insurer)

The Redwise company welded the bridles to the deck plating of the ferry at starboard and port side of the bow. Technical documentation or strength calculation of bridles has not been preserved. According to the information obtained from the master of *MT Ikar* such documentation had not been presented. Due to the lack of calculations, the representative of the insurer required carrying out load test from the master of *MT Ikar*. Each of the bridles was loaded with force of 19 tons acting almost horizontally. According to the information provided by the master of *MT Ikar*, the crew members who were at the tugboat's stern during the tests noticed that the deck of the ferry where the bridles were welded on was working hard (raising). When the tests were completed no damage on the deck was noticed, however, the inside of the pontoon was not inspected for any damage caused by the tests.

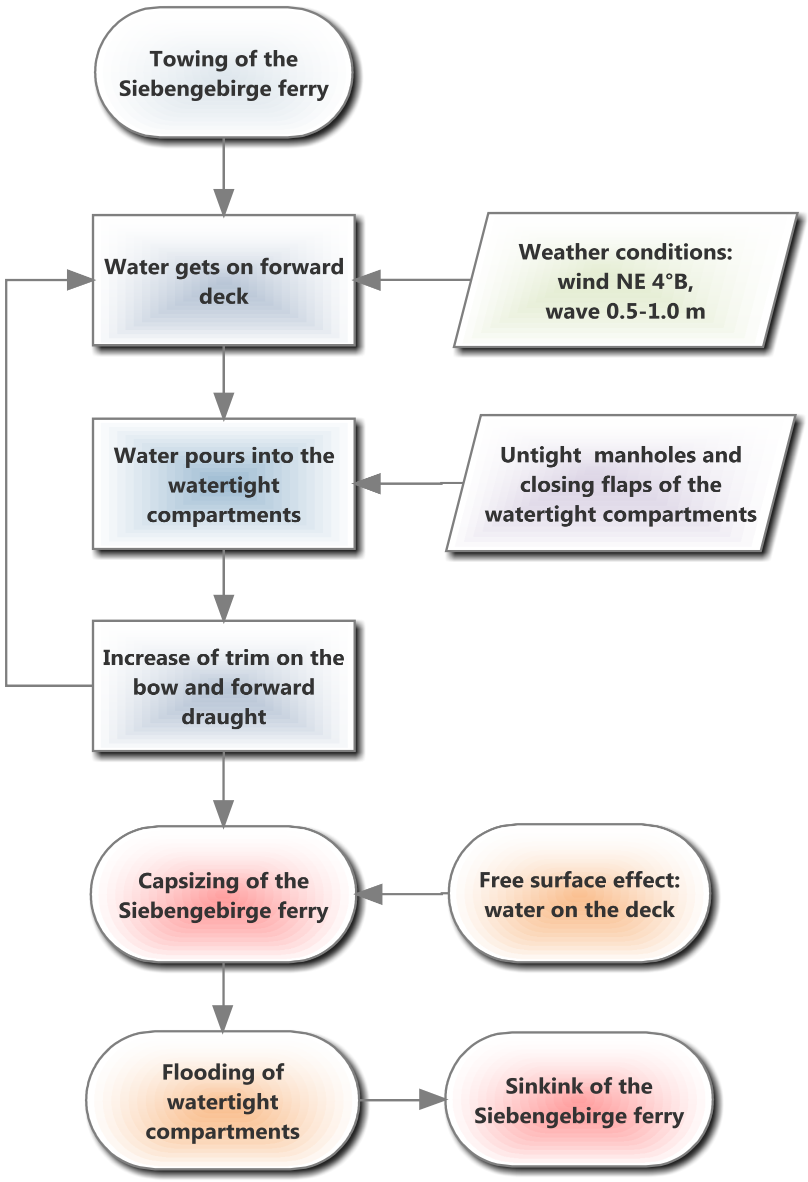


Figure 6: The „Siebengebirge"ferry's sinking scenario

5.2. Human Factors (faults and negligence)

During towage, a vessel of the size of *Siebengebirge* has resistance of 1.5 – 2.0 tons. These values were confirmed by the tugboat master, who was observing the forces on the elevator while towing. Testing of bridles with the force of 19 tons had not been justified.

The Redwise company with many years of experience, specializing in the preparation of vessels for voyages, including those without propulsion, offers comprehensive services for the delivery of vessels to their destination, including assistance in securing the necessary voyage documents.

Despite their extensive experience and access to the stability documents of the ferry, which were located on the bridge of the ferry under tow, the stability had not been checked before the voyage according to Intact Stability Code 2008 and the "delicate" nature of the vessel had not been taken into account. Its construction was a contraindication for transporting the ferry on the towline in sea waters.

Such conduct was inconsistent with the recommendations contained in the Circular MSC/Circ. 884 – "Guidelines for Safe Ocean Towing" [1] and in particular, described in section 13 of the Circular.

5.3. Organizational Factors

The towing unit did not have necessary documents to start the voyage. The „Towage Approval Certificate" received from the Al Mare Consulting AB company was insufficient to leave the port of Rotterdam and start the towage.

According to the information received from the representative of the Maritime Police[2] in Rotterdam, a towing unit intending to leave the port should report this fact to the Port Authority[3], which in such cases notifies the Dutch Shipping Inspectorate.[4] The task of the Shipping Inspectorate is to verify received documents and inspect the towing unit taking into account the recommendations of the Circular MSC/Circ. 884 – "Guidance For Safe Ocean Towing". After positive verification of the method of preparing the vessel and the entire towing unit, a permit to leave the port and start towing is issued.

5.4. Influence of External Factors on the Accident

The towing unit started the voyage with favorable weather conditions. While sailing in port waters, there was shifting wind of Beaufort 2 and slight undulation. After entering the high sea, the wind increased to Beaufort 4 blowing from the NE direction. The wave height was 0.5 - 1 m. There was no swell.

The height of the wave in the time preceding the accident was 1 - 1.5 m, which is the maximum value allowed by the "Towage Approval Certificate". Due to small freeboard and the resulting resistance wave, during towing at this wave height, water was coming on the ferry's deck and could get inside the hull.

[1] MSC/Circ.884 – "Guidelines for Safe Ocean Towing"
[2] Maritime Police, Central Unit, Infrastructure Division
[3] Port Authority
[4] Dutch Shipping Inspection

6. Description of Examination Findings Including the Identification of Safety Issues and Conclusions

Due to the lack of stability calculations of the ferry before the commencement of the towage and the necessity to conduct the analysis of the behavior of *Siebengebirge*, based on documents received from the former owner of the ferry, the Fahrgesellschaft Honnef Pool GmbH u.Co. KG company and with the help of the PolyCad 10.3 software, the calculations were made to simulate the course of the accident.

The following assumptions were made to simulate the capsizing and sinking of the ferry:

- The *Siebengebirge* ferry did not have any documents describing its stability, hydrostatic data and righting arms.
- Hydrostatic data were developed on the basis of dimensions given in the General Arrangement. Appendix 2.
- Hydrostatic parameters of the ferry were calculated on the basis of the PolyCad10.3 software.
- To simulate the accident, the trim of 0.00 m and the draught T = 0.81 m observed on the photographs (Figure 11) were assumed.
- The draught declared by the master of *Ikar*, T = 1.00 m was assumed to be incorrect.
- All calculations were made using standard methods used in assessing the parameters and stability of sea-going vessels.

At the same time, it was established that:

- There are discrepancies between the weight of the ferry defined during stability tests, 86.7 t and the hydrostatic curves, and the weight obtained from the model, 92.4 t for the same draught. The difference in weight is 5.7 t. The discrepancies may result from the inability to fully identify the shape of the hull underwater.
- The displacement of the ferry prepared for towing with a draft of 1 m read by the master of the tugboat should amount to approx. 118.2 t, whereas the displacement of the model, 123.9 t. Adoption of such a weight of the ferry would mean that there was some additional weight of 35 t inside the compartments.

- For the simulation, the draught observed in the photograph was taken (Figure 11).

Photograph 11: Ferry's freeboard: FB = 1.02 m

- From the observation of the photographs of the ferry leaving the port of Rotterdam, it appears that the freeboard amidships was about 1.02 m, so the ferry's immersion was 0.83 m. That was much less than the 1.0 m read by the master of *Ikar*.
- •No draught marks can be seen in any of the photographs obtained from the Al Mare Consulting AB company's report.
- This corresponds to the displacement of the ferry from the Stability Book. The weight of the empty ferry was 78 t as it results from stability tests, assuming a fuel weight of approx. 1.2 t, and the protective materials and the ship's constant of about 2 tons. Totally we get the weight of 81.2 t, which corresponds to the draught of 0.79 m in fresh water.

6.1. Simulation of the Accident

On the basis of the documentation received by the Commission, it was established that the ferry obtained the trim that caused the bow to immerse in water. The reason for this could be the following:

- water getting on the ferry's fore deck and staying for a certain period of time (there were only two drain holes on each side where the mooring bollards were located).
- Water entering the foremost watertight compartments No 1, 2 and 3 through on-board seals or/and through a leak in the bow.
- Protection made at the port of Rotterdam secured the closing devices against opening, but it did not increase the tightness of the secured hatches and doors.
- Water entering the compartment No 3 would cause trim by the head and heel on starboard side.

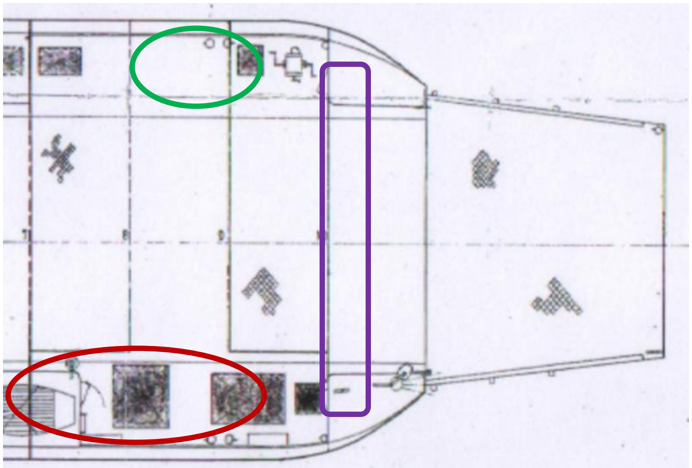


Figure 7: Hatches to the watertight compartment No 3 (red), No 2 (green) and the platform with the deck at the edge of the compartment No 1 (purple)

To analyze the behavior of the *Siebengebirge* ferry under tow, the following accident scenarios were assumed:

A. Ferry without trim.

The pontoon is tight.

a. Water enters the deck as a result of waving, pitching and the bow speed of the ferry.

B. Ferry without trim.

a. As a result of the lack of tightness water gets into the watertight compartments:
   i. third watertight compartment - water enters through leaky hatches,
   ii. first watertight compartment - water gets from the bow through leaky connection of the bow plating,
   iii. first and third watertight compartment - water gets through the leaky hatches,
   iv. water enters the first, second and third watertight compartment.

b. Water enters the deck due to rolling and pitching (Photograph 4).

Since it had been observed before the ferry capsized that it had been heeling on starboard side, in the simulation:

- initial flooding of compartment No 3 was assumed, as an asymmetrical one, which causes heeling on the starboard side.
- initial flooding of compartment No 1 was assumed.

- Initial flooding of a single compartment No 2 was omitted. Water flooding compartment No 2 would cause heeling on the port side.

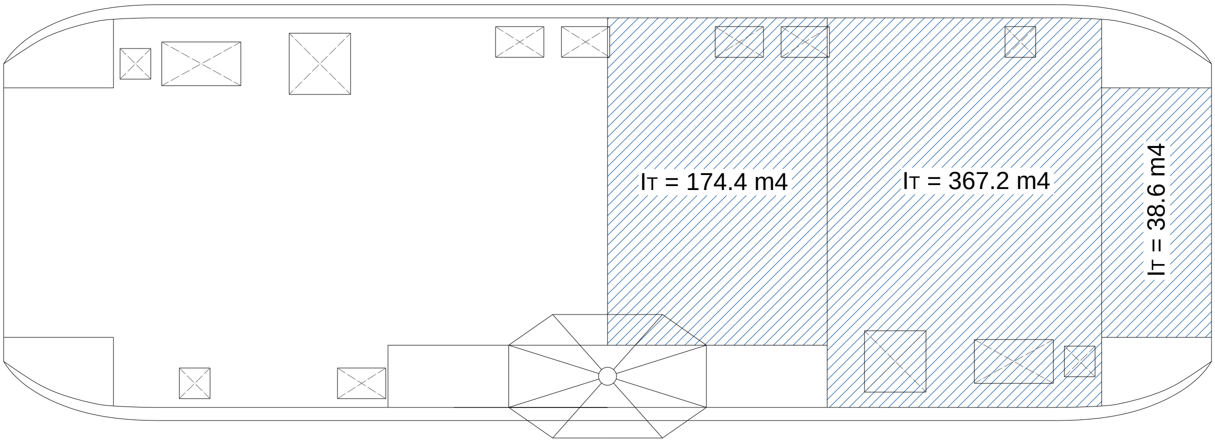


Figure 8: Water on deck of the ferry, moments of inertia of water surface

Water on deck accepted for simulation:

Level of water on deck:	hw = 0.30 m,
Mass of water on deck:	mw = 33 t,
Abscissa of the centre of mass of water:	xw =21.00 m,
Transverse position of the centre of mass of water:	yw = -0.25 m,
Height of the centre of mass of water:	zw = 2.05 m,
Transverse moment of inertia of water plane:	IT = 580.2 m4.

- The simulation did not take into account the influence of pitching and rolling on capsizing of the ferry.

Photograph 12: The „Siebengebirge'' ferry under tow. One can see the starboard

6.2. Stability of the *Siebengebirge* Ferry according to Intact Stability Code 2008

The stability of the *Siebengebirge* ferry had not been checked before the commencement of the voyage. In order to verify the stability of the ferry the criteria were checked according to the requirements of the Intact Stability Code (Appendix 1). Condition 1 undergoes checking.

Condition 1

- Ferry is ready for towing from the port of Rotterdam. Density of overboard water - 1.025 t/m^3.
- Ferry with no trim and tilt with platforms loaded on deck.
- Height of the centre of mass: 1.90 m taking into account the positioning of the platforms and protective material.

