



SMAIC
STATE MARINE ACCIDENT
INVESTIGATION COMMISSION

FINAL REPORT

45/18

Serious marine casualty

**of the “Zeus” tugboat
and the “T-6” pontoon**

**Capsizing of the “T-6” pontoon under tow and loss of
excavators transported on board in the Baltic Sea on
15 July 2018**

June 2019



The investigation of a serious marine casualty of the *Zeus* tugboat and the *T-6* pontoon under tow was conducted under the State 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 state of marine safety.

The State 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 State Marine Accident Investigation Commission Act).

State Marine Accident Investigation Commission

Plac Stefana Batorego 4, 70-207 Szczecin

Landline: +48 91 44 03 290

Mobile: +48 664 987 987

e-mail: pkbwm@mgm.gov.pl

www.pkbwm.gov.pl



1. The Contents

1. The Contents	2
2. Facts	5
3. General Information.....	6
3.1.1. Tugboat Particulars	6
3.1.2. Object Under Tow – the <i>T-6</i> Pontoon	7
3.1.3. Model of the <i>T-6</i> Pontoon	7
3.1.4. Cargo on Board the Pontoon	11
3.1.4.1. Excavator No 1	12
3.1.4.2. Excavator No 2	13
3.2. Voyage Particulars of the Towing Unit Composed of <i>Zeus</i> and the <i>T-6</i> Pontoon	15
3.3. Information About the Accident.....	15
3.4. Shore Services and Rescue Action Information	15
4. Circumstances of the Accident	15
5. Analysis and Comments about Factors Causing the Accident with Regard to Examination Results and Expert Opinions	18
5.1. Mechanical Factors.....	19
5.2. Human Factors (faults and negligence).....	19
5.3. Organizational Factors.....	20
5.4. Influence of External Factors on the Accident	21
6. Description of Examination Findings Including the Identification of Safety Issues and Conclusions	21
6.1. Simulation Assumptions and Analyses of Stability of the <i>T-6</i> Pontoon	21
6.2. Observations Regarding the State of the <i>T-6</i> Pontoon According to the Hearings of the Crew of <i>Zeus</i>	22
6.3. Fastening of Cargo According to the Hearings of the Crew of <i>Zeus</i>	23



6.3.1. Acceleration and Forces Acting of the Excavators During Rolling of the Pontoon at 10° and Pitching at 5°. The Excavator CASE 81 t.....	24
6.3.2. Acceleration and Forces Acting of the Excavators During Rolling of the Pontoon at 10° and Pitching at 5°. The Excavator CASE 70.5 t.....	25
6.4. Simulation of the Accident.....	25
6.4.1. State 1.....	27
6.4.1.1. State 1A.....	30
6.4.2. State 2.....	31
6.4.2.1. State 2A.....	34
6.4.3. State 3.....	35
6.4.3.1. State 3A.....	38
6.4.4. State 4.....	39
6.4.4.1. State 4A.....	41
6.4.5. State 5.....	42
6.4.5.1. State 5A.....	44
6.4.6. State 6.....	45
6.4.6.1. State 6A.....	47
6.4.7. State 7.....	48
6.5. Stability of the T-6 Pontoon According to Intact Stability Code 2008.....	49
6.6. Conclusions from the Analysis of Results of Calculations of Assumed Stability States of the T-6 Pontoon.....	51
7. Safety Recommendations.....	54
7.1. Zakład Usług Żeglugowych Sp. z o.o. & Co. Sp. k.....	54
7.2. UAB Topada – the Owner f the T-6 Pontoon.....	54
8. List of Figures.....	55
9. List of Photographs.....	56
10. List of Tables.....	56
11. Information Sources.....	57



12. Composition of the Investigative Team.....	57
13. Appendices.....	58
13.1. Appendix 1 - Requirements of the Intact Stability Code 2008 Regarding pontoons	58
13.2. Appendix 2 – Theoretical Lines of the T-6 Pontoon.....	60
13.3. Appendix 3 – Hydrostatic Data of the T-6 Pontoon.....	61
13.4. Appendix 4 – Righting Arms.....	68



2. Facts

On 12 July 2018 at 10:45 at the approach to the port in Klaipeda, a port pilot boarded the *Zeus* tugboat, and he led the tugboat to the port and directed it to the wharf No 20 where the vessel moored at 11:30.

The tugboat master was instructed by the shipowner to tow the pontoon (inland barge) to the port of Antwerp.

At 14:30 the pontoon named *T-6* was towed behind the stern of the *Zeus* tugboat, to enable the crew of the tugboat to install the towing equipment and attach the towline.

It was surprising for the master to see that there were two heavy and unfastened excavators placed on a dirty deck smeared with oil. He was trying to obtain confirmation from the shipowner that they had agreed for such towing, and at the same time he informed the agent about his refusal to go to sea. He stated he could do it provided that the deck of the pontoon was cleaned and heavy excavators attached.

Despite the pressure to leave the port with the pontoon as soon as possible, the master managed to persuade the owner of the pontoon to remove spilled oil from the deck of the pontoon and make the fastening which he considered sufficient during the inspection at 22:00.

At 22:30, the port pilot came aboard and led the towing units out of the port. After passing the port heads, the towline was extended to 210 m and the sea towage started.

On the next day, i.e. 13 July 2018 at 12:20 the pontoon capsized.

By the shipowner's decision, the tugboat, with the capsized pontoon approached the territorial waters of Lithuania.

On 17 July, after the decision of the interested parties had been made, the tugboat reached the anchorage No 1 of the Port of Klaipeda, where at 14:30 the towline with the capsized pontoon was handed over to one of the arriving Lithuanian tugboats.



3. General Information

3.1.1. Tugboat Particulars

Name of the tugboat	Zeus
Flag:	Polish
Owner:	Otto Wulf GmbH & Co. KG. Cuxhaven (Germany)
Operator:	Zakład Usług Żeglugowych Sp. z o.o. & Co. Sp. k in Szczecin
Classification society:	PRS S.A.
Vessel's type:	tugboat
Call sign:	SQLH
IMO number:	6605503
Gross tonnage:	186
Year of built:	1966
Power:	1214 kW (2 x BW D526MTB-40)
Width:	8.00 m
Length overall:	28.43 m
Hull material:	steel
Manning:	6 people



Photograph 1. The „Zeus” tugboat



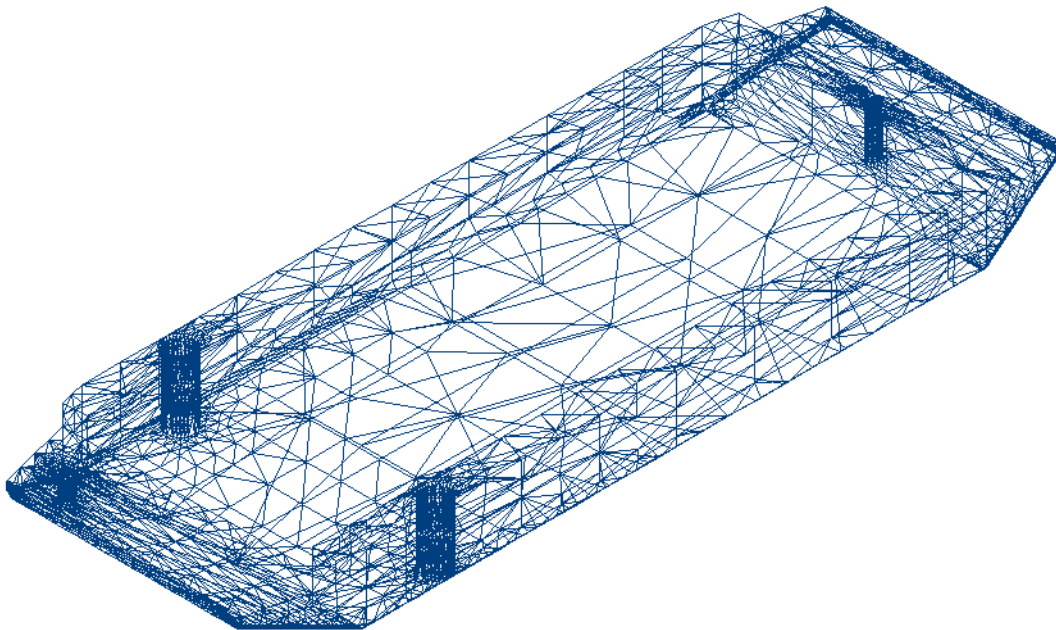
3.1.2. Object Under Tow – the *T-6* Pontoon

The *T-6* pontoon (a barge for inland transportation without propulsions)

Owner:	UAB „Topada”, Klaipeda, Debrecenog 58c-51
Length overall:	32.77 m
Moulded breadth:	11.40 m
Maximum draught:	1.09 m
Cargo capacity ¹ :	20,000 kg

3.1.3. Model of the *T-6* Pontoon

The data needed to carry out stability calculations, which were not obtained from the owner of the pontoon, were obtained from own measurements and photographs and by creating a computerized image of the pontoon.



¹ According to the Registration Certificate of the Inland Navigation Means of Transport issued by the Lithuanian Authority for Safety of Navigation.

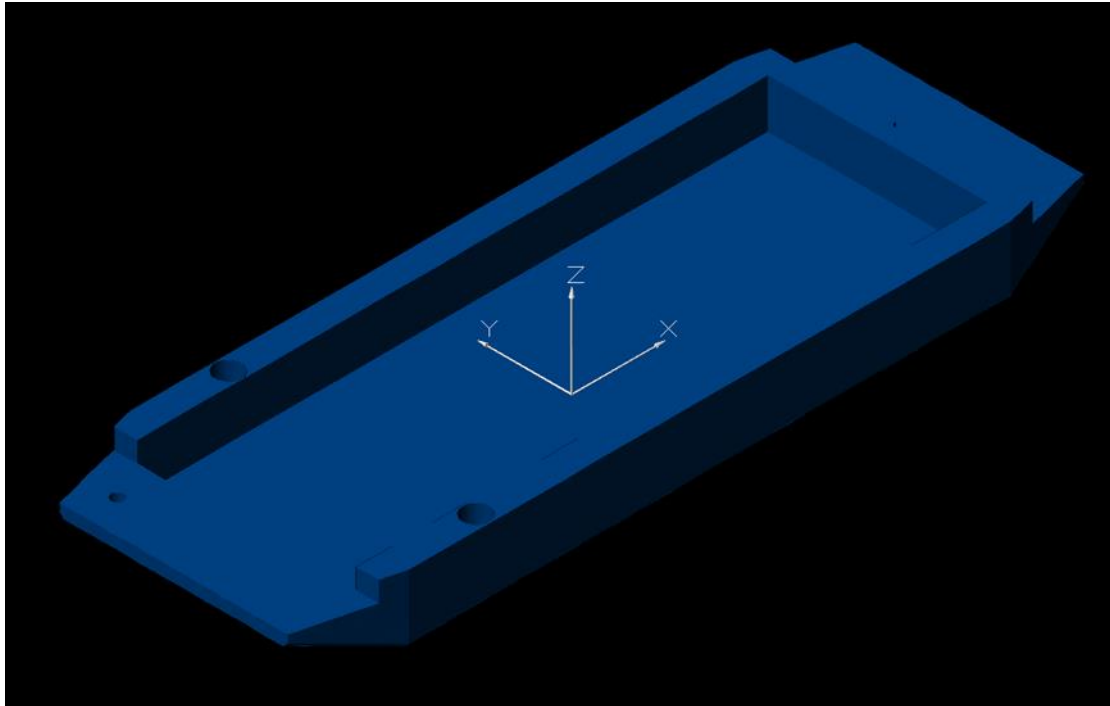


Figure 1. A model of the T-6 pontoon developed on the basis of measurements



Figure 2. Depth of the pontoon



Figure 3. Bow draught

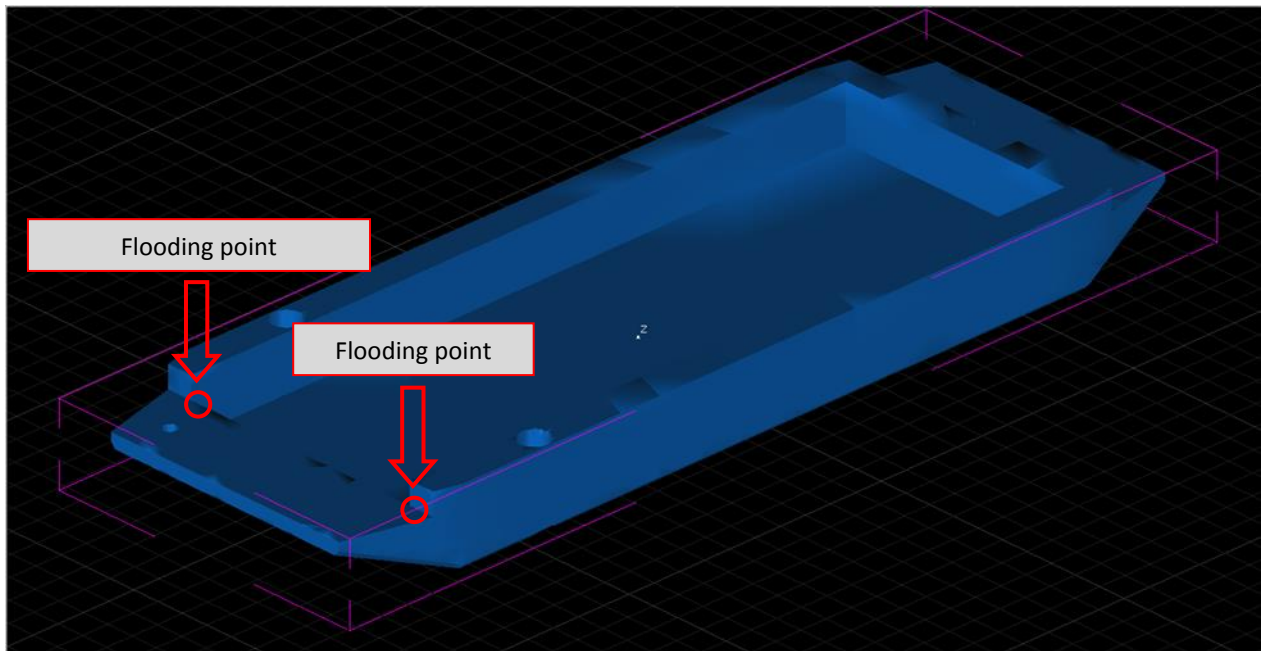


Figure 4. Model of the T-6 pontoon with points of flooding at stern

1	Name of the vessel	T-6 pontoon
2	Main dimensions	
	Length overall	32.77 m
	Length between the perpendiculars	32.77 m
	Moulded breadth	11.40 m
3	Draught of the empty pontoon (on-site verification)	0.82 m
4	Depth of the pontoon (up to the bow deck)	2.00 m
5	Depth of the pontoon (up to the upper deck)	2.82 m
6	Co-ordinates of the points of flooding (starboard/port side stern) (Fig. 1.4)	x = -13.385 m from ⊗ y = 4.500 m from PS z = 2.000 m from PP
7	Dimensions of the hold	
	Length	25.73 m
	Width	9.00 m
	Height	2.00 (1.18 m)
8	Loaded pontoon (reading from a photograph)	
	Trim	0.76 m
	Bow draught	1.00 m
	Bow draught at FP	0.96 m
	Stern draught at AP	1.72 m

Table 1. Characteristic data of the T-6 pontoon obtained from measurements and photographs