Table 1: Mass table. Ferry ready for towing

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50	0	16.50	1.80	0.00	
4	Water in compartment 1					0.00	0.00	0.00	
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3					0.00	0.00	0.00	
7	Water on deck					0.00	0.00	0.00	
8	Total	86.90	13.75	1.91	0.000	1194.88	165.83	0.00	0

Table 2: Parameters of the ferry. Condition 1 (1.025 t/m^3)

1	Mean draught	T	0.81	m
2	Trim	t	0.00	m
3	Draught on FP	TF	0.81	m
4	Draught on AP	TA	0.81	m
5	Freeboard	FB	1.04	m
6	Vertical center of gravity	z_G	1.91	m
7	Free surface correction	ΔGM	0.00	m
8	Vertical center of gravity corrected for free surf.	$z_{G'}$	1.91	m
9	Metacentric height	GM'	12.93	m
10	Ferry list	φ	0.0	°

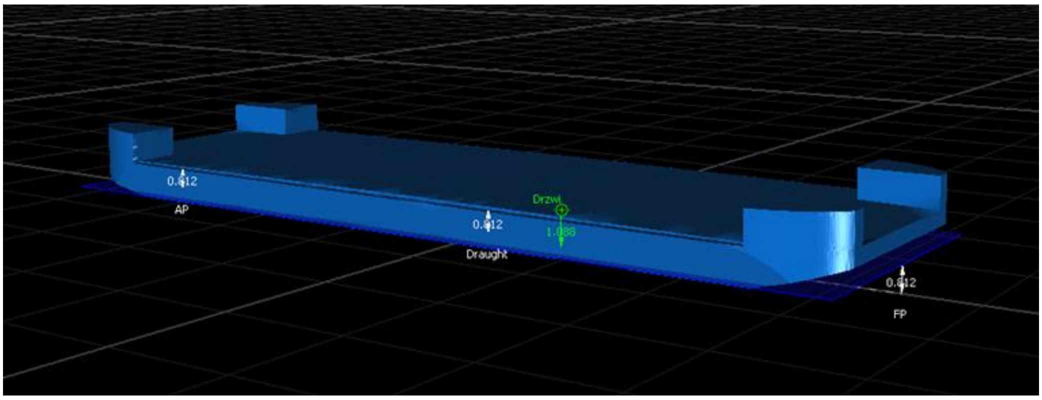


Figure 9: Position of the ferry in Condition 1

Table 3: Righting arms and the work of GZ. Condition 1

Angle of tilt φ [°]	GZ [m]	Work of GZ [m·rad]
0	0.000	0.000
5	1.012	0.044
10	1.614	0.159
15	1.994	0.316
20	2.213	0.500
25	2.286	0.696
30	2.252	0.894
35	2.158	1.087
40	2.013	1.269
50	1.618	1.586
60	1.136	1.826
70	0.596	1.977
80	0.023	2.031

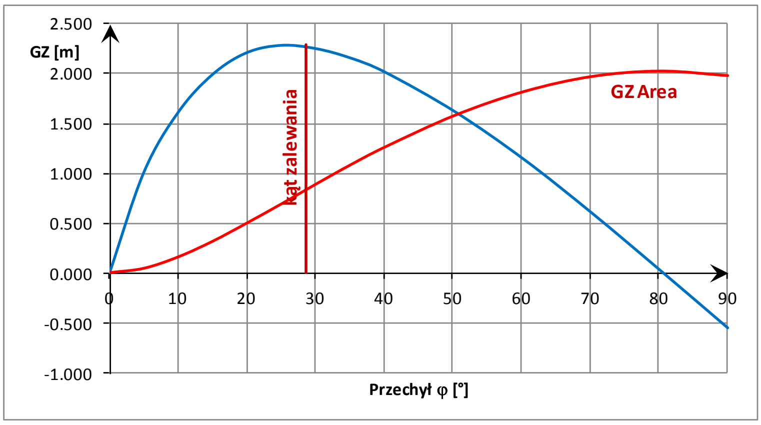


Figure 10: The diagram of righting arms

The *Siebengebirge* ferry as an inland navigation vessel was not obliged to fulfill the stability criteria for sea-going vessels.

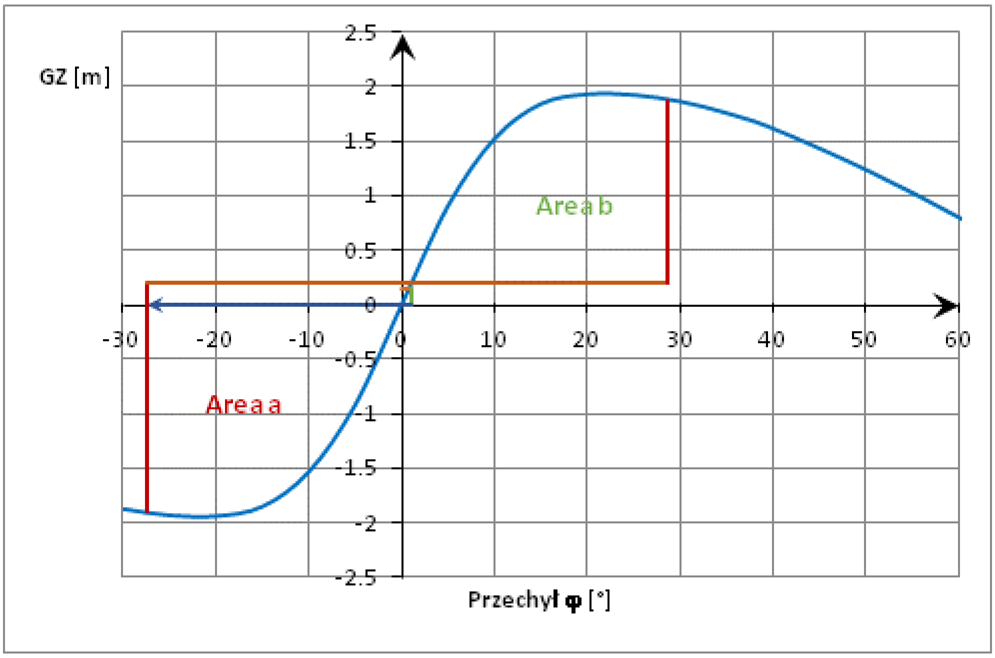


Figure 11: Weather criterion

No	Description	Required values	Achieved values	Criterion
1.	Area under the righting arms curve GZ, from 0° to 30°,	0.055 m·rad	0.815 m·rad	**Fulfilled**
2.	Area area under the righting arms curve GZ, from 0° to 40° (or the angle of flooding = 28°),	0.090 m·rad	0.815 m·rad	**Fulfilled**
3	Area under the righting arms curve GZ, from 30° to 40°(or the angle of flooding),	0.030 m·rad	Angle of flooding of 30° or more	**Unfulfilled**
4	For the angle of 30° or more, the righting arm GZ should be greater or equal to 0.20 m	0.20 m	2.252 m	**Fulfilled**
5	Maximum righting arm should appear for the angle not smaller than 15° for vessels where B/T ≥2.5 Surface area under the righting arms curve GZ, from 0° to $\varphi(GZ_{MAX})$,	15° 0.065 m·rad	25° 0.738 m·rad	**Fulfilled** **Fulfilled**
6	Corrected metacentric height GM' should be higher than 0.15 m	0.15 m	12.93 m	**Fulfilled**
7	Weather criterion: area b should not be smaller than area a: b≥a L_{w1} =0.133 m L_{w2} =0.199 m φ_1 = 28.8°	b≥a	a=0.889 m·rad b=0.776 m·rad	**Unfulfilled**
	Angle of static effect of wind φ0 should be smaller than 16° and 80% of the angle of the deck entering water	16° $0.8 \cdot \varphi_P$ 0.8·16°=12.8°	1° 1°	**Fulfilled**

Table 4: Stability criteria acc. To ICS'2008

Conclusions:

- The *Siebengebirge* ferry does not meet general criteria of the Stability Code IS2008.
- The criterion related to minimum work of the ferry's roll between 30° and 40° and the weather criterion developed for heavy seas are not met.
- Despite of the above, due to its stability, the ferry should be able to survive safely the voyage in existing weather conditions.

6.3. Simulation of Capsizing and Sinking of *Siebengebirge*

Condition 2

The ferry is loaded like in Condition 1. Additionally the mass of water of 33.0 t and 0.30 m high was added on board in the foresection. For calculation, it was assumed that water did not flow immediately overboard and it created free surface with maximum moment of 580.2 tm.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50	0	16.50	1.80	0.00	
4	Water in compartment 1					0.00	0.00	0.00	
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3					0.00	0.00	0.00	
7	Water on deck	33.00	21.00	2.05	-0.25	693.00	67.65	-1.70	580.2
8	Total	119.90	15.75	1.95	-0.014	1887.88	233.48	-1.70	580.2

Table 5: Mass table. Condition 2. Ferry under tow with water getting into the foresection of the deck

1	Mean draught	T	0.87	m
2	Trim	t	0.23	m
3	Draught on FP	TF	0.98	m
4	Draught on AP	TA	0.86	m
5	Freeboard	FB	0.87	m
6	Vertical center of gravity	z_G	1.93	m
7	Free surface correction	ΔGM	5.91	m
8	Vertical center of gravity corrected for free surf.	$z_{G'}$	8.07	m
9	Metacentric height	GM'	5.52	m
10	Ferry list	φ	0.0	°

Table 6: Parameters of the ferry. Condition 2

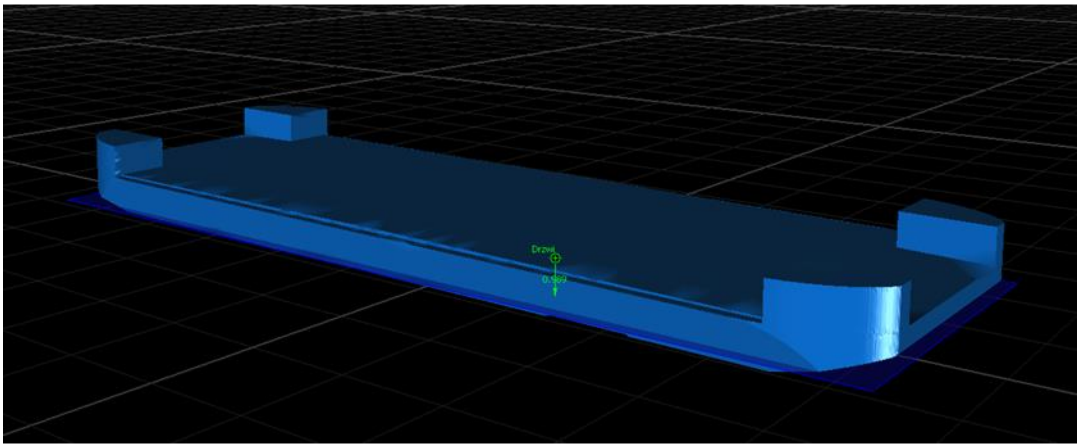


Figure 12: Position of the ferry in Condition 2

Table 7: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0.000	0.000
5	0.409	0.017
10	0.480	0.056
15	0.330	0.092
20	0.004	0.106
25	-0.443	0.087
30	-0.957	0.026
35	-1.508	
40	-2.077	
50	-3.226	
60	-4.315	
70	-5.284	
80	-6.097	

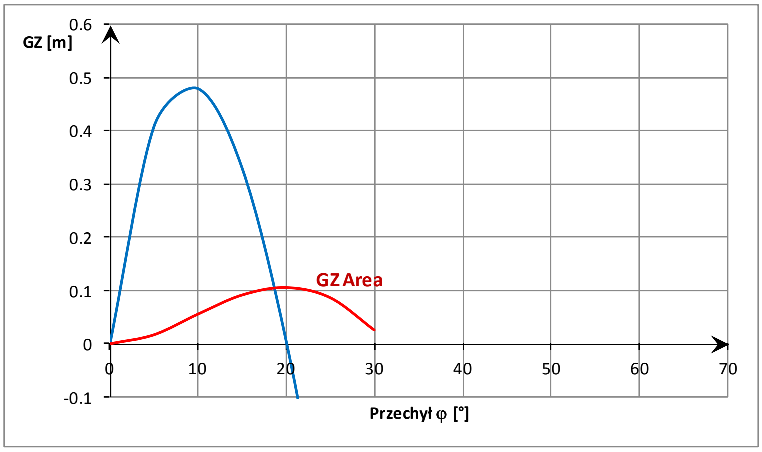


Figure 13: The diagram of righting arms

<u>Conclusions:</u>

- Due to water getting in the deck in the foresection, the metacentric height is diminished to 5.52 m, maximum righting arm diminishes to 0.48 m for 10° angle, whereas the range of righting arms diminishes to 20°.
- Despite the diminishment of the stability parameters, the ferry does not capsize in the weather conditions during towage.

Condition 3

In all Conditions No 3 it was assumed that water would get into the watertight compartments:

- Condition 3.1 – water in compartment 1 up to the height of 1.50 m.
- Condition 3.2 - water in compartment 3 up to the height of 1.50 m.
- Condition 3.3. - water in compartment 1 and 3 up to the height of 1.50 m.
- Condition 3.4. - water in compartment 1, 2 and 3 up to the height of 1.50 m.

In all Conditions No 3 water on deck was not taken into account.

Condition 3/1

- Flooded compartment No 1 up to the height of 1.50 m.
- There is a free surface of liquid in the compartment.
- Water does not appear on deck.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1	14.30	25.70	1.18	0	367.51	16.87	0.00	123
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3					0.00	0.00	0.00	
7	Water on deck					0.00	0.00	0.00	
8	Total	101.20	15.44	1.81	0.000	1562.39	182.70	0.00	123

Table 8: Mass table. Condition 3/1

1	Mean draught	T	0.87	m
2	Trim	t	0.47	m
3	Draught on FP	TF	1.11	m
4	Draught on AP	TA	0.64	m
5	Vertical center of gravity	z_G	1.81	m
6	Free surface correction	ΔGM	1.22	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	3.02	m
8	Metacentric height	GM'	10.33	m
9	Ferry list	φ	0.0	°

Table 9: Parameters of the ferry. Condition 3/1

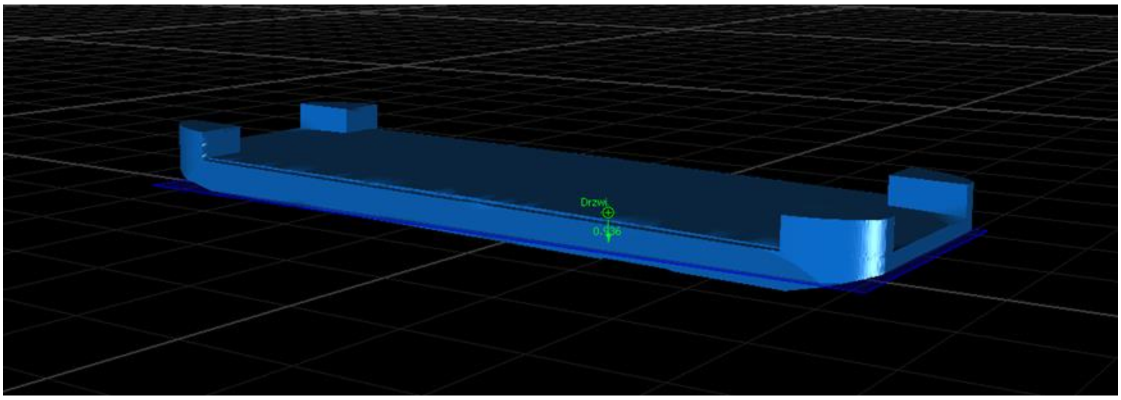


Figure 14: Position of the ferry in Condition 3/1

Table 10: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0.000	0.000
5	0.814	0.035
10	1.326	0.128
15	1.595	0.256
20	1.684	0.399
25	1.646	0.544
30	1.521	0.682
35	1.334	0.807
40	1.104	0.913
50	0.572	1.059
60	-0.003	1.109
70	-0.587	1.058
80	-1.158	0.905

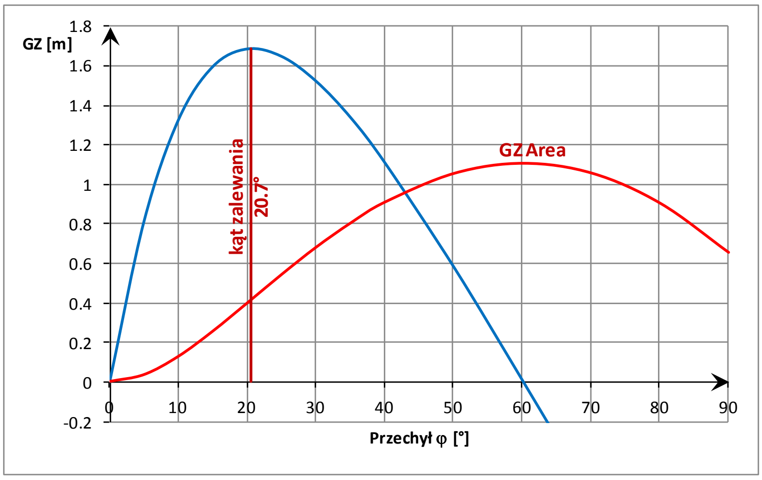


Figure 15: The diagram of righting arms

Conclusions:

- Due to flooding of compartment No 1 up to the height of 1.50 m, the ferry does not capsize.
- Ferry floats with no tilt.
- Foresection deck does not go into water.