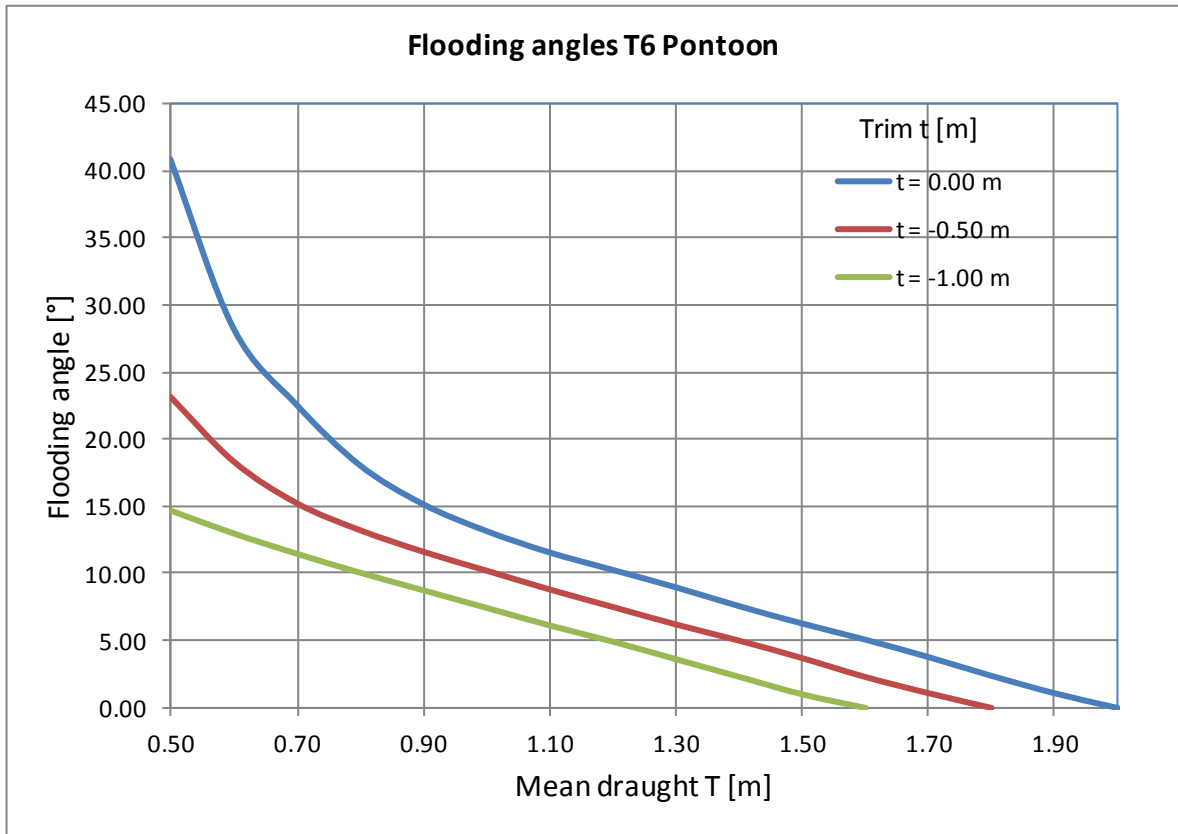


Figure 5. Angles of flooding of the T-6 pontoon for draught and trim

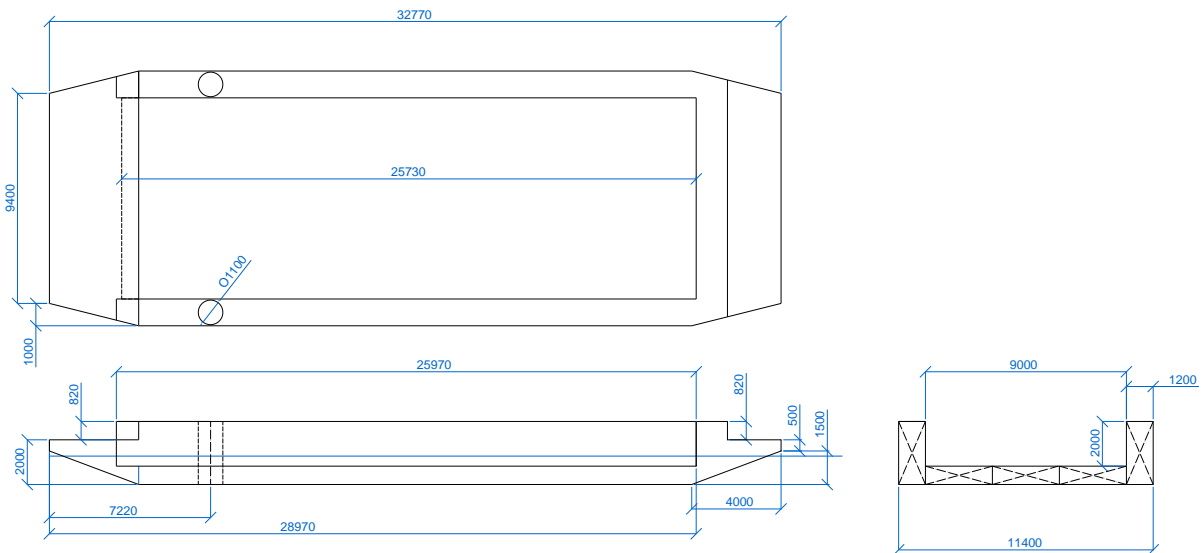


Figure 6. Dimensions of the T-6 pontoon

3.1.4. Cargo on Board the Pontoon

The load of the *T-6* pontoon was composed of two excavators: CASE (in the centre of the hold) and VOLVO (in the aft part of the hold). The kind and type of the excavators were determined based on their photographs. Due to the age of the excavators, the parameters of similar excavators were adopted for analysis.

The excavators were placed partly on the wood planking covering the bottom of the hold.



Photograph 2. Position of the excavators on deck



Photograph 3. Position of the excavators on deck

3.1.4.1. Excavator No 1

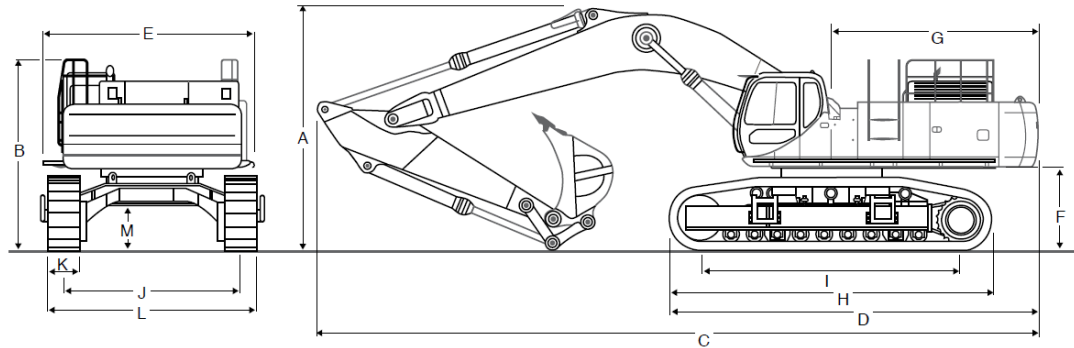
CASE CX700 DL

Weight ca. 81 t

Coordinates of the centre of the excavator on the pontoon: $x = 15.0$ m from AP, $y = 1.35$ m from CP, $z = 2.82$ m from BP.



GENERAL DIMENSIONS



DIMENSIONS – BOOM LENGTH 27 FT 7 IN (8.40 M)

	18 ft 5 in (5.62 m) Arm	14 ft 7 in (4.44 m) Arm	12 ft 0 in (3.66 m) Arm
A. Overall height	20 ft 4 in (6.20 m)	16 ft 5 in (5.00 m)	15 ft 9 in (4.81 m)
B. Cab height	11 ft 10 in (3.61 m)	11 ft 10 in (3.61 m)	11 ft 10 in (3.61 m)
C. Overall length	45 ft 8 in (13.92 m)	47 ft 0 in (14.32 m)	47 ft 1 in (14.36 m)
D. w/o attachment	24 ft 6 in (7.46 m)	24 ft 6 in (7.46 m)	24 ft 6 in (7.46 m)
E. Width of upperstructure	13 ft 11 in (4.25 m)	13 ft 11 in (4.25 m)	13 ft 11 in (4.25 m)
F. Upperstructure ground clearance	5 ft 3 in (1.59 m)	5 ft 3 in (1.59 m)	5 ft 3 in (1.59 m)
G. Tail swing radius	14 ft 1 in (4.30 m)	14 ft 1 in (4.30 m)	14 ft 1 in (4.30 m)
H. Track overall length	20 ft 10 in (6.36 m)	20 ft 10 in (6.36 m)	20 ft 10 in (6.36 m)
I. Center to center (idler to sprocket)	16 ft 8 in (5.07 m)	16 ft 8 in (5.07 m)	16 ft 8 in (5.07 m)
J. Track gauge — extended	11 ft 4 in (3.45 m)	11 ft 4 in (3.45 m)	11 ft 4 in (3.45 m)
K. Track shoe width	29.5 in (750 mm)	29.5 in (750 mm)	29.5 in (750 mm)
L. Track overall width w/29.5 in (750 mm) shoes	14 ft 4 in (4.36 m)	14 ft 4 in (4.36 m)	14 ft 4 in (4.36 m)
L. Track overall width w/29.5 in (750 mm) side frames retracted	12 ft 3 in (3.74 m)	12 ft 3 in (3.74 m)	12 ft 3 in (3.74 m)
M. Minimum ground clearance	2 ft 11 in (0.89 m)	2 ft 11 in (0.89 m)	2 ft 11 in (0.89 m)
Working weight*	180,471 lb (81 860 kg)	179,342 lb (81 348 kg)	178,575 lb (81 000 kg)
Ground pressure	14.4 psi (99 bar)	14.3 psi (98 bar)	14.3 psi (98 bar)

*With 29.5 in (750 mm) track shoe, 6,614 lb (3000 kg) bucket, 165 lb (75 kg) operator, full fuel and standard equipment.

Figure 7. The CASE excavator

3.1.4.2. Excavator No 2

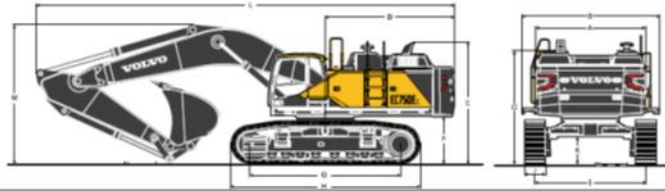
Volvo EC700 DL

Weight 70.5 t

Coordinates of the centre of the excavator on the pontoon: x = 8.00 m from AP, y = -0.40 m from CP, z = 2.40 m from BP.



Maximum material density			
	kg/m ³	lb/yd ³	
A	1,200 - 1,300	2,000 - 2,200	Coal, Caliche, Shale
B	1,400 - 1,600	2,300 - 2,700	Wet earth and clay, Limestone, Sandstone
C	1,700 - 1,800	2,800 - 3,100	Granite, Wet sand, Well blasted rock
D	> 1,900	> 3,200	Wet mud, Iron ore



Description	Unit		EC750E									
	m	ft in	6.6, 21'8"		7.7, 25'3"		4.2, 13'10"					
Boom												
Arm												
A Overall width of superstructure	mm	ft in	3,420	11'3"	3,420	11'3"	3,420	11'3"	3,420	11'3"	3,420	11'3"
B Overall width (Upper Structure)	mm	ft in	4,290	14'1"	4,290	14'1"	4,290	14'1"	4,290	14'1"	4,290	14'1"
C Overall height of cab	mm	ft in	3,520	11'7"	3,520	11'7"	3,520	11'7"	3,520	11'7"	3,520	11'7"
D Tail swing radius	mm	ft in	4,140	13'7"	4,140	13'7"	4,140	13'7"	4,140	13'7"	4,140	13'7"
E Overall height of diffuser	mm	ft in	3,850	12'8"	3,850	12'8"	3,850	12'8"	3,850	12'8"	3,850	12'8"
Overall height of guard rail	mm	ft in	4,000	13'2"	4,000	13'2"	4,000	13'2"	4,000	13'2"	4,000	13'2"
Overall height of engine hood	mm	ft in	3,540	11'8"	3,540	11'8"	3,540	11'8"	3,540	11'8"	3,540	11'8"
Overall height of rain cap	mm	ft in	3,790	12'6"	3,790	12'6"	3,790	12'6"	3,790	12'6"	3,790	12'6"
Overall height of cyclone	mm	ft in	3,850	12'8"	3,850	12'8"	3,850	12'8"	3,850	12'8"	3,850	12'8"
Overall height of oil bath	mm	ft in	4,100	13'6"	4,100	13'6"	4,100	13'6"	4,100	13'6"	4,100	13'6"
F Counterweight clearance *	mm	ft in	1,507	5'0"	1,507	5'0"	1,507	5'0"	1,507	5'0"	1,507	5'0"
G Tumbler length	mm	ft in	4,750	15'8"	4,750	15'8"	4,750	15'8"	4,750	15'8"	4,750	15'8"
H Track length	mm	ft in	5,990	19'8"	5,990	19'8"	5,990	19'8"	5,990	19'8"	5,990	19'8"
I Track gauge (extended)	mm	ft in	3,440	11'4"	3,440	11'4"	3,440	11'4"	3,440	11'4"	3,440	11'4"
J Track gauge (retracted)	mm	ft in	2,750	9'1"	2,750	9'1"	2,750	9'1"	2,750	9'1"	2,750	9'1"
J Shoe width	mm	ft in	650	2'2"	650	2'2"	650	2'2"	650	2'2"	650	2'2"
K Min. ground clearance *	mm	ft in	858	2'10"	858	2'10"	858	2'10"	858	2'10"	858	2'10"
L Overall length	mm	ft in	12,200	40'1"	13,320	43'9"	13,220	43'5"	13,160	43'3"		
M Overall height of boom	mm	ft in	4,855	16'0"	4,660	15'4"	4,600	15'2"	4,950	16'3"		

* With shoe grouser

Figure 8. The Volvo excavator

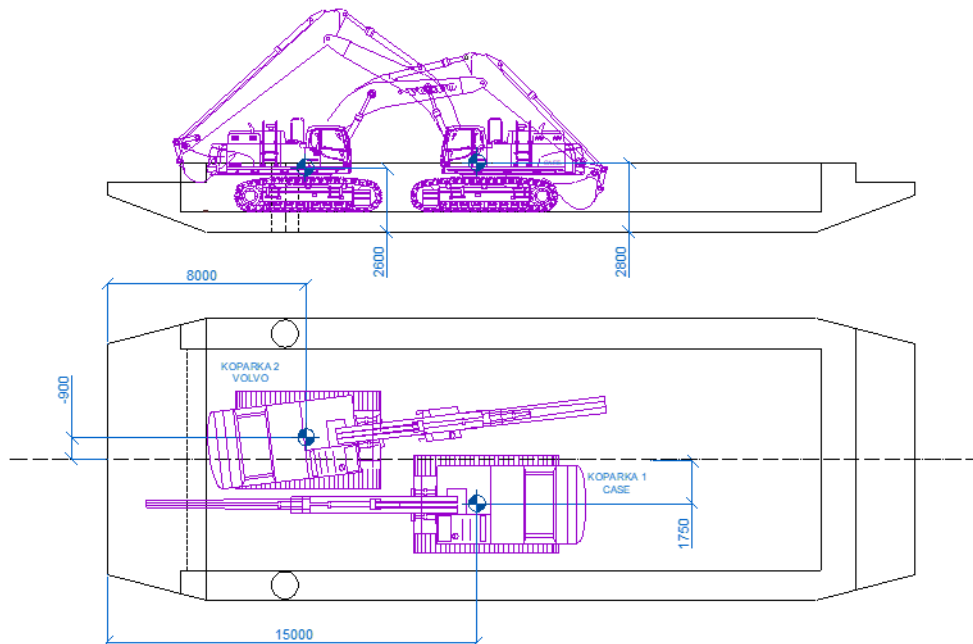


Figure 9. Position of excavators on the deck of the T-6 pontoon. Explanatory figure based on photographs



3.2. Voyage Particulars of the Towing Unit Composed of *Zeus* and the *T-6* Pontoon

3.3. Information About the Accident

Kind:	serious marine casualty
Date and time of the event:	13.07.2018 at 12:20
Geographical position of the event:	$\varphi = 55^{\circ} 35, 398' N$; $\lambda = 018^{\circ} 00, 987' E$
Geographical area of the event:	South Baltic Sea
Nature of the water region:	sea waters
Operational status of the vessel during the event:	tugboat towing at the speed of 7 knots

3.4. Shore Services and Rescue Action Information

The master of the *Zeus* tugboat informed the shipowner's services about capsizing of the pontoon under tow. No rescue operations were carried out and the capsized pontoon was towed to the roadstead of the port of Klaipeda.

4. Circumstances of the Accident

According to the contract for towing, the *Zeus* tugboat, whose shipowner was Zakład Usług Żeglugowych Sp. z o.o. & Co. Sp.k. from Szczecin, was to tow the *T-6* pontoon belonging to a Lithuanian company UAB Topada from Klaipeda. The towing was to be carried out on the route from the port of Klaipeda to Antwerp. According to the contract, the *T-6* pontoon (a barge designed for inland transport without its own propulsion) was supposed to be unmanned in a seaworthy state.

The *Zeus* tugboat entered the port of Klaipeda on the day of 12 July 2018, where it moored to the wharf No 20 at 11:30. To enable the crew of the tugboat to prepare towing equipment and the main towline for scheduled towing, at 14:30 a pontoon was towed by a port tugboat and moored behind the stern of *Zeus* at the same wharf. During the inspection of the pontoon by the master and the tugboat crew, it was found that two unattached heavy excavators² were placed on deck of the pontoon.

² Only the arm of one of the excavators, which might not have been fully lowered, was attached with steel lines (Photograph 4).



Photograph 4. Fastened arm of one of the excavators (Photograph taken by LTSA³ inspectors)



Photograph 5. Position of the excavators on the pontoon without fixing (Photograph taken by LTSA inspectors)

³ Lietuvos Transporto Saugos Administracija – Lithuanian Authority for Safety of Transportation)



Partially damaged wooden planks previously forming a cover of a deck with extensive stains of spilled dirty oil survived on pontoon's deck. In that situation, the master informed the agent's representative at 15:30 that the pontoon with the excavators on board was not suitable for sea transport and he refused to go out to sea with a pontoon. Despite the standpoint of the master and his refusal to start the towage, at 17:15 the representative of the agent gave the master a document in Lithuanian allowing him to tow a pontoon from Klaipeda to Antwerp. At 17:50 a pilot ordered by the agent boarded the tugboat to lead the towing unit out of the port.

The master once again refused to go out to sea and notified the agent's representative, the shipowner's office and other interested parties about his decision. At the same time, he stated that until the pontoon was cleaned of residual oil and the excavators properly secured, he would not start towing. At the same time, he tried to communicate with the shipowner and obtain confirmation if the pontoon should be towed together with the cargo. As the master claimed, he did not receive such a reply from the duty service of the shipowner.

Due to the master's standpoint there arrived a group of workers who started cleaning the pontoon's deck and sides, and fixing the excavators. Steel ropes, chains and load belts were used for fixing. Fixing devices did not have certificates. Periodically the course of fastening was controlled by the tugboat's crew, and the method of fixing was supplemented according to the instructions of the crew of *Zeus*. The cargo restraint plan was not prepared.

At 22:00 the master was notified by the agent that the pontoon was ready for towing.

After the inspection, the master agreed to start the towage.

At 22:30 the pilot re-entered the tugboat. After unmooring from the wharf at 22:45, with additional assistance of the *T-3* tugboat, the towing unit left the Klaipeda port at 23:05. At 23:10 the pilot left the vessel and the port tugboat was released, and when 210 m of towline was given at 23:20, the *Zeus* tugboat started sea towing.

Weather conditions during towage were stable. North wind blowing at the speed of 3° B, sea state of approx. 3. Towage was performed at the constant speed of 7 knots. The pontoon was swaying on both sides to a maximum of 10°.

On the next day, 13 July 2018 at 12:20 The *T-6* pontoon capsized unexpectedly. The master, summoned to the bridge, stopped the tugboat and remained in its vicinity.



He informed the shipowner about the incident and awaited further instructions. In the inverted position the pontoon stayed on water. On the same day, at ca. 17:00, the master was instructed by the shipowner to return with the capsized pontoon to the port of Klaipeda. After notifying the port about the approach planned on 14 July 2018, the master was instructed to remain outside the territorial waters of Lithuania. On 16 July in the morning the master received permission from VTS Klaipeda to approach the anchorage No 1 of the port. After anchoring in the indicated place, the pontoon was approached by a port tugboat, and then the diver inspected the underwater part of the capsized pontoon. It turned out that the excavators and equipment with which they had been attached were not there. The tugboat's crew were of the same opinion, as the pontoon, when being in tow in the capsized position did not give much resistance. It was considered, therefore, that the excavators had sank when the pontoon capsized at the depth of 70 m.

After the diver's inspection, the tugboat's master was instructed to leave the territorial waters of Lithuania and await further instructions.

On 17 July 17 at ca. 13:00 at the request of VTS Klaipeda, the tugboat once again entered the anchorage No 1, where at ca. 14:30, the pontoon's towline was given to the Lithuanian tugboat, *Perkun*. A pontoon on the towline of *Perkun* and of another assisting tugboat was towed to the port of Klaipeda.

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

The *T-6* pontoon was designed and built in 1994 in Ghent in B.V. Scheepswerf en Machinefabriek "Vahali" for conducting navigation on closed waters and internal waters. It did not have any stability documentation⁴ that was not required for inland waterway navigation.

However, in compliance with the recommendations contained in IMO MSC.884 Circular, for objects under tow on sea waters, it was necessary to make calculations determining its stability and the so-called stability limits criteria.

⁴ The 2006/87/EC Directive laying down technical requirements for inland waterway vessels defines technical requirements for these vessels (the Directive is applicable to all inland waterways of the countries of the Community except for the Rhine). In Annex II Article 3.02(3) referring to e.g. pontoons, barges, tugboats, pushers and other inland waterway vessels of a similar type no detailed requirements have been formulated.



On the 24-years-old vessel some of the existing equipment was in poor technical condition, and some was out of order. The excavators of the total weight of 151.5 t placed on deck of the pontoon were positioned in the aft part of the hold. They were set partly on wooden planking.

5.1. Mechanical Factors

The load of excavators was fastened (according to the declaration of the tugboat's crew) to the construction of the pontoon. During the inspection of the pontoon by the members of the Commission, it was noticed that there were not enough points to attach heavy excavators to immobilize them during sea transport.

The load was secured by chains (estimated MSL⁵ of 12 t) and wire ropes from the winches at the stern. In addition, the excavators were joined by belts of unknown strength. In the photographs taken before the accident, there are no visible cargo fastenings.

The load restraint plan (of excavators) recommended in the aforementioned Circular was not made.⁶

5.2. Human Factors (faults and negligence)

No records have been preserved, especially the photographic evidence showing how the excavators had been fastened on the pontoon.

The Lithuanian Authority for Safety of Transportation did not submit any documents on the basis of which it considered the *T-6* pontoon as an object that could take a sea voyage on tow. On the day preceding the transfer of the *T-6* pontoon at the disposal of the master of *Zeus*, the representative of the Lithuanian Authority for Safety of Transportation made a special technical inspection of the *T-6* pontoon - an inland navigation vessel and positively assessed its ability for towage. On the following day, after the master of *Zeus* had inspected the pontoon, it was assessed as unacceptable for towage, regardless of the unattached excavators put on deck and not meant for transport.

Despite many years of experience in sea towing, the tugboat master of *Zeus* started sea towing without the required documents and contrary to regular maritime practice.

⁵ Maximum Securing Load

⁶ MSC/Circ. 884 – Guidelines for safe ocean towing – Annex 13



At the same time, notwithstanding the recommendation of the Lithuanian Authority for Safety of Transportation listed in the protocol to make a special technical survey of the pontoon, the master did not present the towing plan. Such a plan had not been executed.

The shipowner of the *Zeus* tugboat, Zakład Usług Żeglugowych did not show proper support for the tugboat master who, due to the lack of clear instructions, exposed to the pressure of the local agent, made a decision to go out to sea with a loaded pontoon that did not meet the requirements of safe towage.

5.3. Organizational Factors

The towing unit did not have the necessary documents to start the sea voyage.

The *T-6* pontoon did not have any documents specifying its exact dimensions, hydrostatic data and righting arms.

In the Certificate of Registration of the Inland Waterway Vessel issued by the Lithuanian Authority for Safety of Transportation there was a record specifying the capacity of the pontoon for 20 tons (20,000 kg). The weight of both excavators many times exceeded that value.⁷

Considering the type of object under tow that in terms of construction was prepared for operation in inland waters, preparation of documents, inspection and checking of the towing unit should have been done in accordance with the recommendations of the MSC/Circ.884 – “Guidelines for the safe sea towage”.

The shipowner did not give the master part of the terms of the signed towing contract that directly concerned the object under tow. In accordance with the provisions contained in the signed contract, UAB Topada was obliged to prepare a license and consent for the execution of towage. The obtained permit to start towage was issued in Lithuanian, incomprehensible to the tugboat master.

The towing ability certificate should be issued by a recognized company of maritime inspectors or an organization specializing in analyzing and issuing permits for objects described in the contract prepared for towage. Any inspection made by the shipowner’s representative (master) could not be the basis for giving permission to start towage. However, the master was entitled to refuse to start towage in justified cases.

⁷ The State Marine Accident Investigation Commission checked the capacity of the pontoon registered in the Certificate which had been issued by the Netherlands Shipping Inspectorate (NSI) – to be 215.835 t.



Despite regular telephone communication in the port of Klaipeda between the master of the tugboat and the shipowner's office he received no answers to his questions or support in resolving presented doubts. He did not obtain from the shipowner's office an answer whether the excavators loaded on the pontoon were to be transported in accordance with the towing contract signed by the shipowner. The agent servicing the tugboat in the port of Klaipeda assured the master that it was consistent with the towing contract and insisted on leaving immediately.

After sending to the shipowner's office a copy of the permit for towage with a request for translation and reading the content, the master received an answer that due to the Lithuanian language, the shipowner's services could not help him.

The document issued by the Lithuanian Authority for Safety of Transportation, at the request of the shipowner of the pontoon, allowed to tow the pontoon to the port of Antwerp without cargo, with a wave height at sea of up to 1.0 m, wind force up to 4° on the Beaufort scale.

The master asked the pilot on board for translation of the document, when they were leaving the port. Despite getting acquainted with its content, he decided to go out to sea.

5.4. Influence of External Factors on the Accident

The NE wind turning to N, 3 to 4 on the Beaufort scale and fleeting squalls with rainfall caused a lateral sway of the pontoon and slow inflow of water into the pontoon cargo space.

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

Due to the lack of basic information and documentation allowing to clearly establish the cause and course of the accident, a number of calculations were made to simulate the accident taking into account different scenarios.

6.1. Simulation Assumptions and Analyses of Stability of the T-6 Pontoon

- Hydrostatic data and righting arms were developed on the basis of measurements made in the port of Klaipeda on 06.10.2018 by the expert of the SMAIC.
- Measurements included only the surface part of the pontoon and the cargo deck. The shape and dimensions of the underwater part were developed on the basis of photographs of the pontoon made after it had capsized.

- The hydrostatic parameters of the pontoon were calculated based on the PolyCad10.3 software.
- For the simulation of the accident, a visible trim of the pontoon, of ca. 0.76 m by the stern was taken into account.
- All calculations were made using standard methods used in assessing the parameters and stability of sea-going vessels.
- The analysis of photographs shows that the *T-6* pontoon had a small, constant tilt to starboard caused by unsymmetrical positioning of cargo in the hold.
- In the stability analysis of the pontoon the change of trim caused by the operation of the towline and longitudinal sway was not taken into account.
- The pontoon model used in the calculations of the subsequent stages of flooding had a watertight hold. This allowed the simulation to be carried out in relation to partial flooding of the hold.

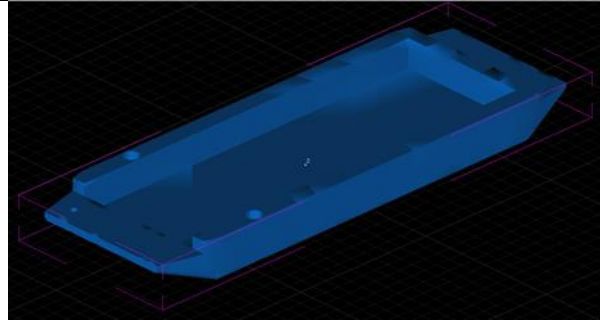
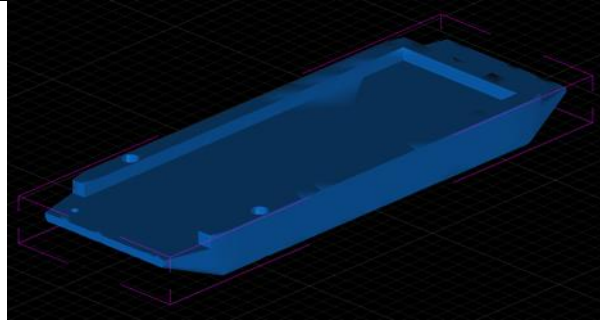
Model with untight hold	Model with tight hold
	

Table 2. Models assumed for hold flooding simulation

6.2. Observations Regarding the State of the *T-6* Pontoon According to the Hearings of the Crew of *Zeus*

After analyzing the depositions and statements of the crew, there were selected pieces of information relevant to the course of capsizing of the *T-6* pontoon.

Draught according to the tugboat's master:

- bow draught less than 1.50 m, TF < 1.50 m,
- stern draught more than 2.00 m, TA > 2.00 m,
- during towage there was a side wind (N) and a wave of about 1.00 m,
- the pontoon was swaying to the sides up to ca. 10°.



Values calculated from draughts declared by the master:

- draught at midship of ca. 1.75 m,
- trim more than 0.5 m by the stern.

Draught obtained from photographic analysis:

- bow draught of ca. 1.00 m,
- - trim of ca. 0.60 m by the stern,
- Stern draught of ca. 1.60 m.

Draught obtained during on-site verification (empty pontoon):

- bow draught: 0.82 m,
- stern draught: 0.82 m,
- trim $t = 0.00$ m.

6.3. Fastening of Cargo According to the Hearings of the Crew of Zeus

According to information received from the tugboat's crew, it appears that:

- no calculations and analyzes of accelerations and forces that could affect the transported load had been made,
- the load was fastened without the assumed and approved cargo restraint plan,
- no graphic of photographic documentation was prepared once the fixings had been completed,
- the load was fixed with a mixed system by using wire ropes (starboard/port side stern) and chains of unknown strength,
- additionally, fastening belts were used for fixing,
- excavators were connected with each other by fastening,
- no stoppers were welded,
- the number of fixing lines and their directions are unknown.

Based on the analysis of the above information, it appears that:

- fixing of the load was done carelessly,
- quantity and quality of the lashing lines may not have been adequate to secure the cargo during sea transport,
- each excavator was affected by transversal forces of ca. 20 t,



- ineffective fixing could have caused the load to break and move to one of the sides,
- from the photographic analysis it can be assumed that the shift could range from 1.50 m to 2.00 m to the side.

6.3.1. Acceleration and Forces Acting of the Excavators During Rolling of the Pontoon at 10° and Pitching at 5°. The Excavator CASE 81 t.

FORCES			ACCELERATIONS		
Forces - Transverse Direction			Final Accelerations (Motion + Wind)		
Force	Value	Units	Direction	Value	Units
Transverse Motion Force, F_{TM}	22.32	MT	Longitudinal (Max.), a_{Lmax}	0.111	g
Transverse Wind Load, F_{TW}	0.13	MT	Transverse (Max.), a_{Tmax}	0.277	g
Total Transverse Force, F_T	22.45	MT	Vertical (Max.), a_{Vmax}	1.209	g
			Vertical (Min.), a_{Vmin}	0.783	g
Forces - Longitudinal Direction					
Force	Value	Units			
Longitudinal Motion Force, F_{LM}	8.91	MT			
Longitudinal Wind Load, F_{LW}	0.06	MT			
Total Longitudinal Force, F_L	8.97	MT			
Forces - Vertical Direction					
Force	Value	Units			
Maximum Vertical Force, F_{VMAX}	97.97	MT			
Minimum Vertical Force, F_{VMAX}	63.42	MT			



6.3.2. Acceleration and Forces Acting of the Excavators During Rolling of the Pontoon at 10° and Pitching at 5°. The Excavator CASE 70.5 t.

FORCES			ACCELERATIONS		
Forces - Transverse Direction			Final Accelerations(Motion + Wind)		
Force	Value	Units	Direction	Value	Units
Transverse Motion Force, F_{TM}	19.43	MT	Longitudinal (Max.), a_{Lmax}	0.111	g
Transverse Wind Load, F_{TW}	0.13	MT	Transverse (Max.), a_{Tmax}	0.277	g
Total Transverse Force, F_T	19.55	MT	Vertical (Max.), a_{Vmax}	1.231	g
			Vertical (Min.), a_{Vmin}	0.762	g
Forces - Longitudinal Direction					
Force	Value	Units			
Longitudinal Motion Force, F_{LM}	7.75	MT			
Longitudinal Wind Load, F_{LW}	0.06	MT			
Total Longitudinal Force, F_L	7.82	MT			
Forces - Vertical Direction					
Force	Value	Units			
Maximum Vertical Force, F_{VMAX}	86.75	MT			
Minimum Vertical Force, F_{VMAX}	53.71	MT			

6.4. Simulation of the Accident

In order to explain why the pontoon had capsized, calculations simulating its behaviour in various states were made.

To analyze the behavior of the *T-6* pontoon during towage, the following accident scenarios have been established:

A. The pontoon loaded symmetrically. The load does not move during sway.

- The *T-6* pontoon is trimmed by the stern due to the distribution of the load.
- During the sea voyage the pontoon is swaying to the sides up to ca. 10°.



- As a result of swaying, the points of flooding get into the water, the water enters the hold.
- Water accumulates in the aft part of the hold. This increases the trim by the stern and thus increases the amount and frequency of water entering the hold.
- After obtaining a sufficiently large trim of the pontoon, water abruptly gets inside the hold.
- This causes a rapid increase in trim by the stern and loss of stability.
- The pontoon capsizes.

B. The pontoon loaded asymmetrically. The load does not move during sway.

- The *T-6* pontoon is trimmed by the stern due to the distribution of the load.
- During the sea voyage the pontoon is swaying to the sides up to ca. 10°.
- As a result of swaying, the points of flooding get into the water, the water enters the hold.
- Water accumulates in the aft part of the hold. This increases the trim by the stern and thus increases the amount and rate of water entering the hold.
- Due to asymmetrical loading, the righting arms diminish and the trim of the pontoon gets deeper and deeper.
- After getting a lot of water, free surfaces of the liquid cause the pontoon to capsize.

C. The pontoon loaded symmetrically. The load can move during sway.

- The *T-6* pontoon is trimmed by the stern due to the distribution of the load.
- During the sea voyage the pontoon is swaying to the sides up to ca. 10°.
- As a result of swaying, the points of flooding get into the water, the water enters the hold.
- Water accumulates in the aft part of the hold. This increases the trim by the stern and thus increases the amount and frequency of water entering the hold.
- The load is dynamically shifted to one of the sides. The dynamic tilting moment is ca. 303 mt (graphic analysis of the excavators' position in the hold).

All scenarios have the following end:

- The pontoon capsizes,
- cargo and wooden planks fall off the pontoon,



- the pontoon maintains buoyancy in the capsized position.