Condition 3/2

- Flooded compartment No 1 up to the height of 1.50 m.
- There is a free surface of liquid in the compartment.
- Water does not appear on deck.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1					0.00	0.00	0.00	
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3	31.30	21.48	0.79	0.86	672.32	24.73	26.92	189
7	Water on deck					0.00	0.00	0.00	
8	Total	118.20	15.80	1.61	0.228	1867.20	190.56	26.92	189

Table 11: Mass table. Condition 3/2. Ferry with flooded compartment 3 up to 1.50 m

1	Mean draught	T	0.94	m
2	Trim	t	0.62	m
3	Draught on FP	TF	1.25	m
4	Draught on AP	TA	0.63	m
5	Vertical center of gravity	z_G	1.61	m
6	Free surface correction	ΔGM	1.60	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	3.21	m
8	Metacentric height	GM'	8.78	m
9	Ferry list	φ	1.4	°

Table 12: Parametres of the ferry. Condition 3/2

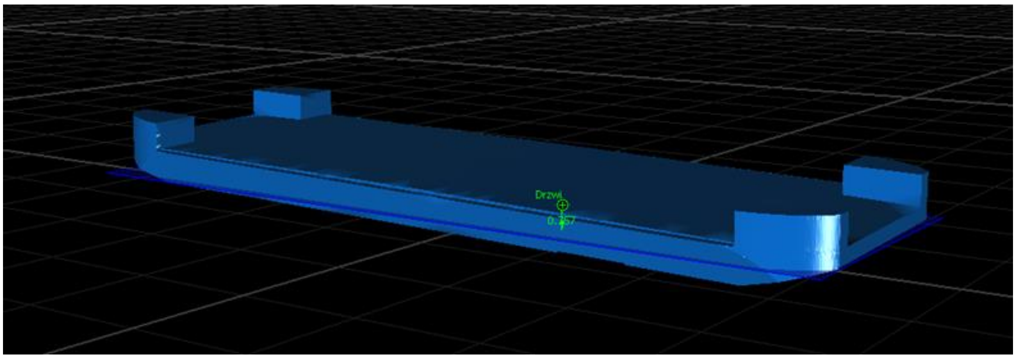


Figure 16: Position of the ferry in Condition 3/2

Table 13: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.220	0.003
5	0.510	0.016
10	1.005	0.082
15	1.227	0.179
20	1.270	0.288
25	1.199	0.396
30	1.044	0.494
35	0.835	0.576
40	0.600	0.638
50	0.090	0.699
60	-0.442	0.668
70	-0.965	0.545
80	-1.461	0.333

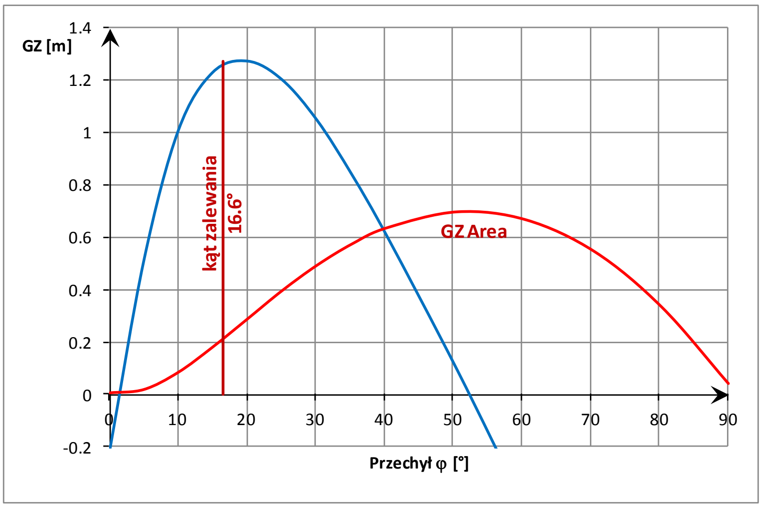


Figure 17: The diagram of righting arms

<u>Conclusions:</u>

- Due to flooding of compartment No 3 up to the height of 1.50 m, the ferry does not capsize.
- Ferry floats with 1.4° tilt on starboard side.
- Foresection deck does not get into water.

Condition 3/3

- Flooded compartments Nos 1 and 3 up to the height of 1.50 m.
- There is a free surface of liquid in both compartments.
- Water does not appear on deck.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1	14.30	25.70	1.18	0	367.51	16.87	0.00	123
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3	31.30	21.48	0.79	0.86	672.32	24.73	26.92	189
7	Water on deck					0.00	0.00	0.00	
8	Total	132.50	16.87	1.57	0.203	2234.71	207.43	26.92	312

Table 14: Mass table. Condition 3/3. Ferry with flooded compartments 1 and 3 up to 1.50 m

1	Mean draught	T	0.99	m
2	Trim	t	1.01	m
3	Draught on FP	TF	1.49	m
4	Draught on AP	TA	1.08	m
5	Vertical center of gravity	z_G	1.57	m
6	Free surface correction	ΔGM	2.35	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	3.92	m
8	Metacentric height	GM'	7.68	m
9	Ferry list	φ	1.6	°

Table 15: Parametres of the ferry. Condition 3/3

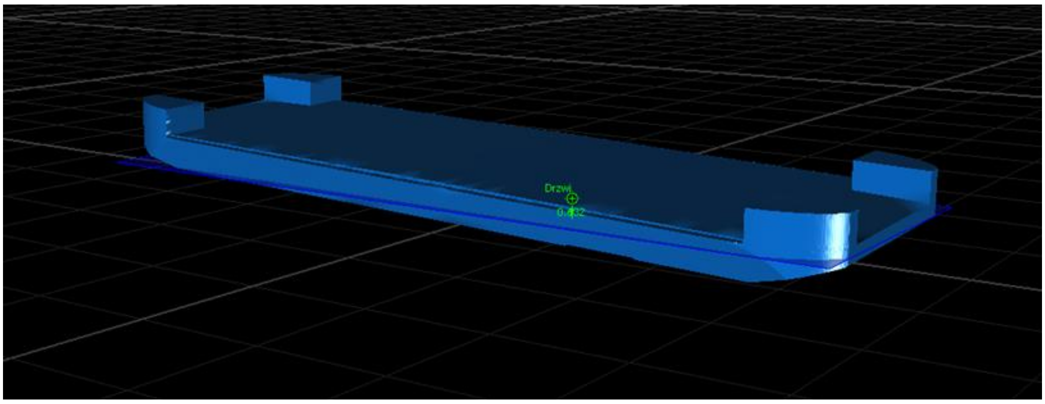


Figure 18: Position of the ferry in Condition 3/3

Table 16: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.217	0.004
5	0.352	0.009
10	0.737	0.057
15	0.842	0.126
20	0.789	0.197
25	0.608	0.258
30	0.369	0.301
35	0.101	0.321
40	-0.181	0.318
50	-0.757	0.236
60	-1.314	0.055
70	-1.824	-0.219
80	-2.276	

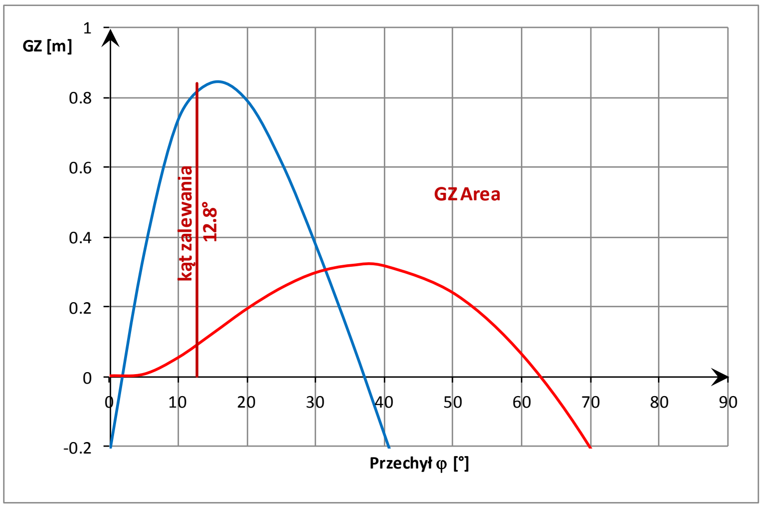


Figure 19: The diagram of righting arms

<u>Conclusions:</u>

- Due to flooding of compartments Nos 1 and 3 up to the height of 1.50 m, the ferry does not capsize.
- Ferry floats with 1.8° tilt on the starboard side.
- Foresection deck does not go into water.

Condition 3/4

- Flooded compartments Nos 1, 2 and 3 up to the height of 1.50 m.
- There is a free surface of liquid in all compartments.
- Water does not appear on deck.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1	14.30	25.70	1.18	0	367.51	16.87	0.00	123
5	Water in compartment 2	17.90	23.30	0.90	-0.80	417.07	16.11	-14.32	76
6	Water in compartment 3	31.30	21.48	0.79	0.86	672.32	24.73	26.92	189
7	Water on deck					0.00	0.00	0.00	
8	Total	150.40	17.63	1.49	0.084	2651.78	223.54	12.60	388

Table 17: Mass table. Ferry with flooded compartments 1, 2, and 3 up to 1.50 m. Condition 3/4

1	Mean draught	T	1.04	m
2	Trim	t	1.41	m
3	Draught on FP	TF	1.75	m
4	Draught on AP	TA	0.34	m
5	Vertical center of gravity	z_G	1.49	m
6	Free surface correction	ΔGM	2.58	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	4.07	m
8	Metacentric height	GM'	5.51	m
9	Ferry list	φ	1.0	°

Table 18: Parametres of the ferry. Condition 3/4

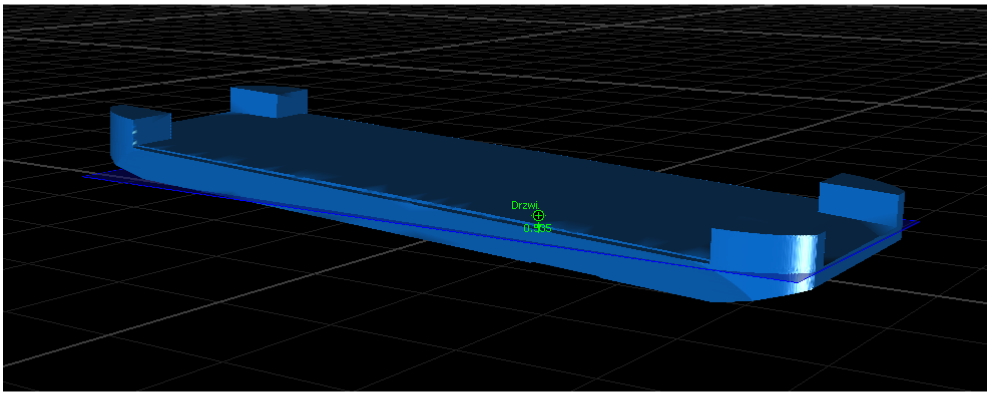


Figure 19: Righting arms and work of GZ

Table 20: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.101	0.001
5	0.353	0.012
10	0.601	0.054
15	0.634	0.107
20	0.476	0.156
25	0.247	0.187
30	-0.021	0.197
35	-0.307	0.183
40	-0.610	0.143
50	-1.180	-0.013
60	-1.690	-0.264
70	-2.141	-0.598
80	-2.528	-1.006

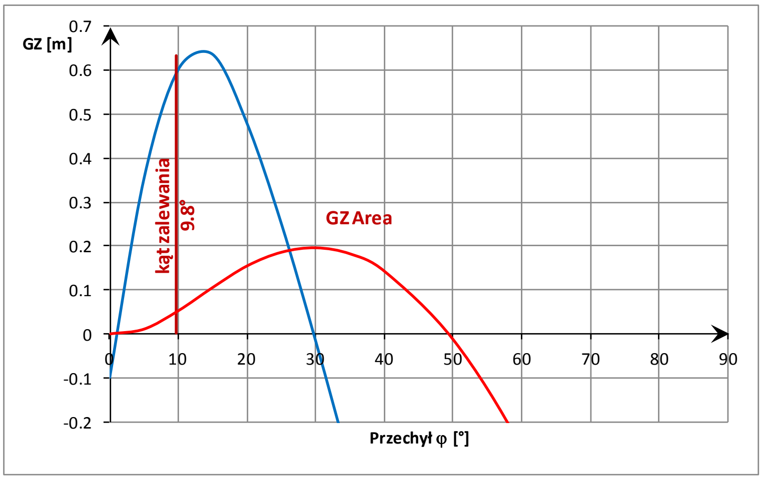


Figure 20: The diagram of righting arms

Conclusions:

- Due to flooding of compartments Nos 1 and 3 up to the height of 1.50 m, the ferry does not capsize.
- Ferry floats with 1.0° tilt on starboard side.
- Due to deep draught the foresection deck is very close to the waterline.

Condition 4

In all Conditions no 4 it was assumed that water would get into the watertight compartments and on deck in the foresection of the ferry:

- Condition 4.1 – water in compartment No 1 up to the height of 1.50 m, water on deck,
- Condition 4.2 - water in compartment No 3 up to the height of 1.50 m, water on deck,
- Condition 4.3 - water in compartment Nos 1 and 3 up to the height of 1.50 m, water on deck,
- Condition 4.4 - water in compartment Nos 1, 2 and 3 up to the height of 1.50 m.

Condition 4/4 was not checked because the ferry capsized in Condition 4/3.

Condition 4/1

- Flooded compartment 1 up to the height of 1.50 m.
- There is a free surface of liquid in compartment 1.
- Water appears on deck.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1	14.30	25.70	1.18	0	367.51	16.87	0.00	123
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3					0.00	0.00	0.00	
7	Water on deck	33.00	21.00	2.05	-0.25	693.00	67.65	-8.25	580.2
8	Total	134.20	16.81	1.87	-0.061	2255.39	250.35	-8.25	703.2

Table 21: Mass table. Condition 4/1. Ferry with flooded compartments 1 and 3 up to 1.50 m

1	Mean draught	T	1.00	m
2	Trim	t	1.03	m
3	Draught on FP	TF	1.51	m
4	Draught on AP	TA	0.48	m
5	Vertical center of gravity	z_G	1.87	m
6	Free surface correction	ΔGM	5.24	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	7.11	m
8	Metacentric height	GM'	3.85	m
9	Ferry list	φ	-0.8	°

Table 22: Parametres of the ferry. 4/1 Condition

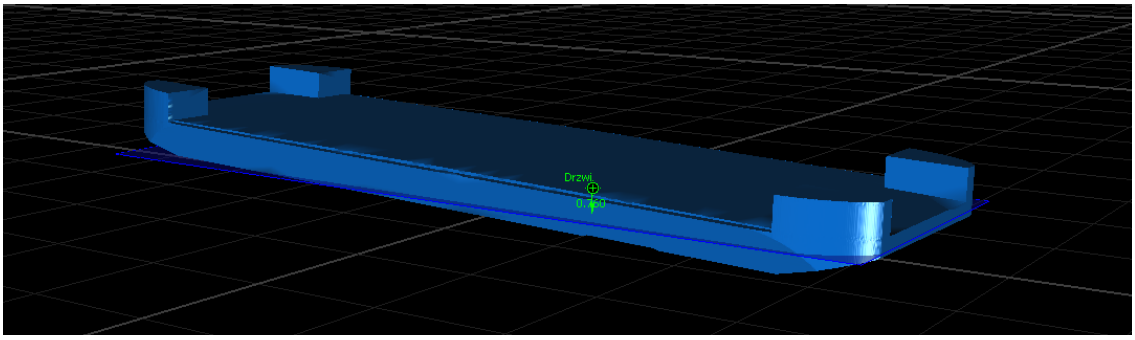


Figure 21: Position of the ferry in Condition 4/1

Table 23: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0.047	0.000
5	0.327	0.017
10	0.422	0.049
15	0.239	0.078
20	-0.111	0.084
25	-0.578	0.054
30	-1.088	-0.019
35	-1.615	-0.137
40	-2.14	-0.301
50	-3.136	-0.761
60	-4.032	-1.387
70	-4.786	-2.156
80	-5.395	-3.045

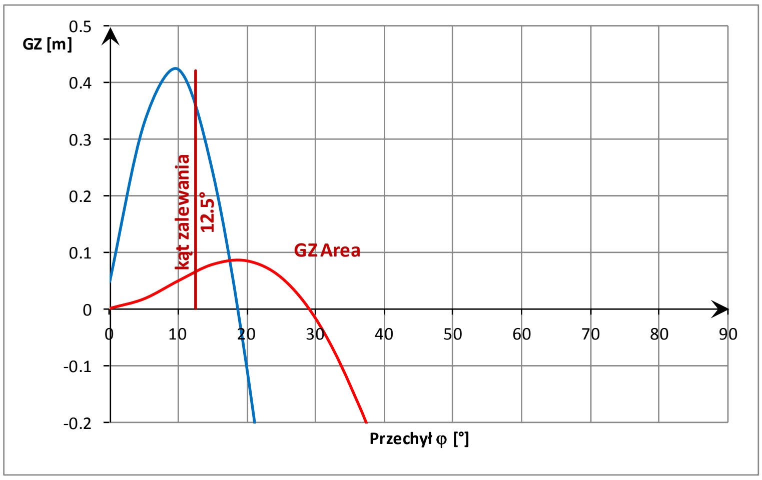


Figure 22: The diagram of righting arms

<u>Conclusions:</u>

- Due to flooding of compartment No 1 up to the height of 1.50 m and water on deck, the ferry does not capsize.
- Ferry floats with 0.8° tilt on the port side.
- Foresection deck does not go into water.

Condition 4/2

- Flooded compartment No 1 up to the height of 1.50 m.
- There is a free surface of liquid in compartment No 3.
- Water appears on deck.

No	Opis	Masa	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1					0.00	0.00	0.00	
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3	31.30	21.48	0.79	0.86	672.32	24.73	26.92	189
7	Water on deck	33.00	21.00	2.05	-0.25	693.00	67.65	-8.25	580.2
8	Total	151.20	16.93	1.71	0.123	2560.20	258.21	18.67	769.2

Table 24: Mass table. Condition 4/2. Ferry with flooded compartment 3 up to 1.50 m and water on deck of 33 t

1	Mean draught	T	1.06	m
2	Trim	t	1.19	m
3	Draught on FP	TF	1.65	m
4	Draught on AP	TA	0.46	m
5	Vertical center of gravity	z_G	1.71	m
6	Free surface correction	ΔGM	5.09	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	6.80	m
8	Metacentric height	GM'	2.92	m
9	Ferry list	φ	2.5	°

Table 25: Parametres of the ferry. Condition 4/2

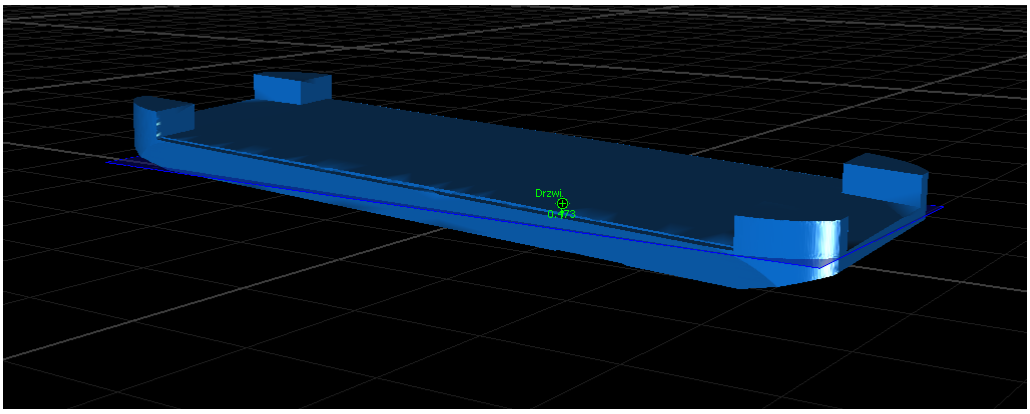


Figure 23: Position of the ferry in Condition 4/2

Table 26: Righting arms and work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.132	0.000
5	0.116	0.002
10	0.170	0.015
15	-0.019	0.021
20	-0.406	0.003
25	-0.862	-0.052
30	-1.340	-0.149
35	-1.836	-0.287
40	-2.325	-0.469
50	-3.239	-0.954
60	-4.026	-1.588
70	-4.674	-2.347
80	-5.522	-0.577

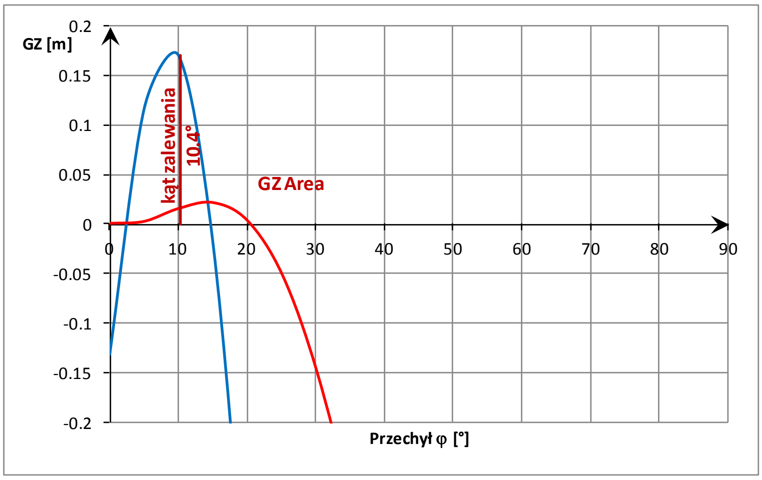


Figure 24: The diagram of righting arms

<u>Conclusions:</u>

- Due to flooding of compartment No 3 up to the height of 1.50 m and water on deck, the ferry does not capsize.
- Righting arms diminish to maximum value of 0.17 m for 10° angle.
- Ferry is floating with 2.5° tilt on starboard side.
- Foresection deck does not go into water.

Condition 4/3

- Flooded compartments Nos 1 and 3 up to the height of 1.50 m.
- There is free surface of liquid in both compartments.
- Water floods the deck.

No	Description	Mass	x	z	y	Mx	Mz	My	FSM
1	Ferry	83.70	13.75	1.90	0	1150.88	159.03	0.00	
2	Protective material	2.00	13.75	2.50	0	27.50	5.00	0.00	
3	Fuel	1.20	13.75	1.50		16.50	1.80	0.00	
4	Water in compartment 1	14.30	25.70	1.18	0	367.51	16.87	0.00	123
5	Water in compartment 2					0.00	0.00	0.00	
6	Water in compartment 3	31.30	21.48	0.79	0.86	672.32	24.73	26.92	189
7	Water on deck	33.00	21.00	2.05	-0.25	693.00	67.65	-8.25	580.2
8	Total	165.50	17.69	1.66	0.113	2927.71	275.08	18.67	892.2

Table 27: Mass table. Condition 4/3. Ferry with flooded compartments 1 and 3 up to 1.50 m and water of 33 t on deck

1	Mean draught	T	-1.30	m
2	Trim	t	1.22	m
3	Draught on FP	TF	-0.69	m
4	Draught on AP	TA	-1.91	m
5	Vertical center of gravity	z_G	1.04	m
6	Free surface correction	ΔGM	1.66	m
7	Vertical center of gravity corrected for free surf.	$z_{G'}$	5.39	m
8	Metacentric height	GM'	7.05	m
9	Ferry list	φ	6.80	m
1	Mean draught	T	179.6	°

Table 28: Parametres of the ferry. Condition 4/3

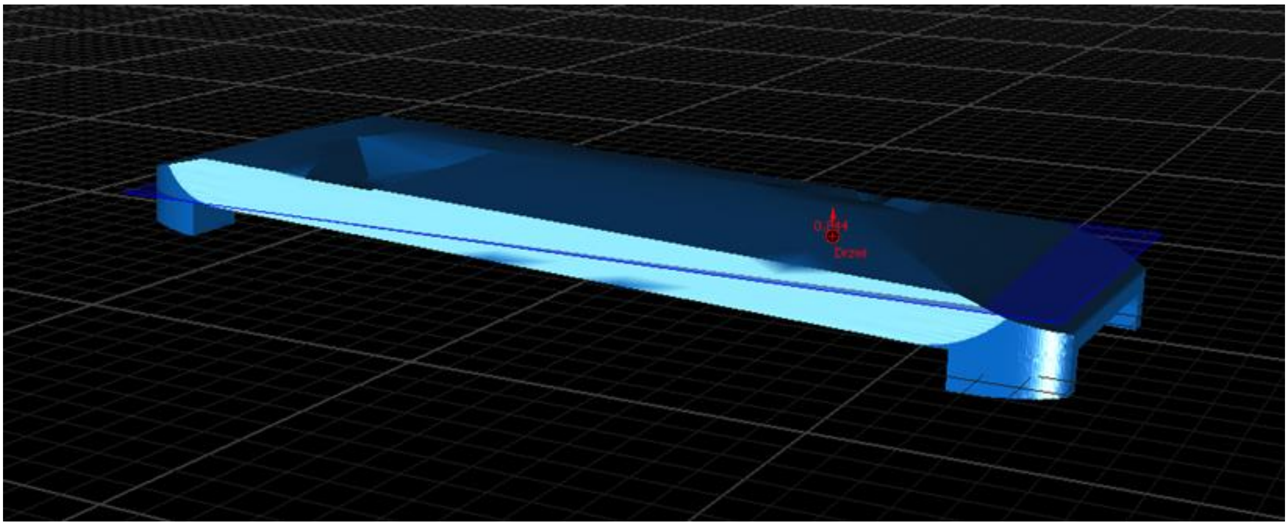


Figure 25: Position of the ferry in Condition 4/3

Table 29: Righting arms and the work of GZ

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.128	0.004
5	-0.013	0.009
10	-0.109	0.057
15	-0.438	0.126
20	-0.905	0.197
25	-1.429	0.258
30	-1.979	0.301
35	-2.510	0.321
40	-2.997	0.318
50	-3.869	0.236
60	-4.560	0.055
70	-5.102	-0.219
80	-5.522	-0.577

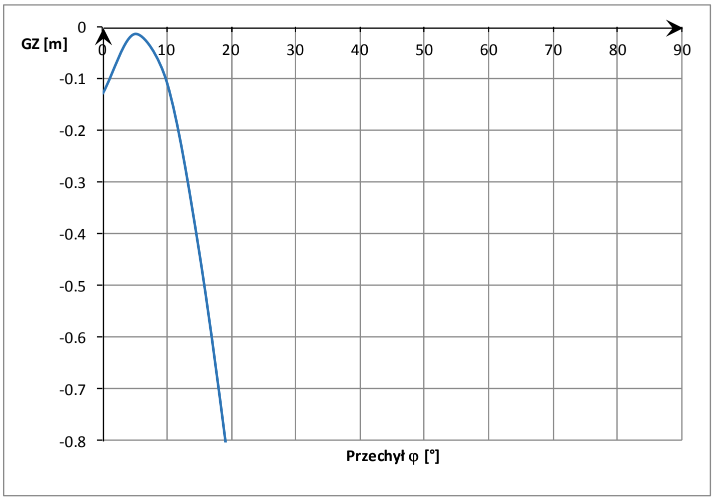


Figure 26: The diagram of righting arms

<u>Conclusions:</u>

- Due to flooding of compartments Nos 1 and 3 up to the height of 1.50 m and water on deck, the ferry capsizes.
- With initial tightness of compartments ferry did not lose its buoyancy.
- Ferry is floating with 179.6° tilt on starboard side.

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6.4. Sequence of Capsizing and Sinking of *Siebengebirge*

On the basis of existing photographs of the ferry during capsizing and sinking, its trim, draught, tilt and buoyancy were being adjusted during simulation.