	Pontoon's parametres		
	On-site verification	Before loading	After loading
Weight	254 t	259 t	410 t
Medium draught	0.82 m	0.84 m	1.29 m
Bow draught	0.82 m	0.84 m	0.91 m
Stern draught	0.82 m	0.84 m	1.67 m
Trim	0.00 m	0.00 m	0.76 m
Distance of the points of flooding from water surface	1.180 m	1.160 m	0.402 m
Angle of flooding	17.4°	16.8°	4.9°

Table 3. Data obtained from moulding of the shape and weight of the load placed on deck of the T-6 pontoon

6.4.1. Condition 1

The T-6 pontoon with the excavators in the hold, loaded symmetrically with no water inside the hold.

No	Description	Weight	x	z	Mx	Mz
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60
2	Constant	5.00	16.39	2.00	81.95	10.00
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30
5	Water in the hold				0.00	0.00
6	Total	410.50	14.67	1.58	6022.74	650.32
7	Deadweight	156.50	[t]			

Table 4. Mass table. Condition 1. The pontoon with the cargo of excavators

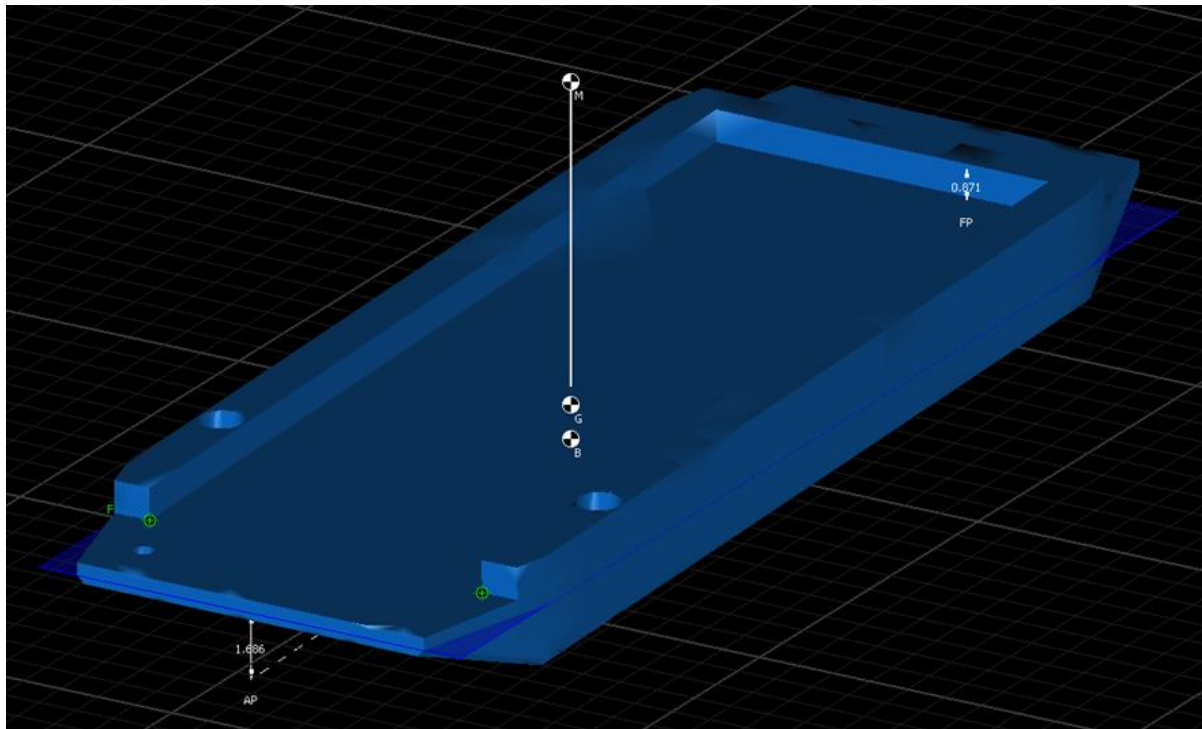


Figure 10. The T-6 pontoon loaded with excavators. No side trim. Condition 1

1	Medium draught	T	1.29	m
2	Trim	t	-0.76	m
3	Bow draught	TF	0.91	m
4	Stern draught	TA	1.67	m
5	Height of the centre of mass	z_G	1.58	m
6	Free surface of liquid correction	ΔGM	0.00	m
7	Height of the centre of mass correction	$z_{G'}$	1.58	m
8	Metacentric height	GM'	8.10	m
9	Angle of flooding	φ_{Flood}	4.9	°

Table 5. Righting arms and work of GZ. Condition 1

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0
5	0.705	0.031
10	1.350	0.121
15	1.786	0.257
20	1.898	0.418
25.1	1.864	0.582
30.1	1.768	0.741
35.1	1.641	0.889
40.2	1.492	1.026
50.3	1.148	1.257
60.4	0.765	1.424
70.3	0.365	1.522
80.2	-0.039	1.551

Diagram of righting arms

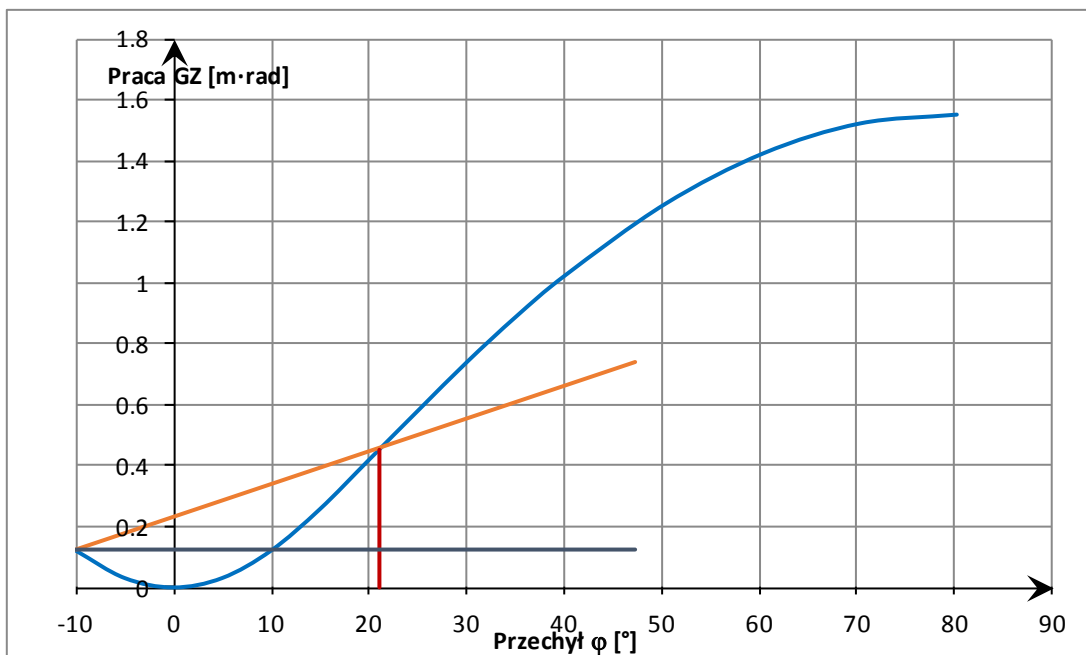
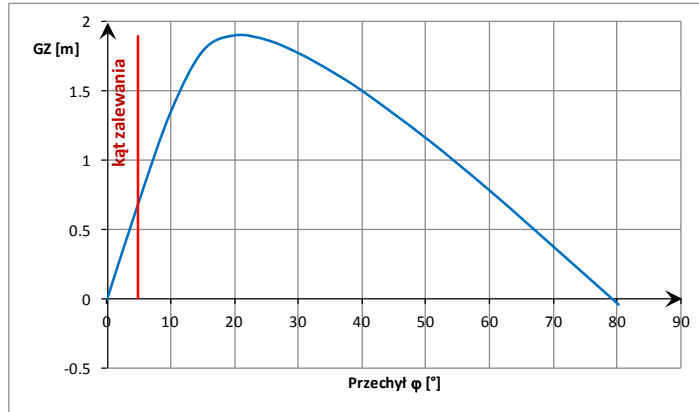


Figure 11. Dynamic heel of the pontoon due to transverse shifting of the excavators

Conclusions:

- Water can get inside the hold when the pontoon is side swaying of ca. 5°.
- Small amounts of water get inside at maximum sway.
- The assumed displacement of excavators together with a 10° sway would cause a uncontrolled tilt of up to ca. 21°, which would not cause the pontoon to capsize.

6.4.1.1. Condition 1A

The pontoon loaded as in the Condition 1; asymmetrically ($y_G = 0.191$ m). The list of the pontoon 1.4° to starboard.

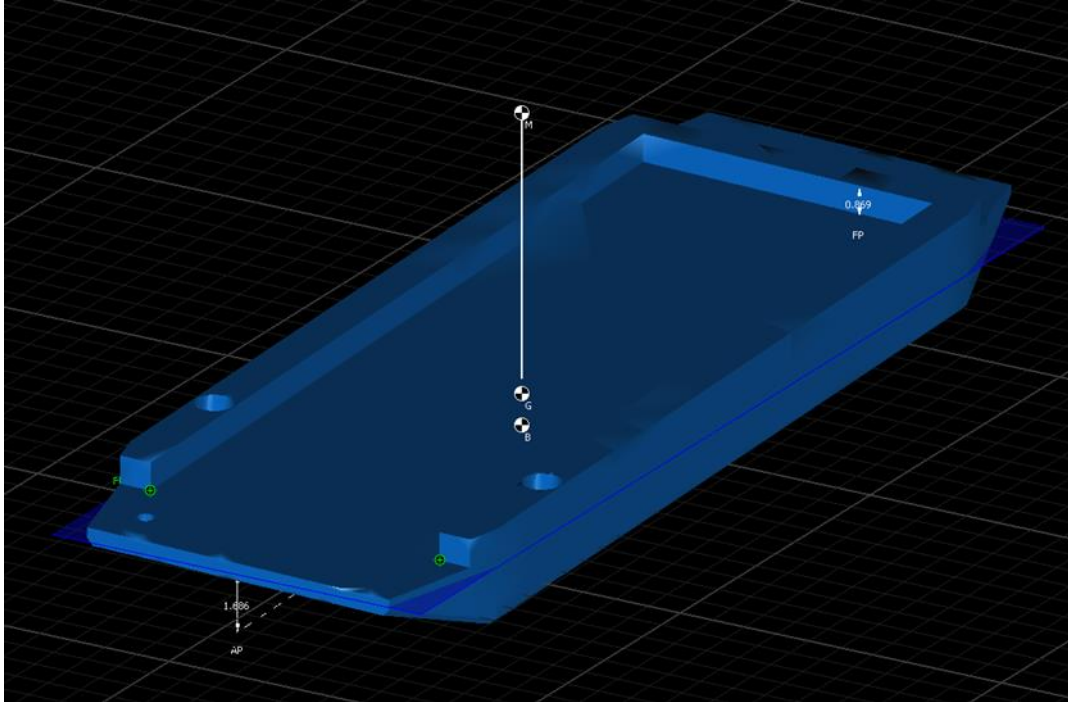


Figure 1: The T-6 pontoon loaded with excavators. The pontoon with list 1.4° . Condition 1A



Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0
5	0.705	0.031
10	1.350	0.121
15	1.786	0.257
20	1.898	0.418
25	1.864	0.582
30	1.768	0.741
35	1.641	0.889
40	1.492	1.026
50	1.148	1.257
60	0.765	1.424
70	0.365	1.522
80	-0.039	1.551

Diagram of righting arms

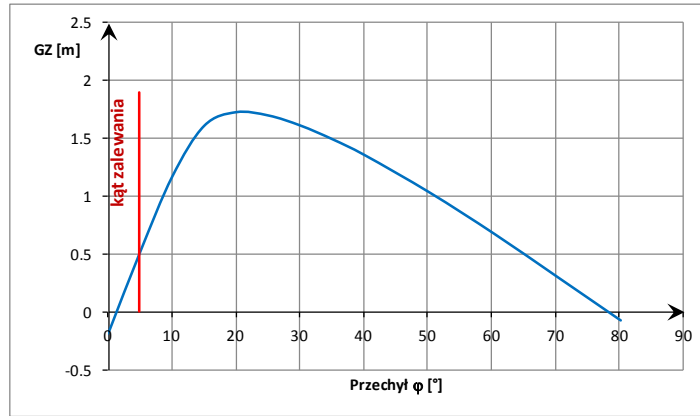


Table 6. Righting arms; work of GZ. Condition 1A

- The pontoon loaded with excavators is sailing with a constant list of 1.4°, which is not dangerous for the pontoon.

6.4.2. Condition 2

The T-6 pontoon with excavators in the hold, loaded symmetrically with 20 t of water inside the hold.

No	Description	Weight	x	z	Mx	Mz	FSM
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60	
2	Constant	5.00	16.39	2.00	81.95	10.00	
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42	
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30	
5	Water in the hold	20.00	4.00	1.00	80.00	20.00	699
6	Total				0.00	0.00	
7	Deadweight	430.50	14.18	1.56	6102.74	670.32	699
8		176.50	[t]				

Table 7. Mass table. Condition 2. The pontoon with the cargo of excavators

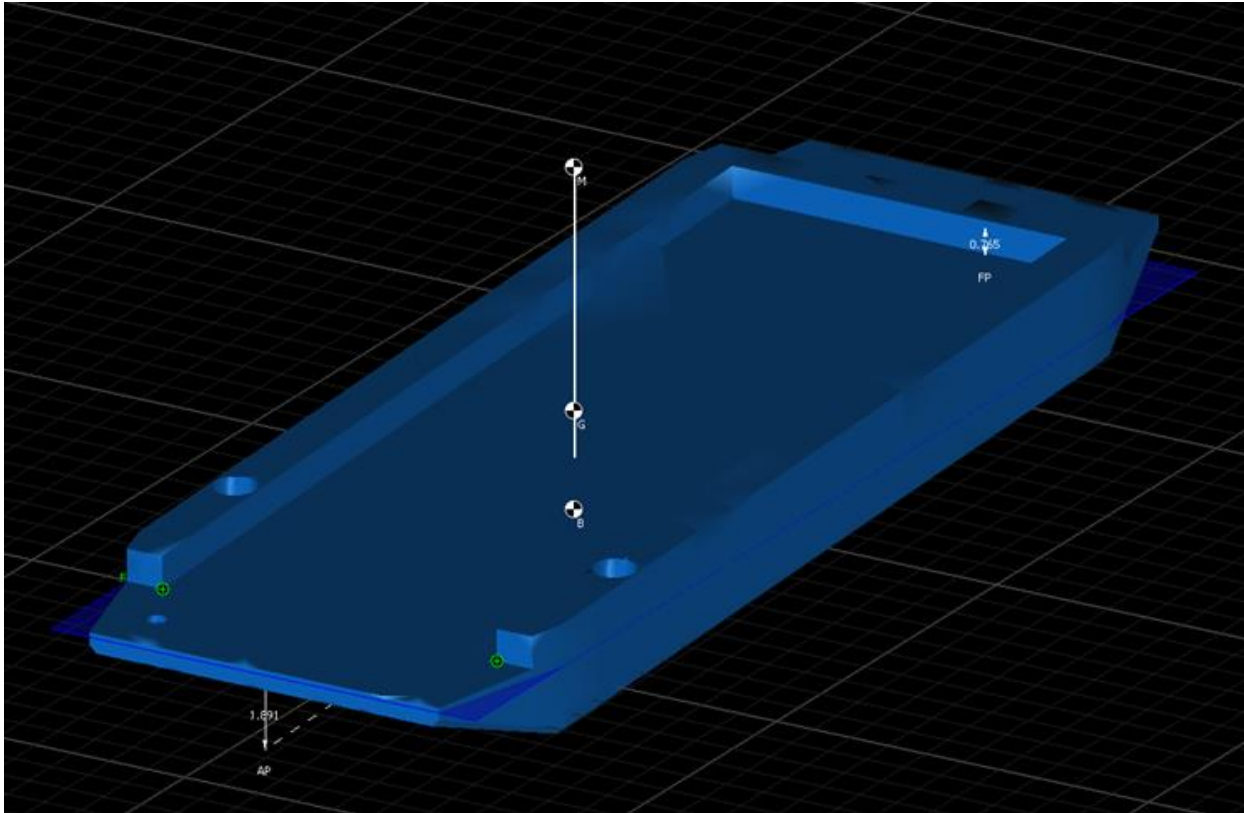


Figure 12. The T-6 pontoon loaded with excavators. Without list. Condition 2

1	Medium draught	T	1.33	m
2	Trim	t	-1.10	m
3	Bow draught	TF	0.78	m
4	Stern draught	TA	1.88	m
5	Height of the centre of mass	z_G	1.56	m
6	Free surface of liquid correction	ΔGM	1.62	m
7	Height of the centre of mass correction	$z_{G'}$	3.18	m
8	Metacentric height	GM'	6.07	m
9	Angle of flooding	φ_{Flood}	2.6	°

Table 8. Parameters of the loaded pontoon with 20 t of water in the hold

Angle of heel ϕ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0
5	0.512	0.022
10	0.942	0.086
15	1.133	0.176
20	1.073	0.273
25	0.901	0.359
30	0.680	0.428
35	0.437	0.476
40	0.182	0.503
50	-0.334	0.490
60	-0.829	0.389
70	-1.282	0.204
80	-1.686	-0.055