Photograph 13: The „Siebengebirge" ferry with the bow under water. The photograph presents the stern – portside of the ferry. One can see the outflow of water from the deck (http://www.general-anzeiger-bonn.de)

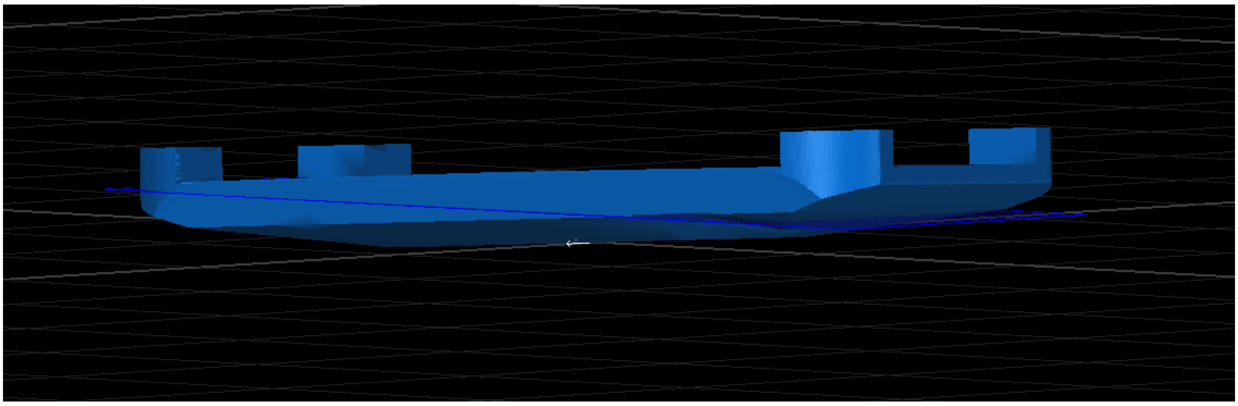


Figure 27: Simulation of the position of the ferry for the displacement of 165 t. Condition 4/3

Photograph 14: Capsized „Siebengebirge”. One can see the stern and portside of the ferry (http:// www.eyes.org/news/sos_1704.html)

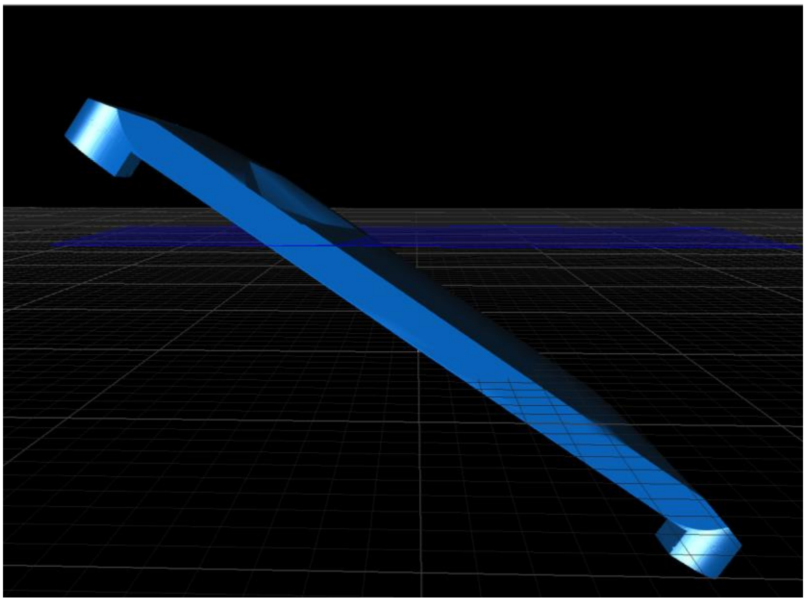


Figure 28: Simulation of the buoyancy of the capsized ferry. Displacement ca 260 t

Photograph 15: Capsized „Siebengebirge". One can see the stern and portside of the ferry (http:www.eyes.org/news/sos_1704.html)

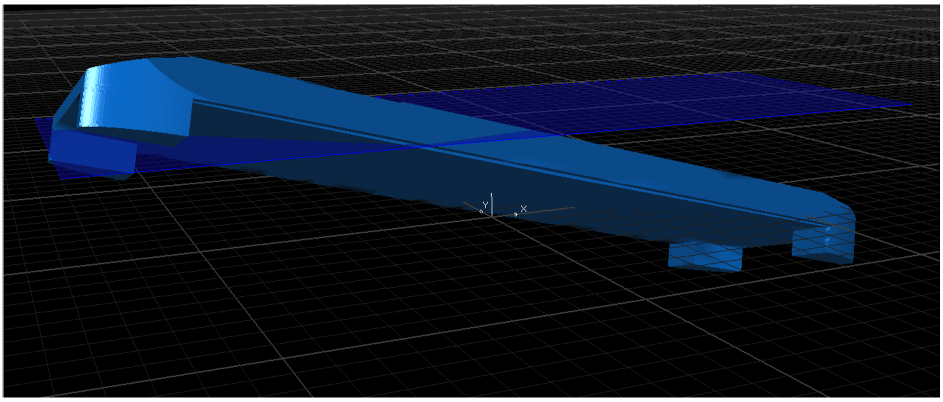
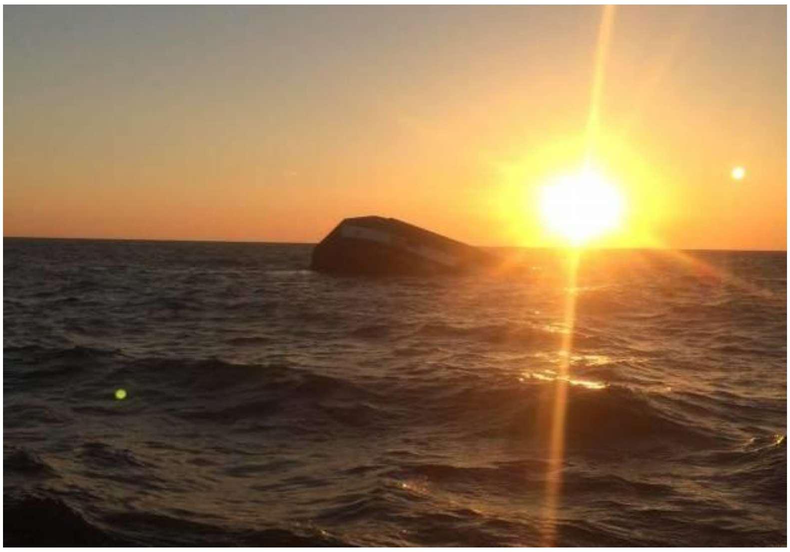


Figure 29: Simulation of the buoyancy of the capsized ferry. Displacement ca 300 t



Photograph 16: Capsized „Siebengebirge". One can see the stern and portside of the ferry (http://general-anzeiger-bonn.de)

6.5. Conclusions from the Analysis

- The protection of the *Siebengebirge* ferry against the ingress of water into the watertight compartments was not effective. This is evidenced by the increasing draught on the bow and the ingress of water on deck (Photograph 4) and the depositions of the crew.

- Flooding the deck with water (33 t) without unsealing the closures could not have led to capsizing of the ferry (Condition 2).

- Water could have also got through the leaky part of the bow at the point of dismantling the platform. The wave created on the bow during towing and additionally wavy motion of the sea could have resulted in the bow getting into water, which could have caused flooding of the watertight compartment No 1.

- When flooding the foresection of the deck, water could have entered the bow watertight compartments Nos 1, 2 and 3 (see Fig. 8).

- Flooding of a single watertight compartment No 1 or No 3, including water on deck, could not have led to capsizing of the ferry (Condition 3/1 and Condition 3/2).

- As the tugboat crew observed, the ferry had an increased draught on the bow and tilt on starboard side, which means that originally the unsymmetrical compartment No 3 (Condition 3/2) had been flooded.

- Flooding of three watertight compartments Nos 1, 2 and 3 without the ingress of water on deck could not have led to capsizing of the ferry (Condition 3/4).

- **Flooding of two watertight compartments: No 1 (14.3 t) and No 3 (31.3 t) and the ingress of water on deck (33 t) causes the ferry to capsize (Condition 4/3).**

- Flooding of more compartments and water on deck always results in capsizing of the ferry.

- After capsizing the ferry loses buoyancy and sinks. This means that closing devices of hatches and vents of watertight compartments were not tight (time of getting water until the loss of buoyancy is 1 hour 15 min).

Loss of buoyancy occurs after reaching the displacement of 351 t.

7. Safety Recommendations

The Condition Marine Accident Investigation Commission has found it justified to refer safety recommendations, which are proposals for actions that may contribute to the prevention of similar accidents in the future, to:

7.1. Operator of *Ikar*

It is the responsibility of the tugboat operator to prepare instructions for the tugboat master that contain requirements for having the necessary documents before towing. The ship's agent appointed by the operator should have been required to present the regulations binding in the port of Rotterdam related to obtaining permission to start towing. The knowledge of the role of individual entities involved in the process of preparing a towing unit to start the voyage would let them avoid treating the document issued by the subcontractor of the insurance company as a document authorizing the commencement of towage.

8. List of Photographs

9. List of Figures

10. List of Tables

11. Information Sources

Notification of the accident
Documents of the tugboat and ferry
Depositions of witnesses
Information received from the Marine Police of the port of Rotterdam
Information and documents received from Fahrgesellschaft Honnef Pool GmbH u. Co. KG
Expert opinion of Captain Mariusz Łapiński
Information included in the report of the Al. Mare Consulting AB company

12. Composition of the Investigative Team

The team conducting the examination was composed of:
the team leader: Marek Szymankiewicz – the Secretary of the SMAIC,
the team member: Monika Hapanionek– the member of the SMAIC,
the team member: Jarosław Soliwoda – the expert of the SMAIC.

13. Appendices

Appendix 1. Requirements of the Intact Stability Code 2008

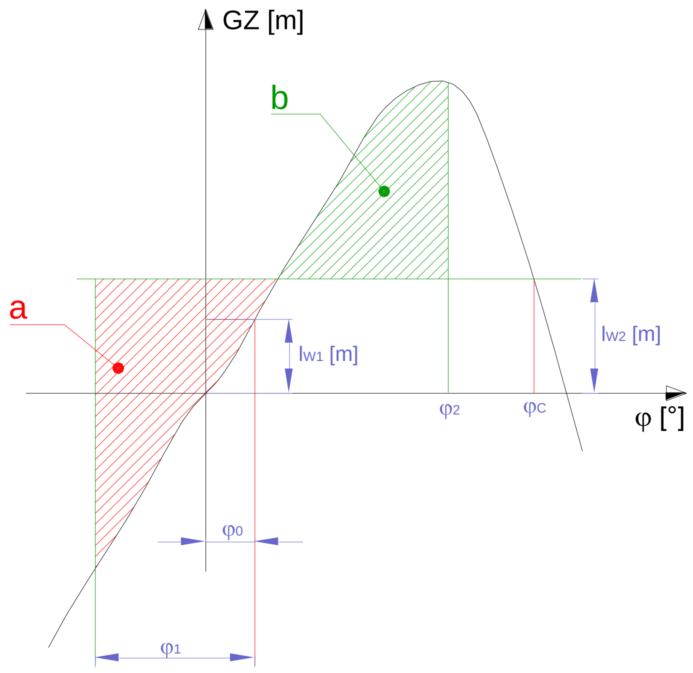
Criteria ISC'2008 for vessels with a length greater than or equal to 24 m.

1. The vessel should navigate without heel.
2. Surface area under the static stability curve, from 0° to 30° should be greater than 0.055 m rad (the value of this field corresponds to the value of the dynamic arm at 30°).
3. Surface area under the static stability curve, from 0° to 40° (or the angle of flooding), should be greater than 0.090 m rad (the value of this field corresponds to the value of the dynamic arm at 40°).
4. Surface area under the static stability curve, from 30° to 40° (or the angle of flooding), should be greater than 0.030 m rad (this field is a difference between the field of 0° - 40° and the field of 0° - 30°).
5. For an angle of 30° or more, the righting arm should be greater than or equal to 0.20 m.
6. The maximum righting arm should occur at an angle of not less than 25°.
7. Weather

   Area b should not be smaller than area a: b≥a

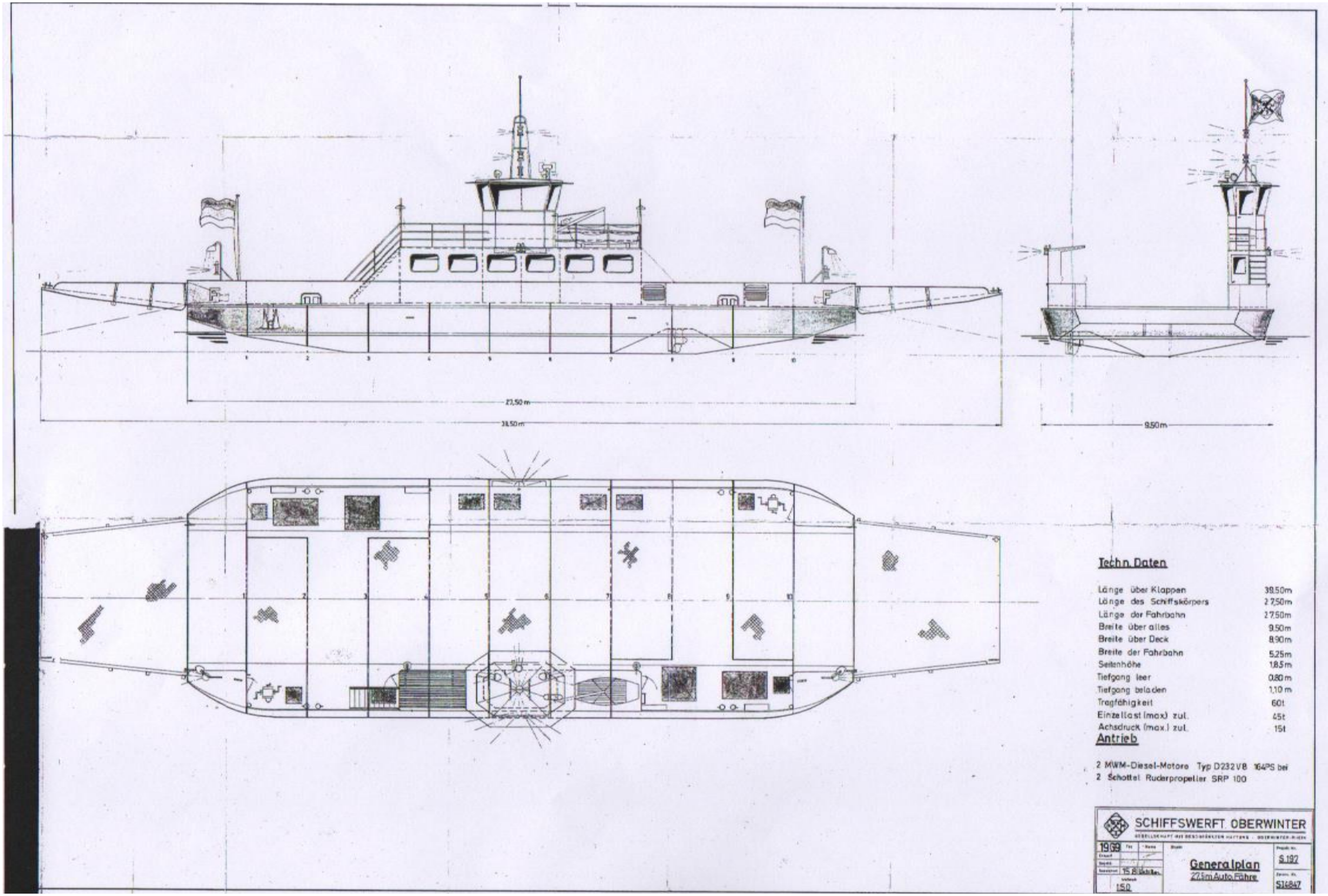
   Lw1 - arm of static effect of wind

   Lw2 – arm of dynamic effect of wind action = 1.5 × Lw1

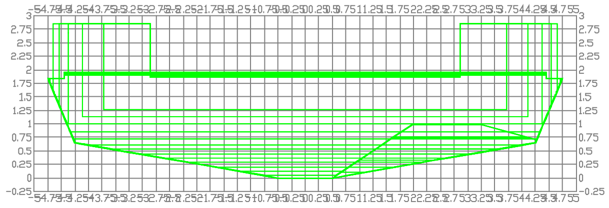


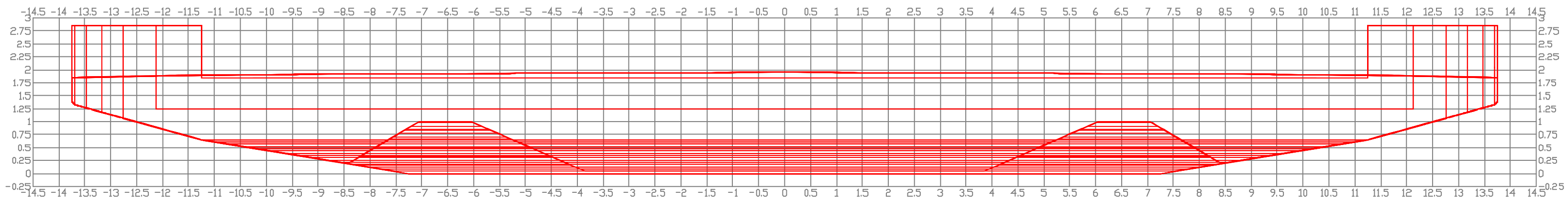
Weather criterion

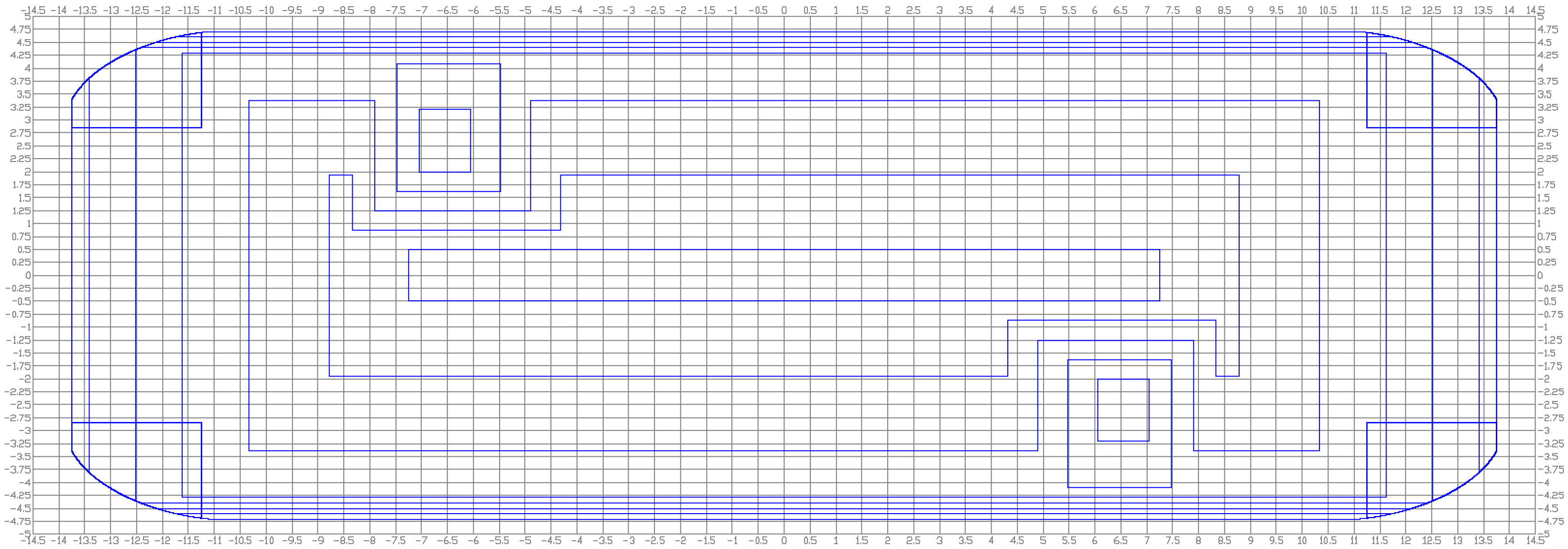
Appendix 2. General scheme of the *Siebengebirge* ferry



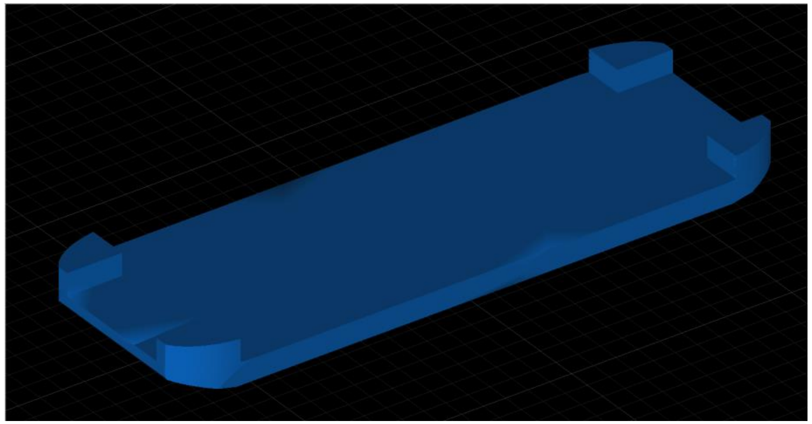
Appendix 3. Body lines of the *Siebengebirge* ferry







Appendix 4. Hydrostatic data of the *Siebengebirge* ferry



Abbreviations:

T [m] - mean draught,
Disp. [t] - displacement for water with density of 1.000 t/m^3,
Vol. [m^3] - volume of the underwater body,
LCB [m] - longitudinal centre of buoyancy from ⊗,
VCB [m] - height of the centre of buoyancy from BP,
KMT [m] - height of the transverse metacentre from BP,
WPA [m^2] - water plane area,
LCF [m] - longitudinal centre of flotation,
TPC [t/cm] - increase in displacement per 1 cm of draught,
Cb [-] - block coefficient of the hull,
Cwp [-] - water plane coefficient,
BMT [m] - transverse metacentric radius,
BML [m] - longitudinal metacentric radius,
MCT [tm/cm] - moment to change trim by 1 cm.

T	Disp	Volume	LCB	VCB	KMT	WPA	LCF	TPC	Cb	Cwp	BMT	BML	MCT
[m]	[t]	[m^3]	[m]	[m]	[m]	[m2]	[m]	[t/cm]	[-]	[-]	[m]	[m]	[tm/cm]
0.60	47.3	46.1	0	0.394	17.387	156.95	0	1.61	0.443	0.905	16.993	134.051	2.905
0.61	48.9	47.7	0	0.401	17.604	159.70	0	1.64	0.442	0.903	17.203	132.594	2.957
0.62	50.6	49.4	0	0.409	18.379	165.87	0	1.70	0.442	0.919	17.970	132.963	3.051
0.63	52.4	51.1	0	0.416	18.593	168.71	0	1.73	0.441	0.917	18.177	131.498	3.104
0.64	54.0	52.7	0	0.422	19.239	175.12	0	1.79	0.439	0.934	18.817	138.793	3.363
0.65	55.9	54.5	0	0.429	19.444	177.98	0	1.82	0.439	0.933	19.015	137.168	3.424
0.66	57.7	56.3	0	0.437	18.965	178.83	0	1.83	0.445	0.933	18.528	134.330	3.451
0.67	59.6	58.1	0	0.444	18.528	179.83	0	1.84	0.450	0.933	18.084	131.972	3.487

0.68	61.4	59.9	0	0.451	18.130	180.97	0	1.85	0.455	0.935	17.679	130.059	3.531
0.69	63.3	61.8	0	0.458	17.758	182.15	0	1.87	0.460	0.937	17.300	128.334	3.578
0.70	65.2	63.6	0	0.465	17.380	183.00	0	1.88	0.465	0.937	16.915	126.088	3.608
0.71	67.1	65.4	0	0.472	17.071	184.04	0	1.89	0.470	0.939	16.600	124.082	3.642
0.72	68.9	67.3	0	0.478	16.777	185.08	0	1.90	0.474	0.940	16.299	122.174	3.676
0.73	70.9	69.1	0	0.485	16.636	187.22	0	1.92	0.479	0.947	16.151	121.245	3.737
0.74	72.8	71.0	0	0.491	16.356	188.24	0	1.93	0.483	0.948	15.865	119.451	3.770
0.75	74.8	73.0	0	0.498	16.066	189.26	0	1.94	0.488	0.949	15.568	117.567	3.804
0.76	76.8	74.9	0	0.505	15.810	190.29	0	1.95	0.492	0.951	15.305	115.928	3.837
0.77	78.7	76.8	0	0.511	15.564	191.31	0	1.96	0.496	0.952	15.053	114.365	3.871
0.78	80.7	78.7	0	0.518	15.329	192.34	0	1.97	0.500	0.953	14.811	112.872	3.904
0.79	82.7	80.7	0	0.524	15.103	193.36	0	1.98	0.504	0.954	14.579	111.446	3.938
0.80	84.7	82.6	0	0.530	15.077	196.29	0	2.01	0.508	0.965	14.546	110.798	3.998
0.81	86.6	84.4	0	0.537	14.882	197.28	0	2.02	0.510	0.966	14.345	109.640	4.031
0.82	88.6	86.4	0	0.543	14.668	198.26	0	2.03	0.514	0.967	14.125	108.331	4.064
0.83	90.6	88.4	0	0.549	14.463	199.25	0	2.04	0.517	0.968	13.914	107.077	4.098
0.84	92.7	90.4	0	0.556	14.266	200.24	0	2.05	0.521	0.969	13.710	105.875	4.132
0.85	94.7	92.4	0	0.562	14.076	201.23	0	2.06	0.524	0.970	13.514	104.722	4.165
0.86	96.8	94.5	0	0.568	13.960	203.04	0	2.08	0.527	0.974	13.392	104.072	4.218
0.87	99.0	96.6	0	0.574	13.764	204.01	0	2.09	0.531	0.975	13.190	102.869	4.251
0.88	101.1	98.6	0	0.581	13.591	204.98	0	2.10	0.534	0.976	13.010	101.826	4.285
0.89	103.2	100.7	0	0.587	13.423	205.96	0	2.11	0.537	0.977	12.836	100.823	4.319
0.90	105.3	102.8	0	0.593	13.261	206.93	0	2.12	0.539	0.977	12.668	99.857	4.352

0.91	107.5	104.8	0	0.599	13.105	207.90	0	2.13	0.542	0.978	12.506	98.927	4.386
0.92	109.6	106.9	0	0.605	12.954	208.88	0	2.14	0.545	0.979	12.349	98.031	4.420
0.93	111.7	109.0	0	0.612	12.808	209.86	0	2.15	0.547	0.980	12.196	97.167	4.454
0.94	113.9	111.1	0	0.618	12.666	210.84	0	2.16	0.550	0.980	12.049	96.333	4.489
0.95	116.1	113.2	0	0.624	12.529	211.81	0	2.17	0.552	0.981	11.906	95.529	4.523
0.96	118.2	115.3	0	0.630	12.397	212.80	0	2.18	0.554	0.982	11.767	94.753	4.557
0.97	120.4	117.5	0	0.636	12.268	213.78	0	2.19	0.557	0.983	11.632	94.003	4.592
0.98	122.6	119.6	0	0.642	12.176	215.32	0	2.21	0.559	0.986	11.534	93.513	4.638
0.99	124.8	121.7	0	0.648	12.120	217.35	0	2.23	0.561	0.991	11.472	93.165	4.689
1.00	127.0	123.9	0	0.654	11.994	218.27	0	2.24	0.563	0.992	11.340	92.434	4.722
1.01	129.2	126.1	0	0.661	11.963	220.90	0	2.26	0.565	1.000	11.303	92.313	4.786
1.02	131.5	128.3	0	0.667	11.836	221.73	0	2.27	0.567	1.000	11.169	91.572	4.818
1.03	133.8	130.5	0	0.673	11.712	222.56	0	2.28	0.569	1.000	11.039	90.852	4.849
1.04	136.1	132.8	0	0.679	11.591	223.39	0	2.29	0.571	1.000	10.913	90.151	4.881
1.05	138.4	135.0	0	0.685	11.474	224.21	0	2.30	0.573	0.999	10.789	89.470	4.912
1.06	140.7	137.2	0	0.691	11.360	225.03	0	2.31	0.575	0.999	10.669	88.806	4.943
1.07	143.0	139.5	0	0.697	11.248	225.85	0	2.31	0.577	0.999	10.551	88.159	4.974
1.08	145.3	141.8	0	0.703	11.140	226.67	0	2.32	0.579	0.999	10.437	87.529	5.005
1.09	147.6	144.0	0	0.709	11.034	227.48	0	2.33	0.580	0.999	10.325	86.915	5.036
1.10	150.0	146.3	0	0.715	10.931	228.29	0	2.34	0.582	0.999	10.216	86.316	5.067
1.11	152.4	148.7	0	0.721	10.825	229.10	0	2.35	0.584	0.998	10.104	85.692	5.098
1.12	154.7	151.0	0	0.727	10.727	229.90	0	2.36	0.585	0.998	10.000	85.122	5.128

1.13	157.1	153.3	0	0.733	10.632	230.71	0	2.36	0.587	0.998	9.899	84.566	5.159
1.14	159.5	155.6	0	0.739	10.538	231.51	0	2.37	0.588	0.998	9.799	84.022	5.189
1.15	161.8	157.9	0	0.745	10.446	232.30	0	2.38	0.590	0.997	9.702	83.489	5.219
1.16	164.2	160.2	0	0.751	10.357	233.09	0	2.39	0.591	0.997	9.606	82.968	5.249
1.17	166.6	162.5	0	0.757	10.274	233.88	0	2.40	0.592	0.997	9.517	82.493	5.279
1.18	169.0	164.8	0	0.763	10.188	234.67	0	2.41	0.593	0.996	9.425	81.992	5.309
1.19	171.4	167.2	0	0.769	10.104	235.45	0	2.41	0.594	0.996	9.336	81.500	5.338
1.20	173.8	169.5	0	0.775	10.022	236.23	0	2.42	0.596	0.996	9.247	81.018	5.368
1.21	176.2	171.9	0	0.781	9.942	237.00	0	2.43	0.597	0.995	9.161	80.544	5.397
1.22	178.6	174.3	0	0.787	9.863	237.77	0	2.44	0.598	0.995	9.076	80.079	5.425
1.23	181.2	176.7	0	0.792	9.781	238.51	0	2.44	0.599	0.994	8.989	79.562	5.452
1.24	183.6	179.1	0	0.798	9.703	239.15	0	2.45	0.600	0.993	8.904	78.996	5.472
1.25	186.1	181.5	0	0.804	9.623	239.70	0	2.46	0.601	0.992	8.819	78.348	5.486
1.26	188.5	183.9	0	0.810	9.543	240.15	0	2.46	0.602	0.990	8.733	77.622	5.493
1.27	191.0	186.3	0	0.816	9.462	240.51	0	2.47	0.603	0.988	8.647	76.818	5.494
1.28	193.5	188.8	0	0.822	9.381	240.77	0	2.47	0.604	0.986	8.559	75.939	5.488
1.29	195.9	191.2	0	0.828	9.342	242.67	0	2.49	0.605	0.991	8.514	76.659	5.603
1.30	198.4	193.6	0	0.834	9.266	243.01	0	2.49	0.607	0.991	8.432	75.879	5.611
1.31	200.9	196.0	0	0.840	9.191	243.36	0	2.49	0.609	0.990	8.352	75.131	5.620
1.32	203.4	198.5	0	0.845	9.119	243.73	0	2.50	0.610	0.990	8.274	74.413	5.630
1.33	205.9	200.9	0	0.851	9.049	244.11	0	2.50	0.612	0.989	8.198	73.723	5.641
1.34	208.4	203.3	0	0.857	8.980	244.51	0	2.51	0.614	0.989	8.123	73.061	5.653
1.35	210.9	205.8	0	0.863	8.914	244.92	0	2.51	0.615	0.988	8.051	72.427	5.666