Diagram of righting arms

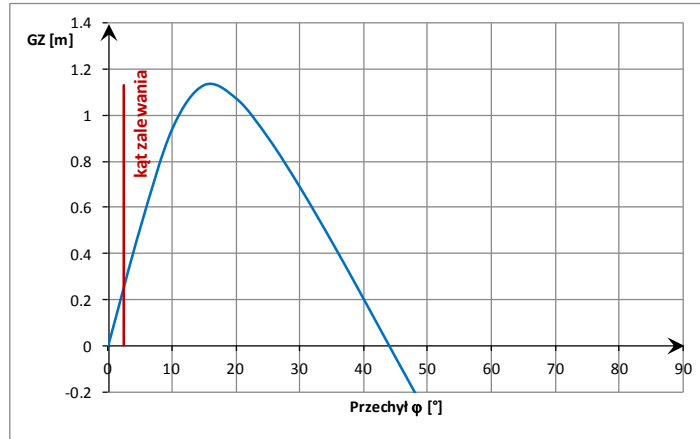


Table 9. Righting arms, work of righting arms. Condition 2

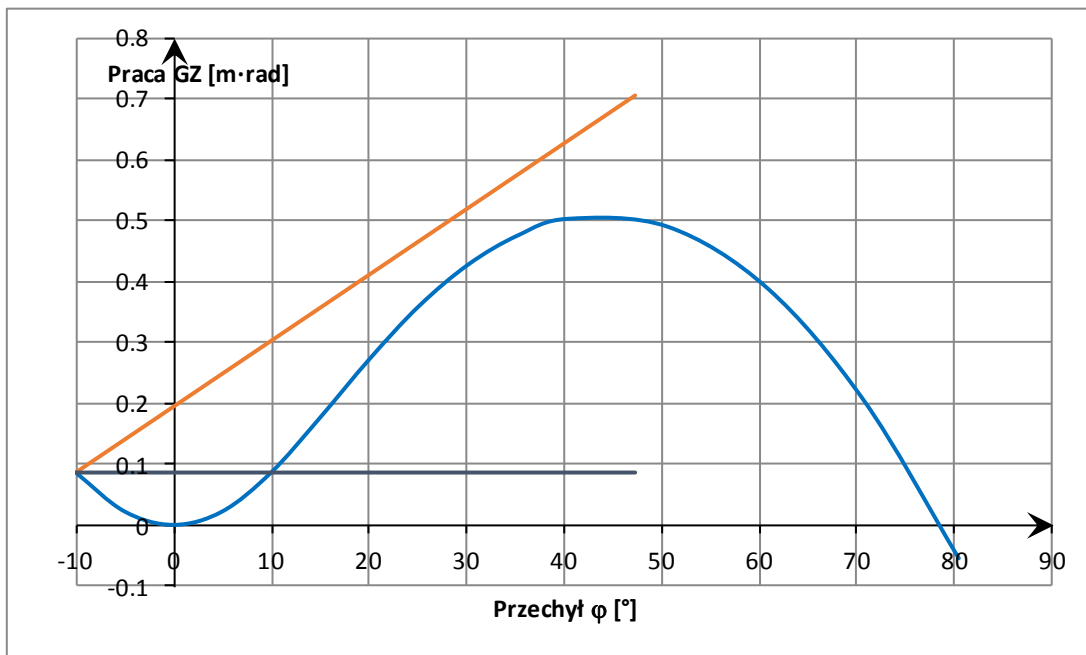


Figure 13. Uncontrolled tilt of the pontoon due to transverse shifting of the excavators

Conclusions:

- Water can get inside the hold when the pontoon is side swaying of ca. 2.6°.
- Large amounts of water get inside with subsequent sways.
- The assumed displacement of excavators together with a 10° rolling would cause a uncontrolled capsizing of the pontoon.

According to scenario C (shifting of the cargo) the pontoon capsized.

6.4.2.1. Condition 2A

The T-6 pontoon loaded as in the Condition 2; asymmetrically ($y_G = 0.182\text{m}$). List 1.7° .

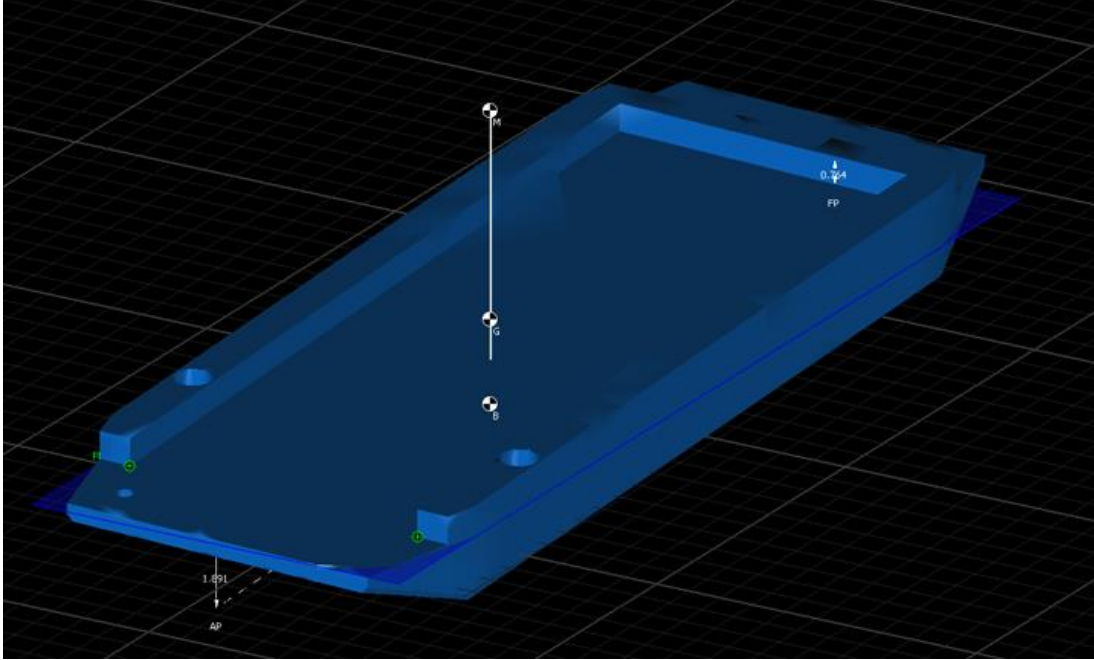


Figure 14. The T-6 pontoon loaded with excavators. The pontoon with list 1.7° . Condition 2A

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.180	0.003
5	0.333	0.009
10	0.765	0.057
15	0.959	0.133
20	0.905	0.214
25	0.740	0.286
30	0.528	0.341
35	0.294	0.377
40	0.050	0.392
50	-0.441	0.358
60	-0.909	0.240
70	-1.335	0.044
80	-1.713	-0.222

Diagram of righting arms

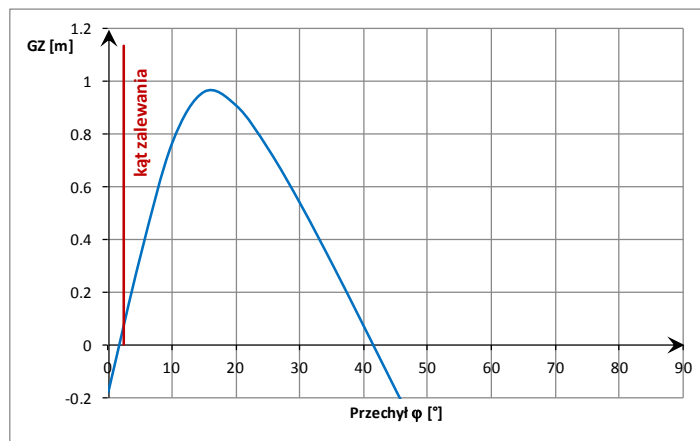


Table 10: Righting arms, work of righting arms. Condition 2A

- The pontoon loaded with excavators is floating with a constant list of 1.7°, which is not dangerous for the pontoon.

6.4.3. Condition 3

The T-6 pontoon with excavators in the hold with 40 t of water inside the hold. No initial tilt.

LP	Description	Weight	x	z	Mx	Mz	FSM
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60	
2	Constant	5.00	16.39	2.00	81.95	10.00	
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42	
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30	
5	Water in the hold	40.00	4.00	1.00	160.00	40.00	876
6	Total	450.50	13.72	1.53	6182.74	690.32	876
7	Deadweight	196.50	[t]				

Table 10. Mass table. Condition 3

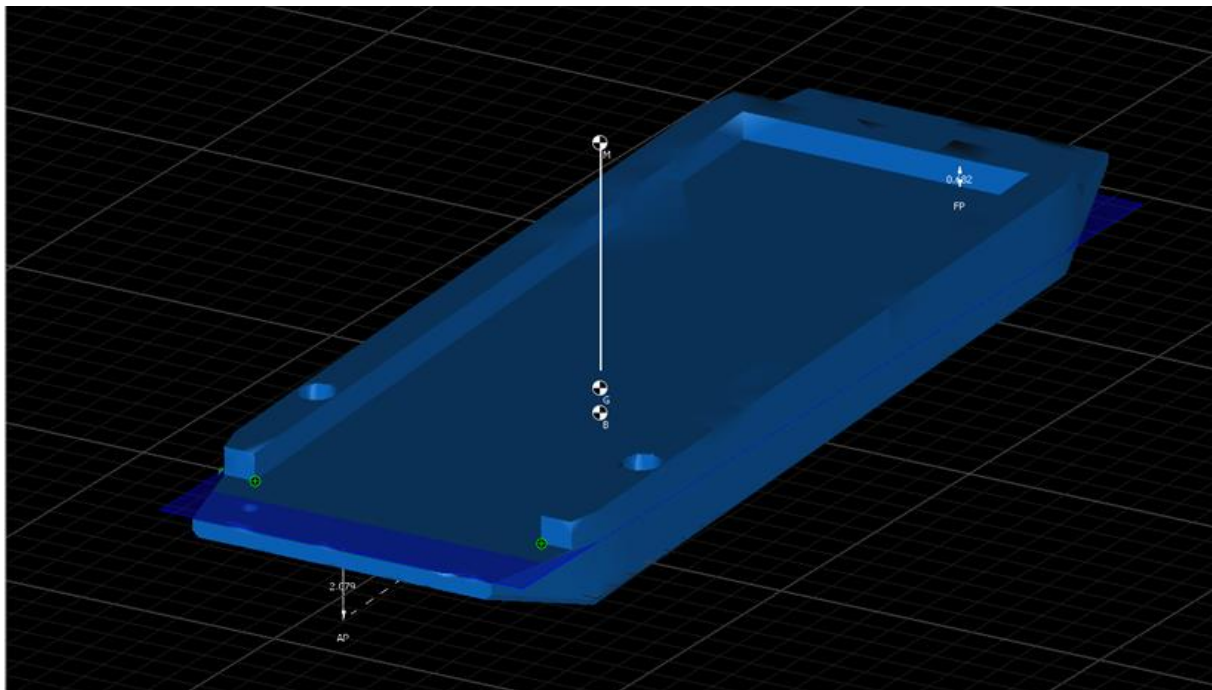


Figure 15. The T-6 pontoon loaded with excavators with water inside the hold. Condition 3



1	Medium draught	T	1.38	m
2	Trim	t	-1.40	m
3	Bow draught	TF	0.68	m
4	Stern draught	TA	2.08	m
5	Height of the centre of mass	z_G	1.53	m
6	Free surface of liquid correction	ΔGM	1.94	m
7	Height of the centre of mass correction	$z_{G'}$	3.48	m
8	Metacentric height	GM'	5.16	m
9	Angle of flooding	φ_{Flood}	0.5	°

Table 11. Parametres of the loaded pontoon with 40 t of water in the hold

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0.000
5	0.413	0.018
10	0.733	0.068
15	0.801	0.135
20	0.679	0.200
25	0.471	0.250
30	0.222	0.280
35	-0.046	0.288
40	-0.318	0.272
50	-0.841	0.171
60	-1.307	-0.017
70	-1.707	-0.280
80	-2.049	-0.607

Diagram of righting arms

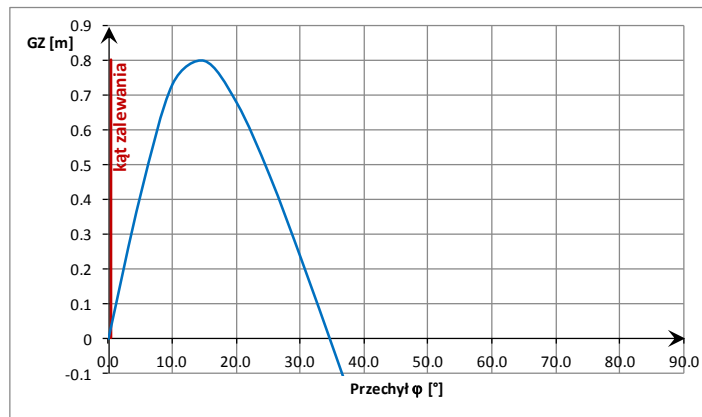


Table 12. Righting arms, work of righting arms. Condition 3

Uncontrolled shifting of the excavators (MH = 303 mt) might have caused the capsizing of the pontoon.

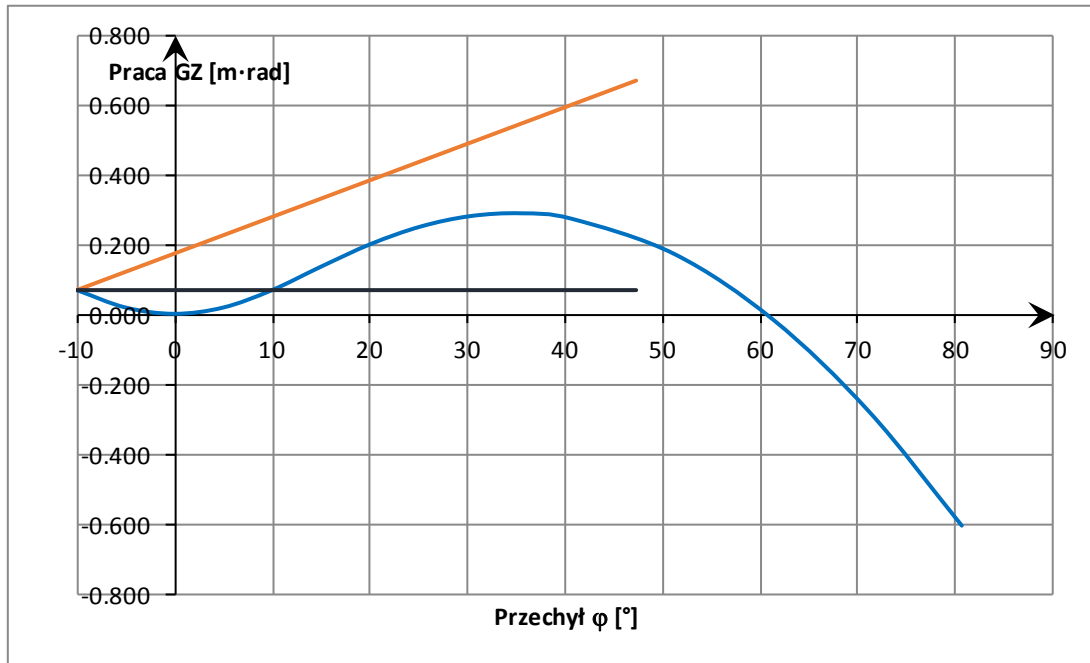


Figure 16. Moment of tilting due to uncontrolled shifting of the excavators

Conclusions:

- Water can get inside the hold when the pontoon is side rolling of ca. 0.5° .
- Large amounts of water get inside with subsequent sways.
- The assumed shifting of excavators together with a 10° rolling would cause an uncontrolled capsizing of the pontoon.

According to scenario C (shifting of the cargo) the pontoon capsized.

6.4.3.1. Condition 3A

The T-6 pontoon loaded as in the Condition 3; asymmetrically ($y_G = 0.174$ m).

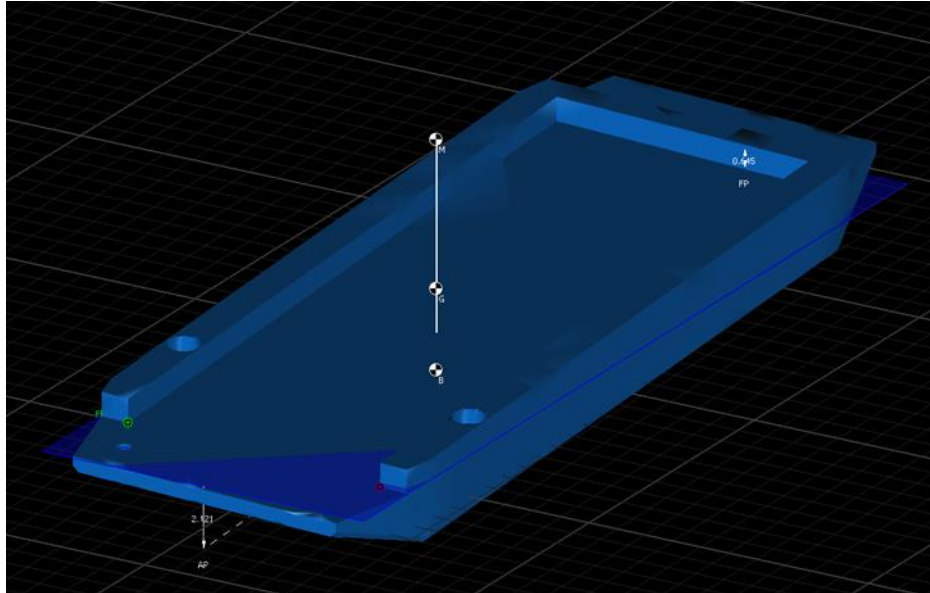


Figure 17. Condition 3A. The pontoon with list 1.9°

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.18	0.003
5	0.234	0.006
10	0.556	0.040
15	0.628	0.092
20	0.512	0.142
25	0.311	0.178
30	0.072	0.194
35	-0.184	0.189
40	-0.444	0.162
50	-0.940	0.041
60	-1.381	-0.161
70	-1.756	-0.435
80	-2.074	-0.769

Diagram of righting arms

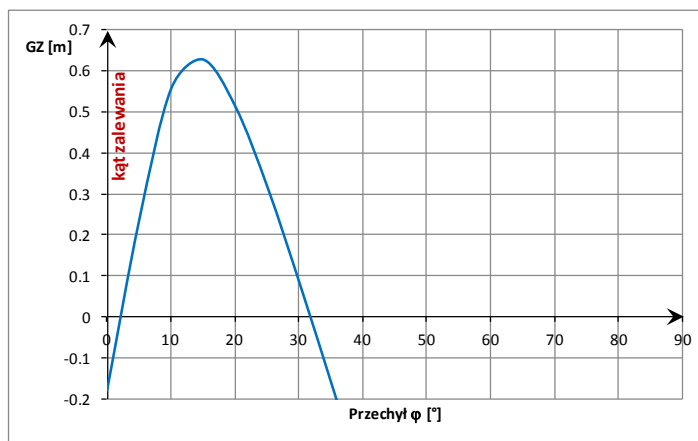


Table 13. Righting arms, work of righting arms

The pontoon with a constant list of 1.8° is taking water continually and loses its buoyancy

6.4.4. Condition 4

The T-6 pontoon with excavators in the hold with 60 t of water inside the hold. No initial list.

LP	Description	Weight	x	z	Mx	Mz	FSM
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60	
2	Constant	5.00	16.39	2.00	81.95	10.00	
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42	
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30	
5	Water in the hold	60.00	4.00	1.10	240.00	66.00	885
6	Total	470.50	13.31	1.52	6262.74	716.32	885
7	Deadweight	216.50	[t]				

Table 14. Mass table. Condition 4

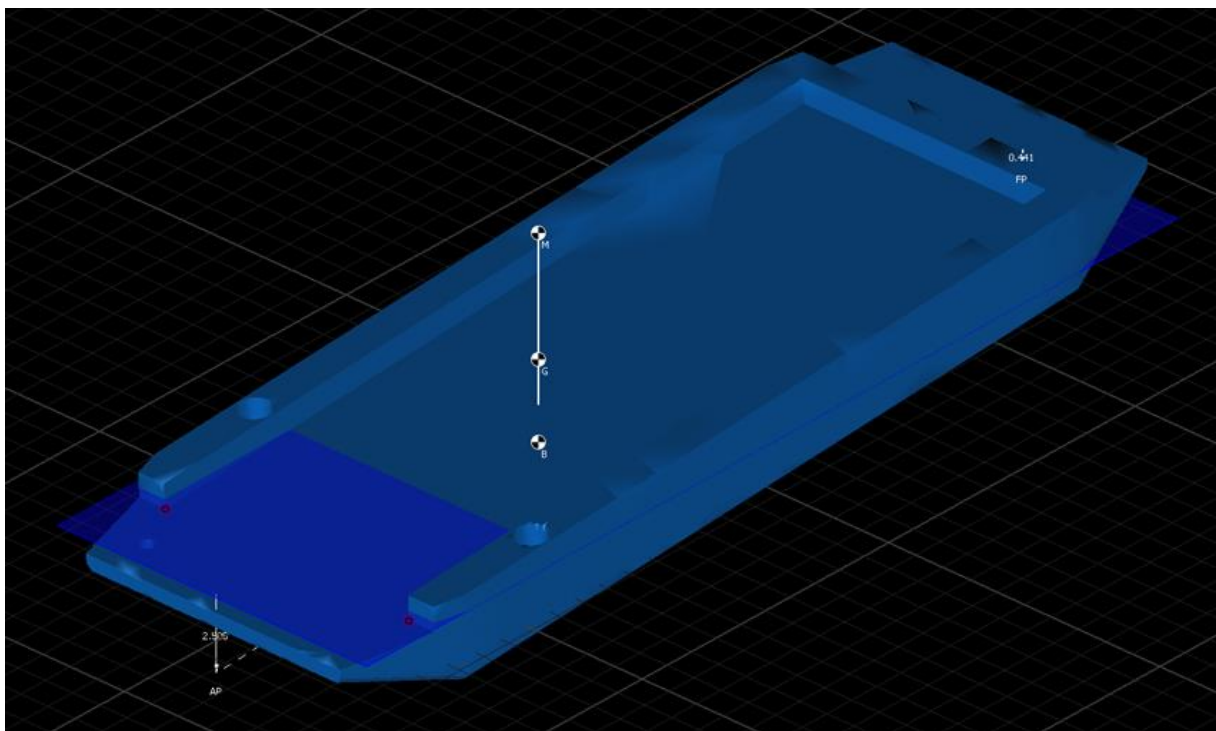


Figure 18. The pontoon without tilt. Condition 4



1	Medium draught	T	1.47	m
2	Trim	t	-2.06	m
3	Bow draught	TF	0.44	m
4	Stern draught	TA	2.51	m
5	Height of the centre of mass	z_G	1.52	m
6	Free surface of liquid correction	ΔGM	1.88	m
7	Height of the centre of mass correction	$z_{G'}$	3.40	m
8	Metacentric height	GM'	4.02	m
9	Angle of flooding	φ_{Flood}	-	°

Table 15. Parameters of the pontoon with 60 t of water in the hold. Condition 4

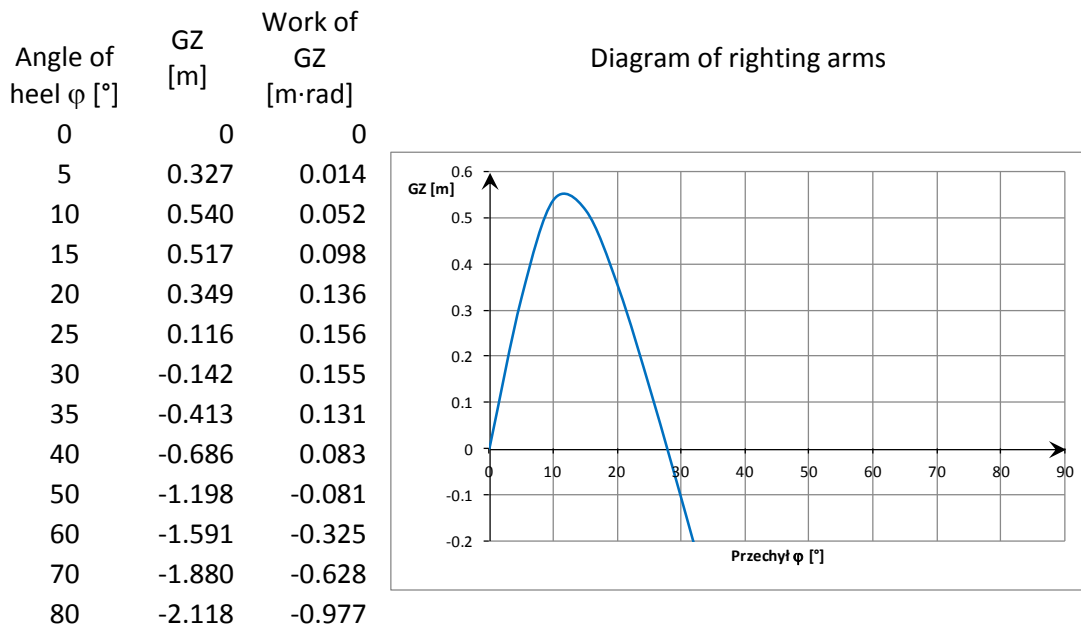


Table 16. Righting arms, work of GZ. Condition 4

Conclusions:

- Taking of 60 t of water into the hold causes deeper trim of the pontoon by the stern and the increase of flooding of the hold. The pontoon does not lose its buoyancy.

6.4.4.1. Condition 4A

The pontoon loaded as in the Condition 4 with water in the hold and shifted centre of mass ($y_G = 0.18$ m).

Angle of heel ϕ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.180	0.004
5	0.148	0.003
10	0.363	0.025
15	0.346	0.056
20	0.184	0.079
25	-0.039	0.086
30	-0.286	0.071
35	-0.542	0.035
40	-0.796	-0.023
50	-1.264	-0.203
60	-1.631	-0.455
70	-1.907	-0.764
80	-2.134	-1.117

Diagram of righting arms

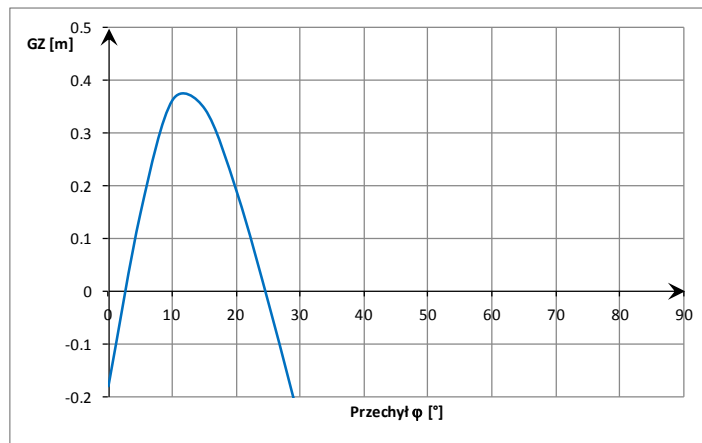


Table 17. Righting arms, work of righting arms. State 4A

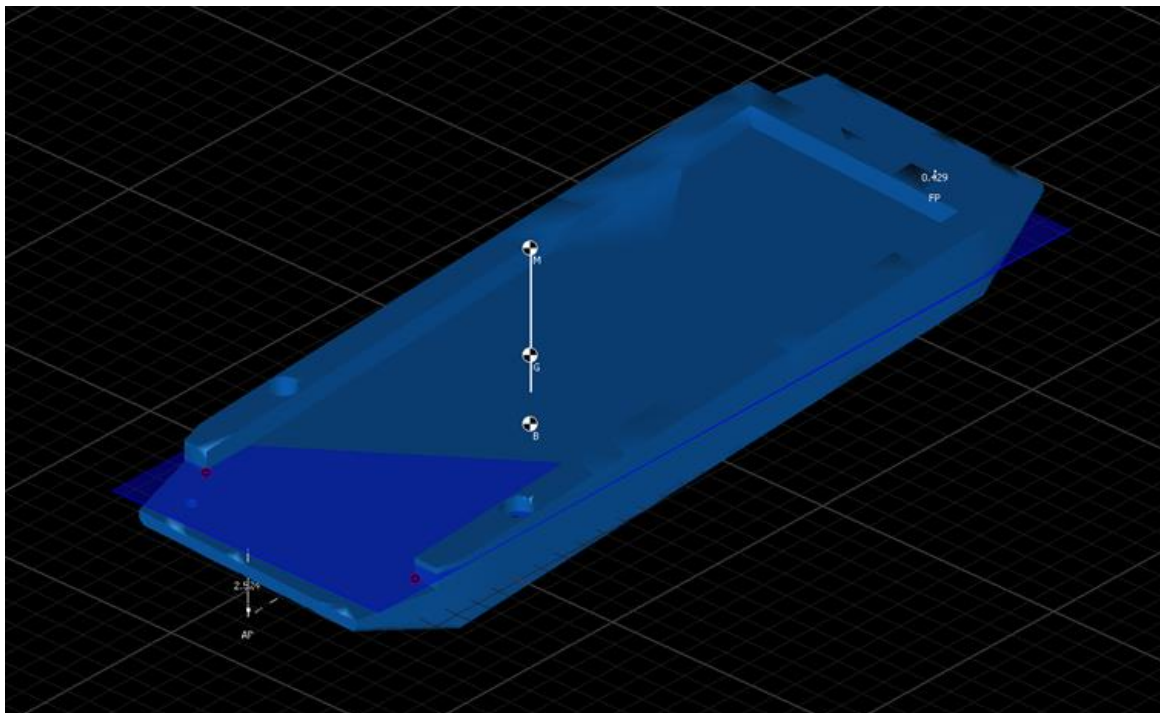


Figure 19. Condition 3A. The pontoon with list 2.5°

Conclusions:

- The pontoon gets list 2.5° due to uneven loading.
- The pontoon does not lose its stability.
- The pontoon loses its buoyancy.

6.4.5. Condition 5

The T-6 pontoon with the excavators in the hold. 80 t of water in the hold. No initial list.

LP	Description	Weight	x	z	Mx	Mz	FSM
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60	
2	Constant	5.00	16.39	2.00	81.95	10.00	
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42	
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30	
5	Water in the hold	80.00	4.00	1.12	320.00	89.60	824
6	Total	490.50	12.93	1.51	6342.74	739.92	824
7	Deadweight	236.50	[t]				

Table 18. Mass table. Condition 5

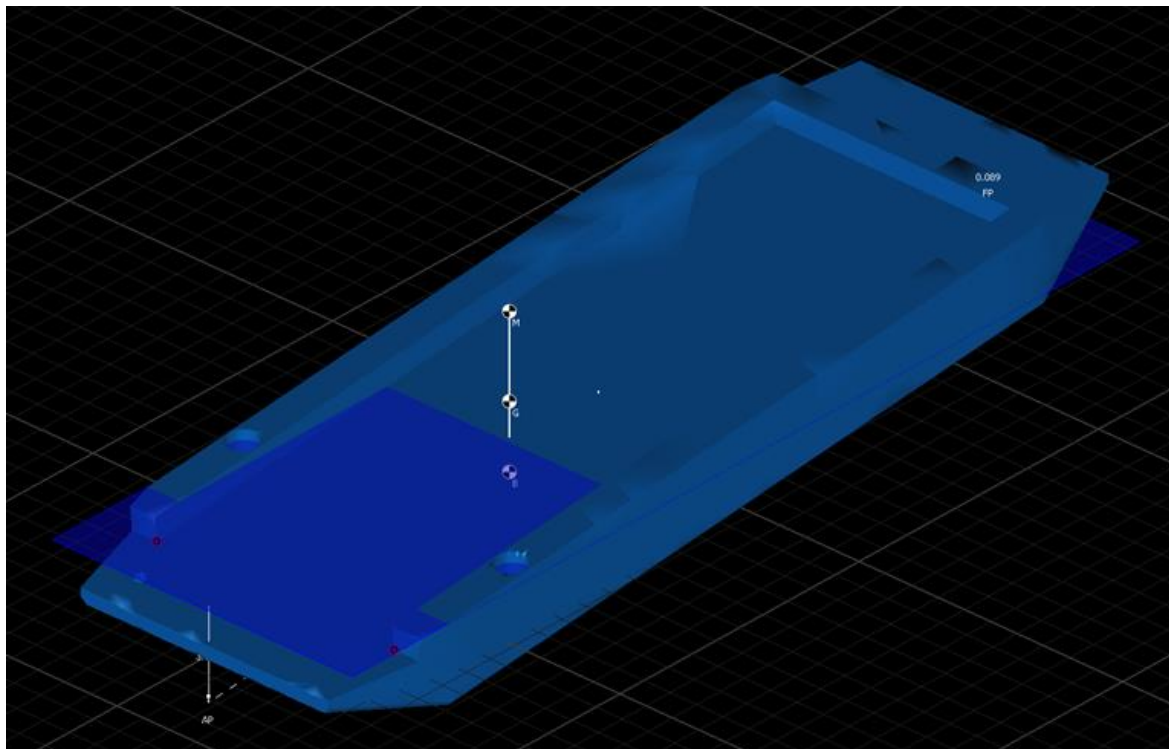


Figure 20. Condition 5. The pontoon without list



1	Medium draught	T	1.64	m
2	Trim	t	-3.10	m
3	Bow draught	TF	0.09	m
4	Stern draught	TA	3.19	m
5	Height of the centre of mass	z_G	1.51	m
6	Free surface of liquid correction	ΔGM	1.68	m
7	Height of the centre of mass correction	$z_{G'}$	3.19	m
8	Metacentric height	GM'	2.93	m
9	Angle of flooding	φ_{Flood}	-	°

Table 19. Parametres of the pontoon with 60 t of water in the hold. State 5

Angle of tilt φ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0
5	0.234	0.010
10	0.319	0.034
15	0.233	0.058
20	0.008	0.069

Diagram of righting arms

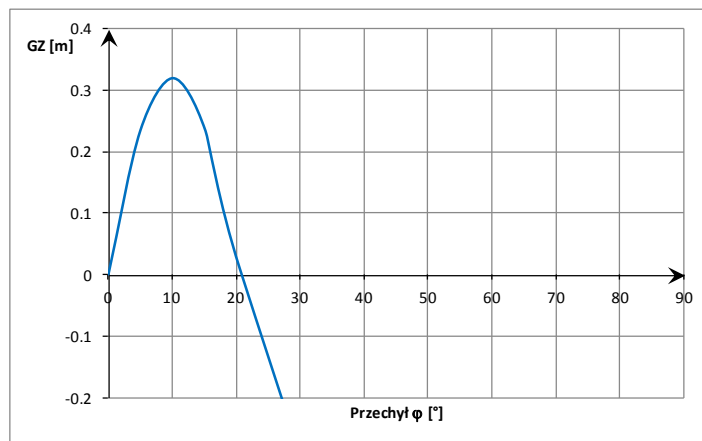


Table 20. Righting arms, work of righting arms. State 5

Conclusions:

- After getting of 80 t of water into the hold, righting arms diminish drastically to 0.32 m.
- The pontoon does not lose its stability.
- The pontoon loses its buoyancy.