1.36	213.5	208.2	0	0.869	8.849	245.35	0	2.51	0.617	0.988	7.980	71.821	5.680
1.37	216.0	210.7	0	0.875	8.786	245.79	0	2.52	0.618	0.988	7.911	71.241	5.696
1.38	218.5	213.2	0	0.880	8.724	246.24	0	2.52	0.619	0.988	7.844	70.687	5.712
1.39	221.0	215.6	0	0.886	8.665	246.71	0	2.53	0.621	0.987	7.778	70.158	5.729
1.40	223.6	218.1	0	0.892	8.607	247.20	0	2.53	0.622	0.987	7.715	69.654	5.748
1.41	226.1	220.6	0	0.898	8.550	247.70	0	2.54	0.624	0.987	7.652	69.173	5.768
1.42	228.7	223.1	0	0.903	8.495	248.21	0	2.54	0.625	0.987	7.591	68.704	5.788
1.43	231.2	225.6	0	0.909	8.435	248.41	0	2.55	0.627	0.987	7.526	67.989	5.792
1.44	233.7	228.0	0	0.915	8.377	248.61	0	2.55	0.629	0.987	7.462	67.289	5.797
1.45	236.3	230.5	0	0.921	8.321	248.80	0	2.55	0.631	0.987	7.400	66.604	5.802
1.46	238.8	233.0	0	0.926	8.265	249.00	0	2.55	0.633	0.987	7.339	65.933	5.807
1.47	241.4	235.5	0	0.932	8.211	249.20	0	2.55	0.634	0.987	7.279	65.273	5.812
1.48	244.0	238.0	0	0.938	8.157	249.39	0	2.56	0.636	0.987	7.220	64.627	5.816
1.49	246.5	240.5	0	0.943	8.105	249.59	0	2.56	0.638	0.987	7.162	63.994	5.821
1.50	249.1	243.0	0	0.949	8.054	249.78	0	2.56	0.640	0.986	7.105	63.373	5.826
1.51	251.6	245.5	0	0.955	8.005	249.98	0	2.56	0.641	0.986	7.050	62.764	5.831
1.52	254.2	248.0	0	0.960	7.956	250.17	0	2.56	0.643	0.986	6.995	62.167	5.835
1.53	256.8	250.5	0	0.966	7.908	250.37	0	2.57	0.645	0.986	6.942	61.582	5.840
1.54	259.3	253.0	0	0.972	7.862	250.56	0	2.57	0.646	0.986	6.890	61.008	5.845
1.55	261.9	255.5	0	0.977	7.816	250.76	0	2.57	0.648	0.986	6.839	60.444	5.850
1.56	264.5	258.0	0	0.983	7.771	250.95	0	2.57	0.650	0.986	6.788	59.891	5.854
1.57	267.0	260.5	0	0.988	7.727	251.15	0	2.57	0.651	0.986	6.739	59.348	5.859
1.58	269.6	263.0	0	0.994	7.684	251.34	0	2.58	0.653	0.985	6.690	58.813	5.864

1.59	272.2	265.6	0	1.000	7.642	251.53	0	2.58	0.654	0.985	6.642	58.288	5.868
1.60	274.8	268.1	0	1.005	7.601	251.72	0	2.58	0.656	0.985	6.595	57.772	5.873
1.61	277.4	270.6	0	1.011	7.560	251.91	0	2.58	0.657	0.985	6.549	57.266	5.878
1.62	279.9	273.1	0	1.016	7.520	252.11	0	2.58	0.659	0.985	6.504	56.769	5.882
1.63	282.5	275.6	0	1.022	7.482	252.30	0	2.59	0.660	0.985	6.460	56.280	5.887
1.64	285.1	278.2	0	1.028	7.443	252.49	0	2.59	0.661	0.985	6.416	55.799	5.892
1.65	287.7	280.7	0	1.033	7.406	252.68	0	2.59	0.663	0.984	6.373	55.327	5.897
1.66	290.3	283.2	0	1.039	7.369	252.87	0	2.59	0.664	0.984	6.331	54.863	5.901
1.67	292.9	285.7	0	1.044	7.333	253.06	0	2.59	0.665	0.984	6.289	54.405	5.906
1.68	295.5	288.3	0	1.050	7.298	253.25	0	2.60	0.667	0.984	6.248	53.955	5.910
1.69	298.1	290.8	0	1.055	7.263	253.44	0	2.60	0.668	0.984	6.208	53.513	5.915
1.70	300.7	293.4	0	1.061	7.229	253.62	0	2.60	0.669	0.984	6.168	53.077	5.919
1.71	303.3	295.9	0	1.066	7.196	253.81	0	2.60	0.671	0.984	6.129	52.649	5.924
1.72	305.9	298.4	0	1.072	7.163	254.00	0	2.60	0.672	0.983	6.091	52.228	5.929
1.73	308.5	301.0	0	1.077	7.131	254.19	0	2.61	0.673	0.983	6.053	51.813	5.933
1.74	311.1	303.5	0	1.083	7.099	254.37	0	2.61	0.674	0.983	6.016	51.403	5.938
1.75	313.7	306.1	0	1.088	7.068	254.55	0	2.61	0.675	0.983	5.979	51.000	5.942
1.76	316.3	308.6	0	1.094	7.037	254.73	0	2.61	0.677	0.983	5.943	50.603	5.946
1.77	318.9	311.2	0	1.099	7.007	254.92	0	2.61	0.678	0.983	5.907	50.212	5.951
1.78	321.5	313.7	0	1.105	6.977	255.10	0	2.61	0.679	0.982	5.872	49.827	5.955
1.79	324.2	316.3	0	1.110	6.948	255.28	0	2.62	0.680	0.982	5.838	49.448	5.960
1.80	326.8	318.8	0	1.116	6.920	255.46	0	2.62	0.681	0.982	5.804	49.075	5.964

1.81	329.4	321.4	0	1.121	6.892	255.65	0	2.62	0.682	0.982	5.770	48.707	5.969
1.82	332.0	323.9	0	1.127	6.864	255.83	0	2.62	0.683	0.982	5.737	48.345	5.973
1.83	334.6	326.5	0	1.132	6.837	256.00	0	2.62	0.684	0.982	5.704	47.986	5.977
1.84	337.3	329.0	0	1.138	6.810	256.18	0	2.63	0.685	0.981	5.672	47.632	5.981
1.85	339.9	331.6	0	1.143	6.783	256.35	0	2.63	0.686	0.981	5.640	47.283	5.985

Appendix 5. Cross Curves of Stability

Trim: t = 0.00 m

T [m]	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90
Angle of flooding [°]	-	65.10	40.60	29.40	23.40	18.90	15.30	12.50	10.20	8.20	6.40	4.90	3.10	1.30	0.00
Heel [°]	Cross Curves of Stability [m]														
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.260	1.277	1.243	1.186	1.108	1.025	0.939	0.866	0.803	0.749	0.697	0.636	0.541	0.404	0.233
10	2.190	2.112	2.033	1.951	1.876	1.797	1.716	1.617	1.496	1.347	1.179	1.000	0.813	0.617	0.406
15	2.874	2.716	2.593	2.498	2.409	2.304	2.174	2.022	1.851	1.662	1.459	1.241	1.004	0.753	0.507
20	3.329	3.170	3.027	2.882	2.739	2.586	2.421	2.245	2.056	1.851	1.624	1.375	1.114	0.852	0.603
25	3.569	3.459	3.294	3.113	2.930	2.751	2.572	2.384	2.178	1.950	1.709	1.460	1.202	0.939	0.694
30	3.691	3.575	3.420	3.229	3.038	2.852	2.658	2.455	2.233	2.001	1.764	1.522	1.273	1.017	0.779
35	3.711	3.599	3.445	3.275	3.085	2.895	2.690	2.474	2.251	2.026	1.798	1.566	1.329	1.085	0.858
40	3.671	3.560	3.415	3.258	3.081	2.887	2.677	2.459	2.244	2.030	1.814	1.596	1.373	1.144	0.931
50	3.448	3.354	3.234	3.097	2.940	2.752	2.553	2.358	2.168	1.982	1.797	1.612	1.424	1.232	1.055
60	3.088	3.016	2.918	2.804	2.663	2.502	2.335	2.175	2.018	1.867	1.721	1.575	1.429	1.281	1.148
70	2.620	2.566	2.493	2.403	2.285	2.165	2.039	1.919	1.802	1.693	1.590	1.489	1.389	1.291	1.206
80	2.063	2.028	1.983	1.913	1.833	1.756	1.678	1.601	1.530	1.466	1.409	1.356	1.306	1.263	1.227
90	1.437	1.423	1.405	1.360	1.324	1.293	1.263	1.234	1.211	1.194	1.185	1.182	1.183	1.196	1.210

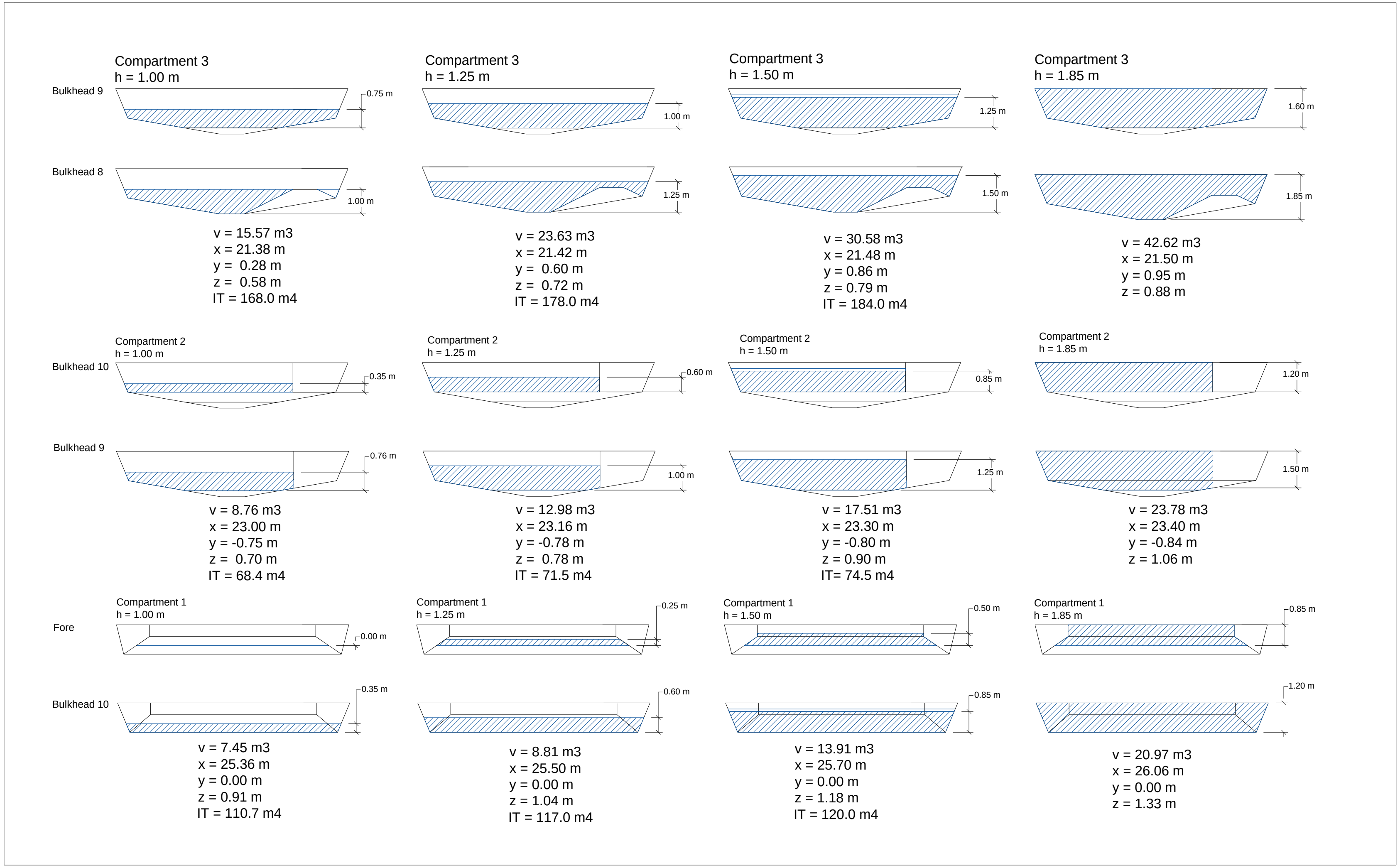
Trim: t =0 .50 m

T [m]	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**	**1.10**	**1.20**	**1.30**	**1.40**	**1.50**	**1.60**	**1.70**	**1.80**	**1.90**
Angle of flooding [°]	76.1	45.00	30.90	24.10	19.30	15.60	12.60	10.30	8.30	6.60	5.00	3.10	1.40	0.10	-
Heel [°]	Cross Curves of Stability [m]														
0	-0.108	-0.084	-0.052	-0.032	-0.015	-0.006	-0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.195	1.199	1.168	1.119	1.051	0.978	0.908	0.844	0.788	0.734	0.673	0.596	0.498	0.394	0.300
10	2.145	2.059	1.980	1.905	1.827	1.744	1.654	1.549	1.427	1.285	1.127	0.957	0.778	0.610	0.475
15	2.825	2.676	2.556	2.451	2.343	2.229	2.097	1.944	1.775	1.589	1.383	1.162	0.944	0.757	0.608
20	3.294	3.122	2.967	2.817	2.672	2.514	2.345	2.160	1.960	1.747	1.525	1.296	1.069	0.871	0.708
25	3.552	3.400	3.220	3.047	2.869	2.680	2.481	2.271	2.059	1.845	1.623	1.391	1.158	0.960	0.800
30	3.653	3.527	3.354	3.169	2.972	2.762	2.545	2.330	2.120	1.906	1.687	1.456	1.230	1.038	0.883
35	3.672	3.553	3.399	3.211	3.004	2.784	2.567	2.356	2.149	1.940	1.725	1.503	1.288	1.106	0.959
40	3.634	3.516	3.376	3.193	2.982	2.766	2.557	2.352	2.151	1.949	1.744	1.535	1.335	1.165	1.026
50	3.423	3.315	3.188	3.020	2.830	2.638	2.451	2.268	2.089	1.910	1.734	1.559	1.394	1.251	1.135
60	3.070	2.977	2.867	2.722	2.567	2.408	2.252	2.100	1.951	1.807	1.667	1.533	1.407	1.297	1.208
70	2.607	2.534	2.441	2.330	2.214	2.095	1.978	1.862	1.752	1.648	1.550	1.461	1.376	1.303	1.244
80	2.057	2.001	1.935	1.864	1.792	1.717	1.642	1.569	1.503	1.442	1.390	1.345	1.304	1.270	1.241
90	1.440	1.399	1.363	1.341	1.315	1.288	1.258	1.232	1.211	1.197	1.192	1.192	1.195	1.198	1.202

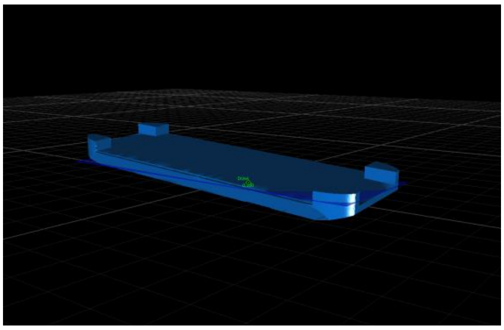
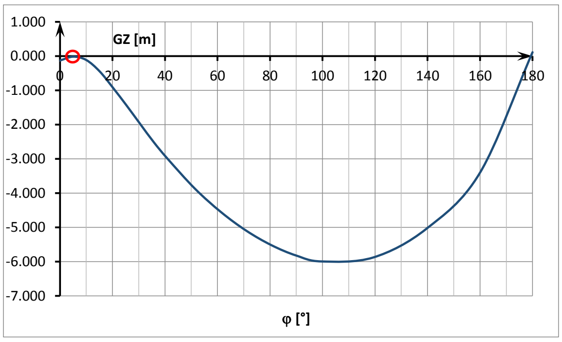
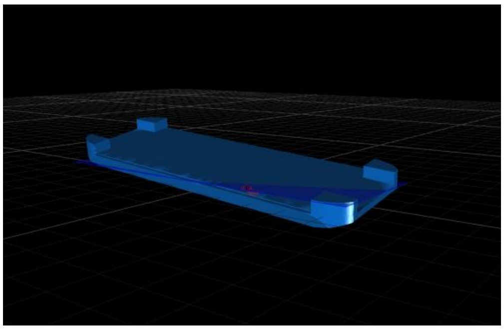
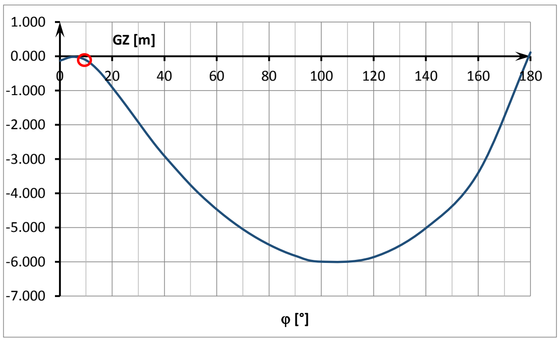
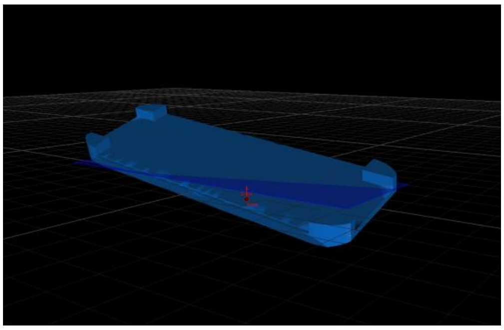
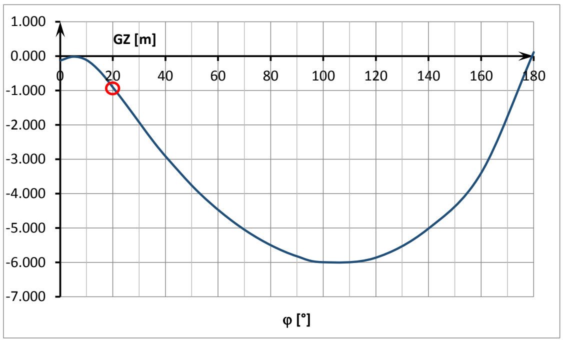
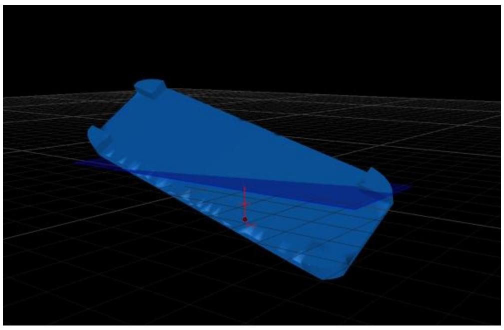
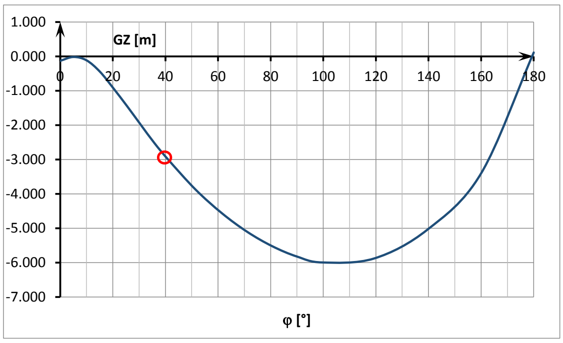
Trim: t =1 .00 m

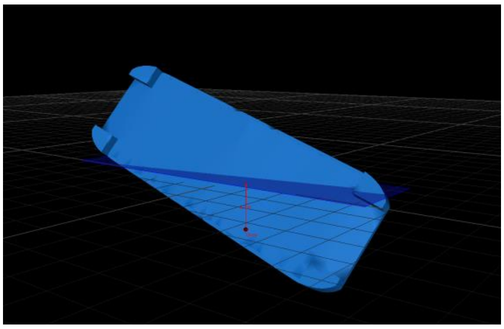
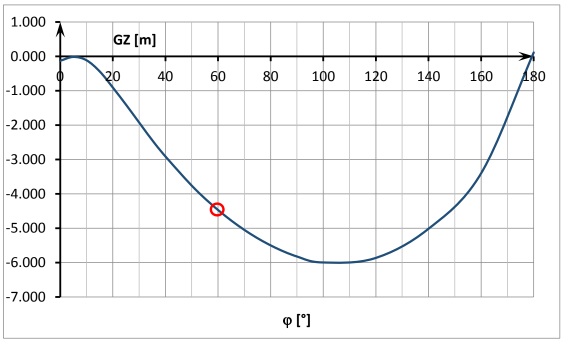
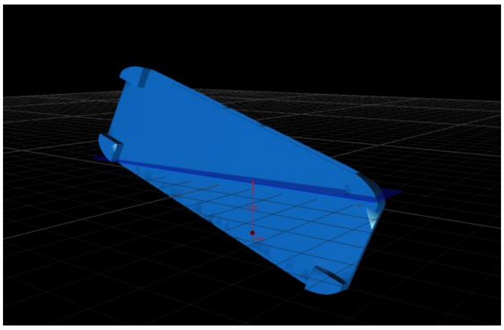
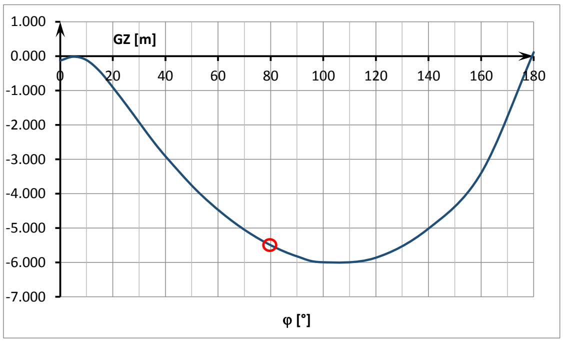
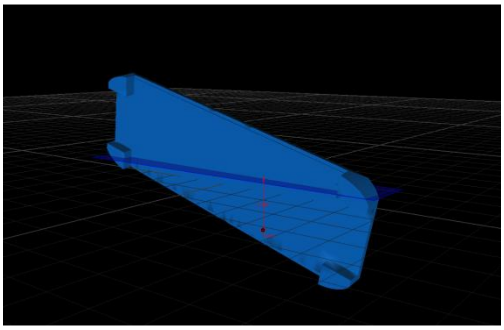
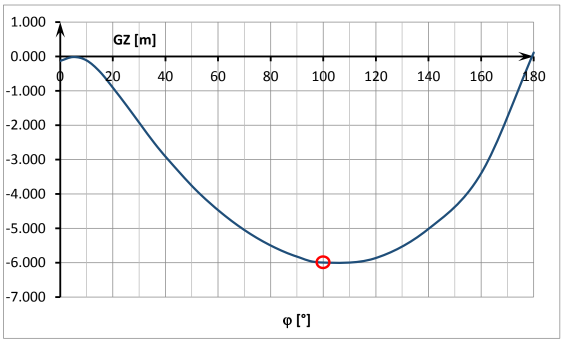
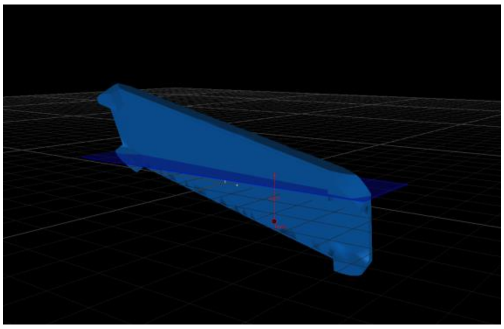
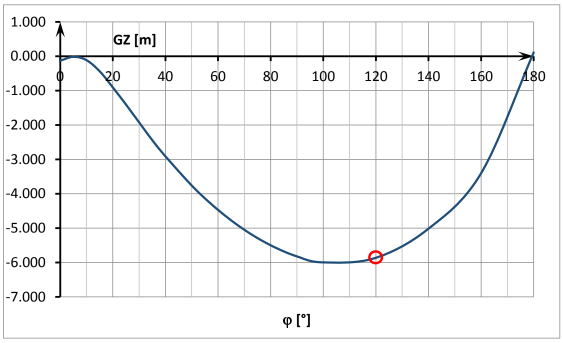
T [m]	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**	**1.10**	**1.20**	**1.30**	**1.40**	**1.50**	**1.60**	**1.70**	**1.80**	**1.90**
Angle of flooding [°]	47.4	31.70	24.40	19.40	15.60	12.70	10.40	8.40	6.60	4.90	3.10	1.60	0.20	-	-
Heel [°]	Cross Curves of Stability [m]														
0	-0.155	-0.122	-0.090	-0.057	-0.030	-0.013	-0.005	-0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.136	1.103	1.055	1.001	0.947	0.894	0.845	0.793	0.736	0.670	0.597	0.525	0.459	0.400	0.342
10	2.061	1.972	1.885	1.801	1.709	1.614	1.507	1.395	1.267	1.137	1.002	0.866	0.741	0.628	0.530
15	2.714	2.579	2.450	2.325	2.194	2.052	1.916	1.751	1.582	1.390	1.206	1.043	0.905	0.786	0.680
20	3.153	2.983	2.823	2.662	2.491	2.325	2.128	1.940	1.737	1.530	1.336	1.171	1.032	0.913	0.804
25	3.411	3.233	3.054	2.861	2.669	2.454	2.242	2.042	1.833	1.623	1.431	1.271	1.136	1.016	0.899
30	3.534	3.368	3.169	2.959	2.743	2.515	2.310	2.100	1.893	1.687	1.503	1.350	1.219	1.096	0.981
35	3.557	3.413	3.204	2.979	2.761	2.534	2.332	2.127	1.926	1.730	1.556	1.410	1.282	1.163	1.053
40	3.525	3.385	3.176	2.950	2.738	2.517	2.323	2.128	1.937	1.752	1.590	1.453	1.329	1.218	1.114
50	3.329	3.188	2.991	2.788	2.598	2.402	2.233	2.063	1.899	1.746	1.611	1.491	1.387	1.294	1.208
60	2.993	2.856	2.697	2.520	2.362	2.200	2.063	1.925	1.796	1.680	1.573	1.478	1.397	1.326	1.262
70	2.546	2.427	2.305	2.171	2.045	1.937	1.823	1.730	1.643	1.563	1.488	1.421	1.365	1.318	1.277
80	2.008	1.925	1.846	1.766	1.680	1.614	1.544	1.492	1.449	1.406	1.364	1.326	1.296	1.273	1.254
90	1.402	1.362	1.335	1.306	1.277	1.252	1.229	1.223	1.221	1.216	1.208	1.201	1.198	1.198	1.200

Appendix 6. Water in the watertight compartments



Appendix 7. Sequence of capsizing of the *Siebengebirge* ferry

Heel 5° starboard		
10°starboard		
20° starboard		
40° starboard		

60° starboard		
80° starboard		
100° starboard		
120° starboard		

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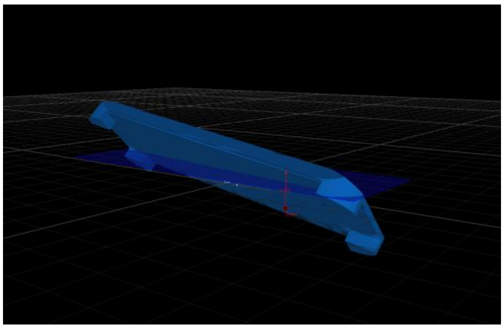
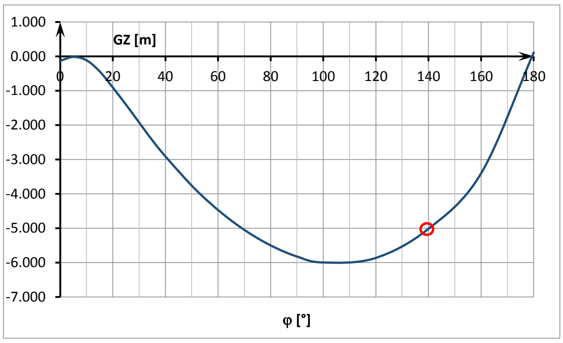
<td></td>
<td>
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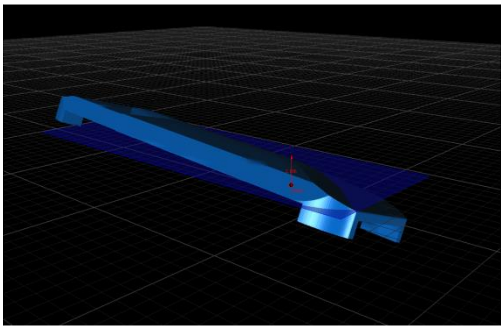
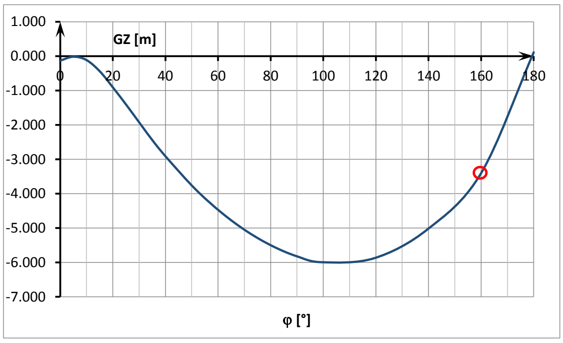
<td></td>
<td>
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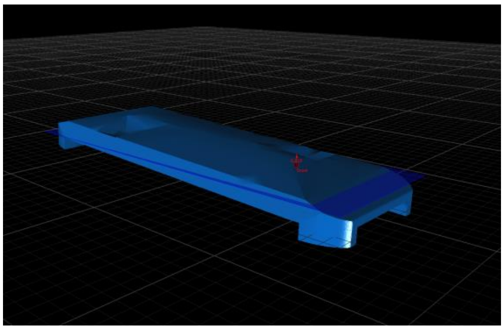
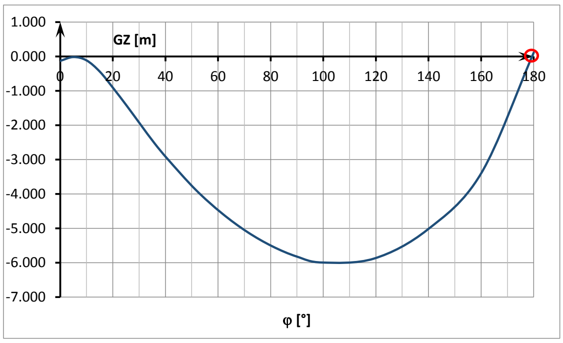
<td></td>
<td>
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