6.4.5.1. State 5A

The pontoon loaded as in the State 5 with water in the hold and shifted centre of mass ($y_G = 0.18$).

Angle of tilt φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.180	0.006
5	0.055	0.001
10	0.144	0.009
15	0.064	0.018
20	-0.143	0.015

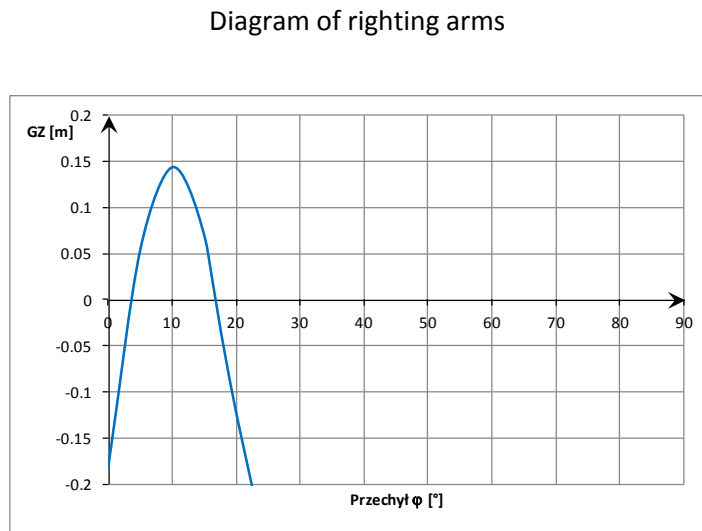


Table 21. Righting arms, work of righting arms. State 5A

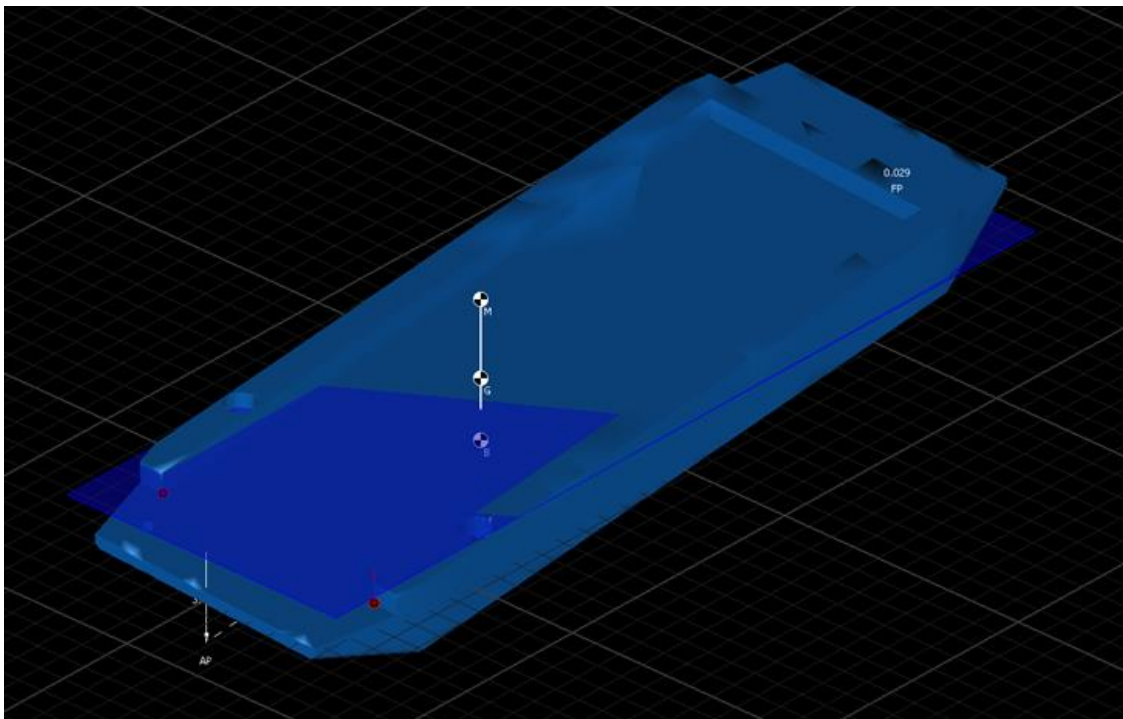


Figure 21. State 5A. The pontoon with 3.2° tilt

Conclusions:

- The pontoon gets 3.2° tilt due to uneven loading.
- The pontoon does not lose its stability.
- The pontoon loses its buoyancy.

6.4.6. State 6

The T-6 pontoon with the excavators in the hold. 90 t of water in the hold. No initial tilt.

LP	Description	Weight	x	z	Mx	Mz	FSM
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60	
2	Constant	5.00	16.39	2.00	81.95	10.00	
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42	
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30	
5	Water in the hold	90.00	4.00	1.48	360.00	133.20	802
6	Total	500.50	12.75	1.57	6382.74	783.52	802
7	Deadweight	246.50	[t]				

Table 22. Mass table. State 6

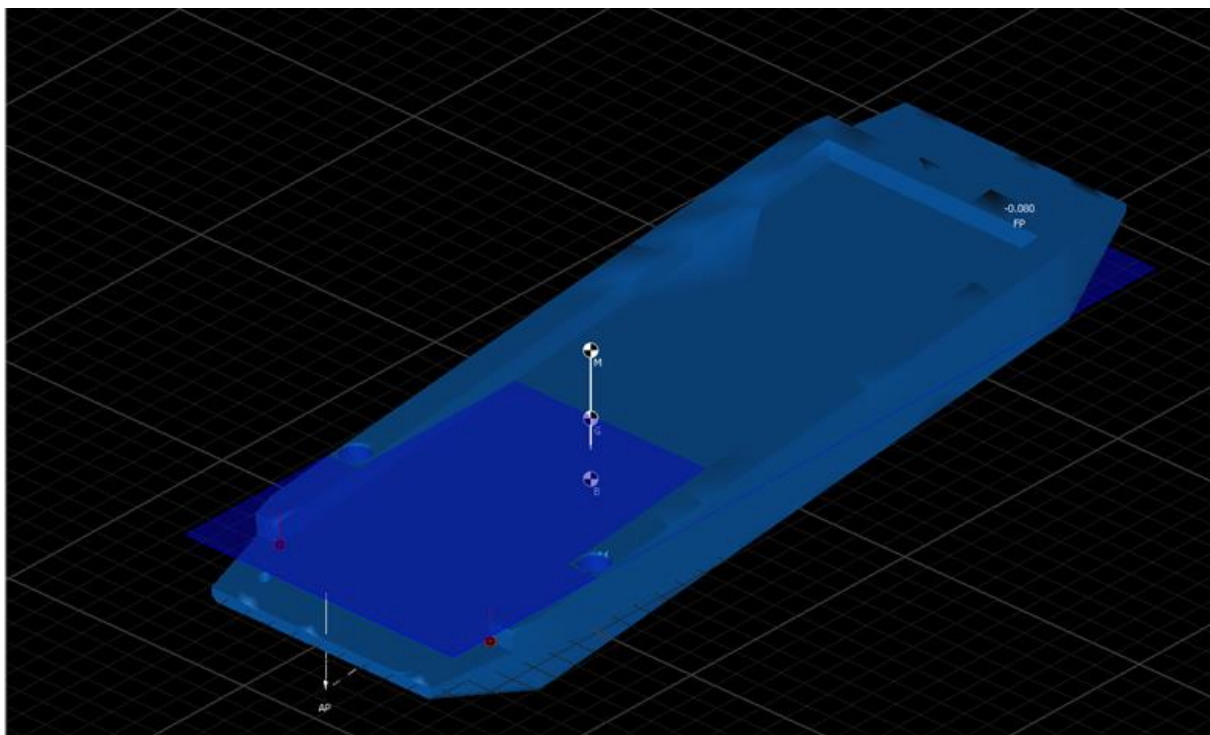


Figure 22. State 6. The pontoon without tilt



1	Medium draught	T	1.90	m
2	Trim	t	-3.60	m
3	Bow draught	TF	-0.37	m
4	Stern draught	TA	4.17	m
5	Height of the centre of mass	z_G	1.57	m
6	Free surface of liquid correction	ΔGM	1.60	m
7	Height of the centre of mass correction	$z_{G'}$	3.17	m
8	Metacentric height	GM'	2.49	m
9	Angle of flooding	φ_{Flood}	-	°

Table 23. Parametres of the pontoon with 90 t of water in the hold. Condition 6

Angle of list φ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0
1	0.035	0
2	0.067	0.001
3	0.098	0.003
4	0.118	0.005
5	0.11	0.005
9	0	0.006

Diagram of righting arms

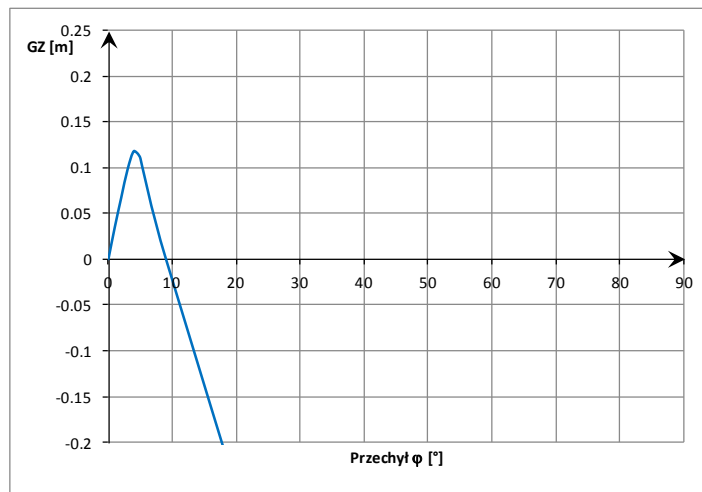


Table 24. Righting arms, work of righting arms. State 6

Conclusions:

- After getting of 90 t of water into the hold, righting arms diminish drastically to 0.12 m.
- The pontoon does not lose its stability.
- The pontoon may capsize at the raolling of 9°.

6.4.6.1. Condition 6A

Taking into regard an additional transversal shift of the centre of mass the pontoon capsized.

Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	-0.18	0
1	-0.145	0
2	-0.113	0
3	-0.082	0
4	-0.061	0
10	-0.180	0

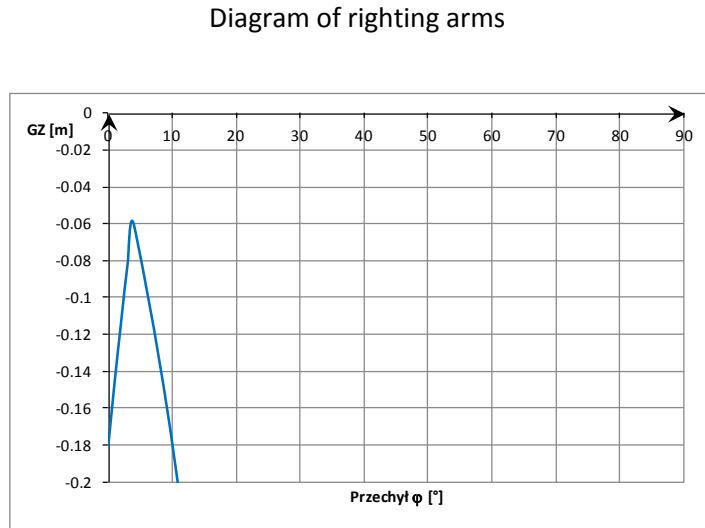


Table 25. Righting arms, work of righting arms. Condition 6

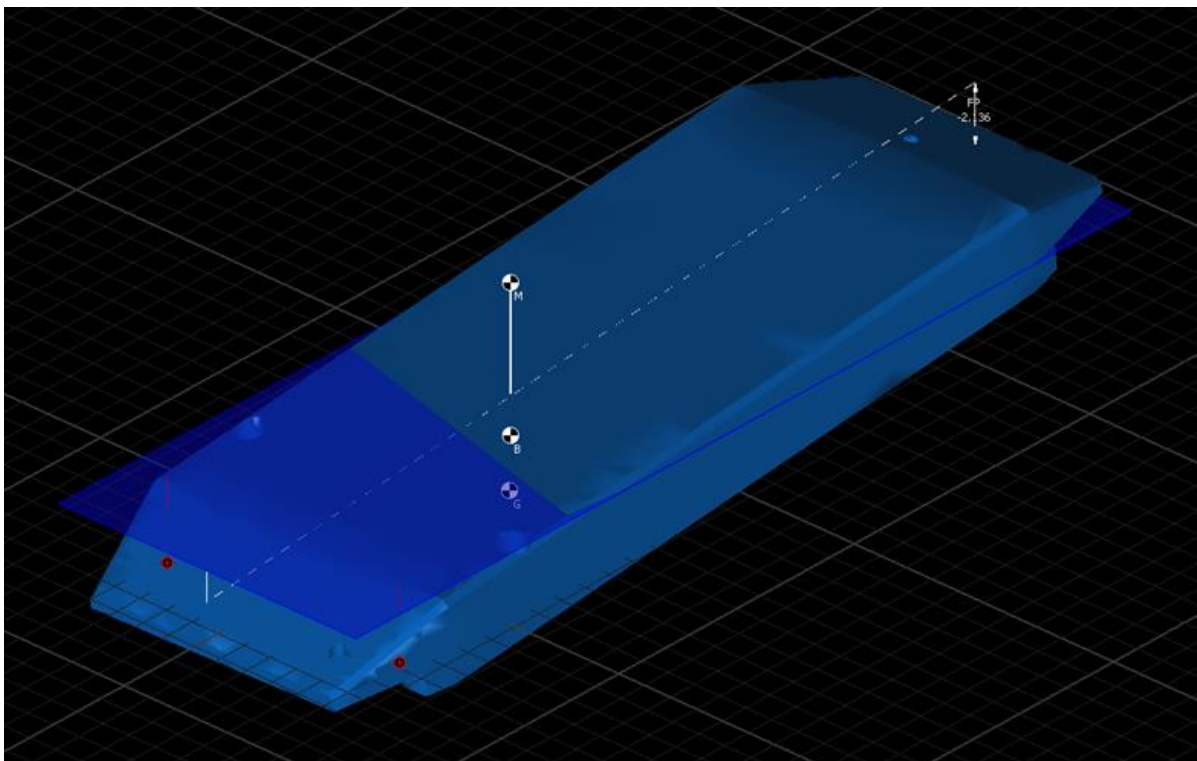


Figure 23. Condition 6A. The pontoon capsized due to transversal shifting of the centre of mass

Conclusions:

- Taking into regard transversal shifting of the centre of mass of the pontoon and getting 90 t of water into the hold the pontoon loses its stability and capsizes.

According to scenario B (asymmetrical load) the pontoon loses its stability.

6.4.7. Condition 7

There are 94 t of water in the hold. The pontoon is loaded symmetrically.

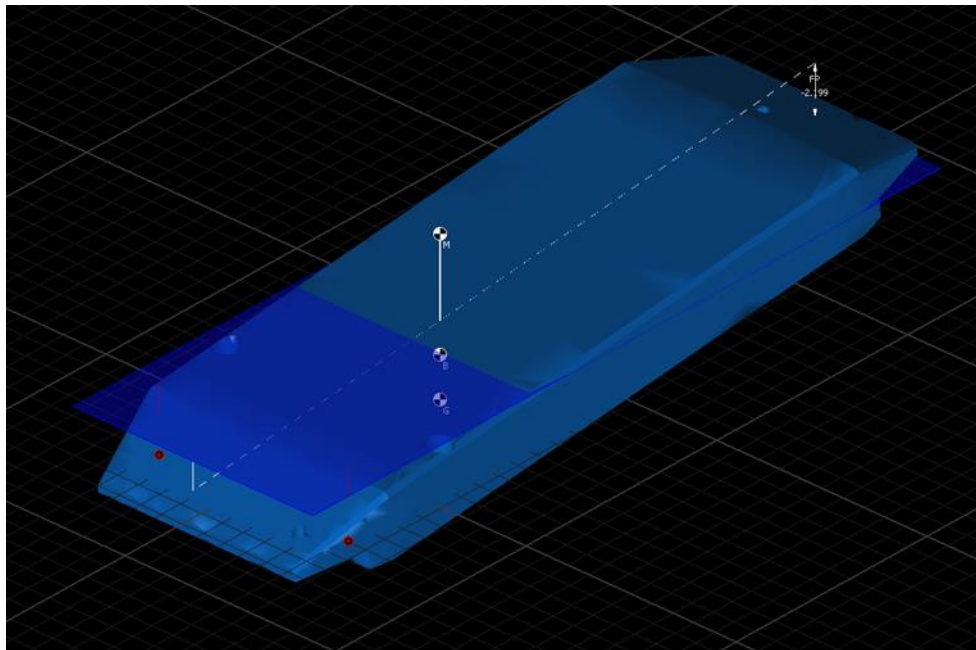


Figure 24. Condition 7. The pontoon capsized due to excessive trim

$$t = -5.65 \text{ m}$$

Conclusions:

- After getting 94 t of water into the hold the pontoon loses its stability and capsizes despite its symmetrical loading.

According to scenario A (symmetrical load) the pontoon loses its stability.



6.5. Stability of the T-6 Pontoon According to Intact Stability Code 2008

The stability of the T-6 pontoon had not been checked before the commencement of the voyage. In order to verify the stability of the T-6 pontoon, the criteria were checked according to the requirements of the Intact Stability Code (Appendix 1). State 1 undergoes checking.

No	Description	Mass	x	z	Mx	Mz
1	Empty pontoon	254.00	16.39	0.90	4161.79	228.60
2	Constant	5.00	16.39	2.00	81.95	10.00
3	Excavator No 1	81.00	15.00	2.82	1215.00	228.42
4	Excavator No 2	70.50	8.00	2.60	564.00	183.30
5	Water in the hold				0.00	0.00
6	Total	410.50	14.67	1.58	6022.74	650.32
7	Deadweight	156.50	[t]			

Table 26. Mass table. Condition 1. The pontoon with the load of excavators without water in the hold

1	Medium draught	T	1.29	m
2	Trim	t	-0.76	m
3	Bow draught	TF	0.91	m
4	Stern draught	TA	1.67	m
5	Height of the centre of mass	z_G	1.58	m
6	Free surface of liquid correction	ΔGM	0.00	m
7	Height of the centre of mass correction	$z_{G'}$	1.58	m
8	Metacentric height	GM'	8.10	m
9	Angle of flooding	φ_{Flood}	4.9	°

Table 27. Parameters of the loaded pontoon. Condition 1



Angle of heel φ [°]	GZ [m]	Work of GZ [m·rad]
0	0	0
5	0.705	0.031
10	1.350	0.121
15	1.786	0.257
20	1.898	0.418
25.1	1.864	0.582
30.1	1.768	0.741
35.1	1.641	0.889
40.2	1.492	1.026
50.3	1.148	1.257
60.4	0.765	1.424
70.3	0.365	1.522
80.2	-0.039	1.551

Diagram of righting arms

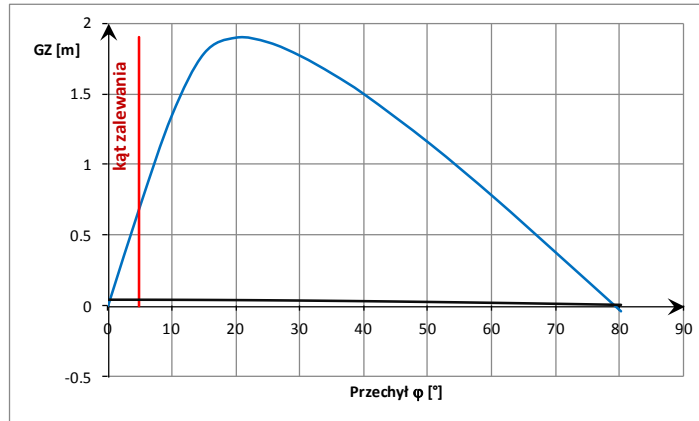


Table 28. Righting arms, work of GZ. Condition 1

Maximum righting arm GZ_{MAX} equals 1.898 m for the angle of heel of 20°.

Work of the righting arms (area) up to 20° equals 0.418 m·rad

Half of the angle of freeboard: $\varphi_{FB/2} = 2.45^\circ$

Rolling moment due to the action of wind (30 m/s): $M_w = 16.36$ mt

Angle of heel due to the action of wind: $\varphi_w = 0.3^\circ$

The range of positive values of righting arms is limited by the angle of flooding and equals 4.9°.

No	Description	Required values	Achieved values	Criterion
1.	Surface area under the righting arms curve up to the maximum value of GZ	0.08 m·rad	0.1173 m·rad	Fulfilled
2.	Static tilt due to the action of wind	$\varphi_{FB/2} = 2.45^\circ$	0.3°	Fulfilled
3	Minimum range of positive righting arms	20°	4.9°	Unfulfilled

Table 29. Criteria ICS'2008

The stability criteria ICS'2008 have not been fulfilled due to too small angle of flooding which limited the range of righting arms.



6.6. Conclusions from the Analysis of Results of Calculations of Assumed Stability States of the T-6 Pontoon

- The *T-6* pontoon was loaded with two excavators with a total weight of 151.5 t (weight determined on the basis of the manufacturer's data). The excavators were placed in the aft part of the hold. The excavators were set partly on wooden planking.
- In the hold and on the after deck there was a wooden boarding of unknown weight and in the hold there could have been placed other devices, and aggregates. The total weight of wooden boarding and additional devices was estimated for 5 t.
- The load of excavators was fixed (according to the declaration of the *Zeus* tugboat's master) to the construction of the pontoon with chains, iron ropes and belts. There are no visible fixings on the photographs obtained.
- The pontoon after loading had a trim by the stern of 0.76 m and bow draught of 0.96 m (photographic analysis). This was assumed as the initial state.
- A large trim by the stern (0.76 m) and a large stern draught (1.67 m) resulted in the reduction of the angle of flooding 4.9°.
- According to the declaration of the *Zeus* tugboat's master, the pontoon was rolling on a side wave of ca. 10°.
- Following the analysis of the state of cargo and accident scenarios, it can be stated that:
 - large stern draught of the pontoon, a small angle of flooding and side sway during towage could lead to water getting into the hold by its rear corners. Initially, it could have been small amounts of water getting inside during the biggest sway.
 - Water entering the stern of the hold resulted in the increase in the draught at the stern and thus the increase in the frequency of water intrusion. In addition, water in the hold caused a decrease in the stability parameters of the pontoon - metacentric height and righting arms.
- On the assumption that cargo was loaded symmetrically and well fixed, the amount of water needed to capsize the pontoon was 94 t (Condition 7).
- On the assumption that cargo was loaded asymmetrically and well fixed, the amount of water needed to capsize the pontoon was 90 t (Condition 6A).



- On the assumption that cargo was loaded symmetrically but shifted, the amount of water needed to roll over the pontoon was about 20 t (Condition 2).
- When 45 t of water got into the hold of the T-6 pontoon (TF = 0.65 m, TA = 2.15 m), water was entering the hold continuously, flooding the inside of the pontoon (Figure 25). The T-6 pontoon is submerging uncontrollably until it loses its stability.

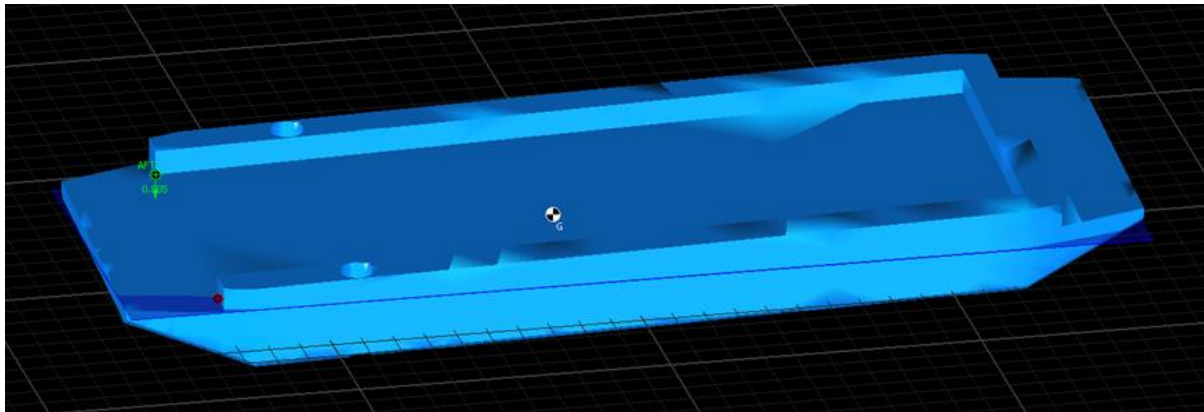


Figure 25. The T-6 pontoon, loaded state, no pitching. List 4.9°. Water enters the hold at the stern

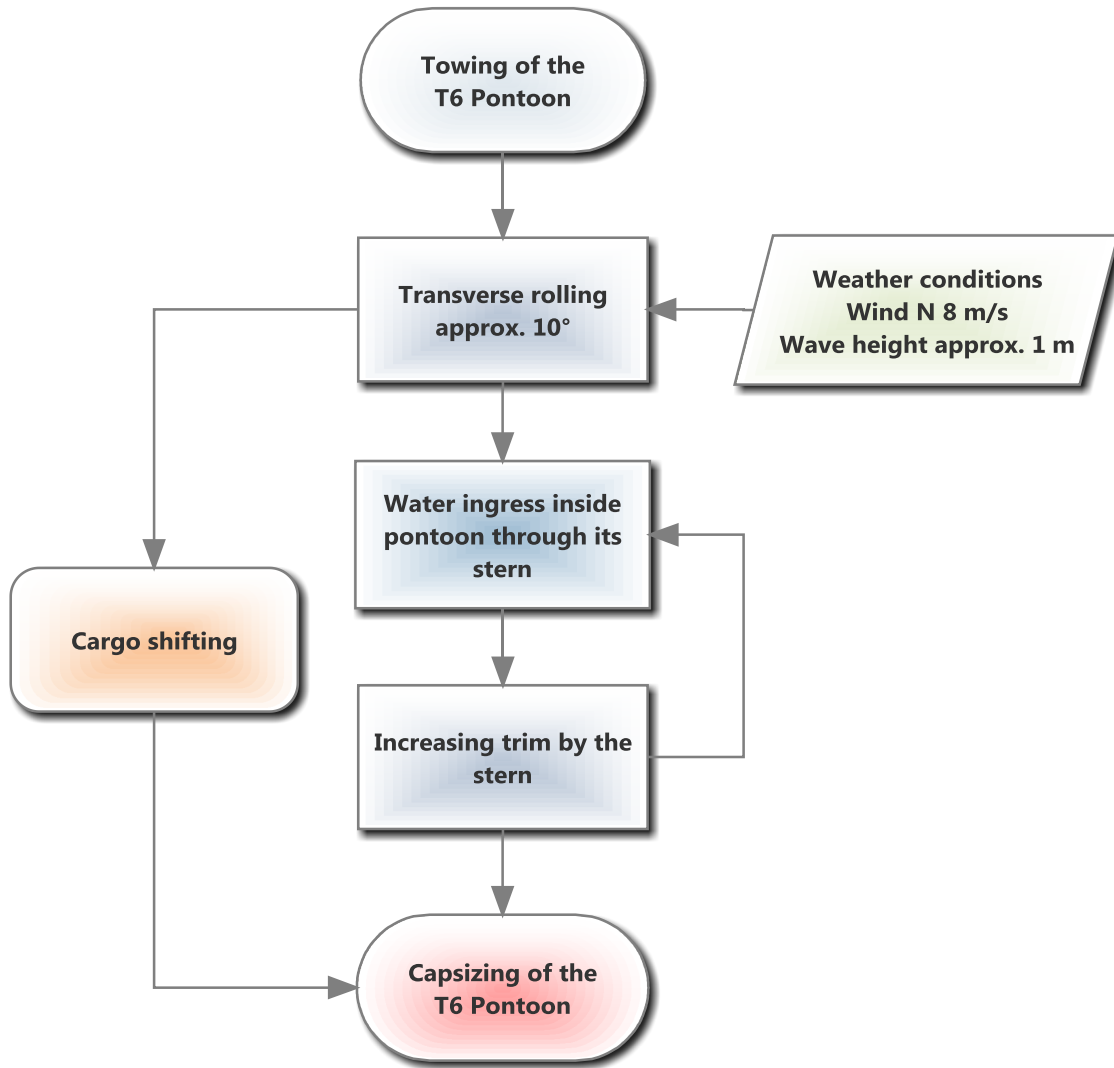


Figure 26. The T-6 pontoon capsizing scenario

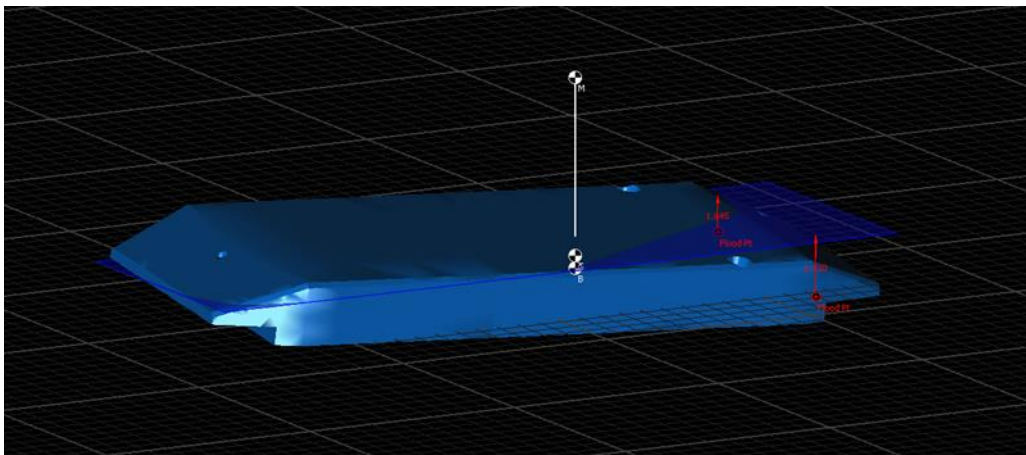


Figure 27. State 7. The T-6 pontoon after capsizing and losing the cargo



7. Safety Recommendations

7.1. Zakład Usług Żeglugowych Sp. z o.o. & Co. Sp. k

The State Marine Accident Investigation Commission has recommended to create procedures describing the principles of cooperation and information exchange between the shipowner (especially the Operations Department) and vessels (tugboats) performing services for the shipowner's clients.

These procedures should include a catalogue of activities for which the shipowner is responsible due to the implementation of contracts serviced by designated tugboats. This applies, among others, to extracts from the terms of contracts signed by the shipowner with a chosen client, instructions for masters for a given voyage, the absolute obligation to help masters awaiting additional information and instructions, providing them with adequate communication facilities on the operated vessels enabling constant contact with the shipowner's office, control of the performance of duties imposed on the masters of vessels, organization of towage, taking into account the recommendations contained in the IMO MSC/Circ.884 Circular.

As part of the recommended procedures, each time an instruction should be prepared for the master of the vessel, containing, among other things, an extract from the signed contract and the resulting responsibilities for the master. It should be required to create a voyage plan which is mistaken for a towing plan, as well as a cargo restraint plan⁸ on the vessel under tow. Each time the master must be notified of the documents he should possess to start the towage, regardless of his autonomous decision about going out to sea with an object under tow. A copy of the IMO MSC/Circ.884 Circular should be sent to the vessels in service and masters should be obliged to become acquainted with it.

Tugboats should be equipped with appropriate photographic equipment that allows taking photographs, even in difficult weather conditions to secure photographic documentation of the objects under tow.

7.2. UAB Topada – the Owner of the T-6 Pontoon

The State Marine Accident Investigation Commission has recommended that the provisions of signed contracts should be implemented correctly and reliably, especially when they

⁸ IMO MSC. 884 Resolution, Chapter 13.



concern maritime safety. Misleading the parties to the contract that could result in a risk to the safety of shipping should not take place when executing a commercial contract.

8. List of Figures

<i>Figure 1. A model of the T-6 pontoon developed on the basis of measurements.....</i>	<i>8</i>
<i>Figure 2. Depth of the pontoon.....</i>	<i>8</i>
<i>Figure 3. Bow draught.....</i>	<i>8</i>
<i>Figure 4. Model of the T-6 pontoon with points of flooding at stern.....</i>	<i>9</i>
<i>Figure 5. Angles of flooding of the T-6 pontoon for draught and trim.....</i>	<i>10</i>
<i>Figure 6. Dimensions of the T-6 pontoon.....</i>	<i>10</i>
<i>Figure 7. The CASE excavator.....</i>	<i>13</i>
<i>Figure 8. The Volvo excavator.....</i>	<i>14</i>
<i>Figure 9. Position of excavators on the deck of the T-6 pontoon. Explanatory figure based on photographs.....</i>	<i>14</i>
<i>Figure 10. The T-6 pontoon loaded with excavators. No side trim. State 1.....</i>	<i>28</i>
<i>Figure 11. Dynamic tilt of the pontoon due to transverse shifting of the excavators.....</i>	<i>29</i>
<i>Figure 12. The T-6 pontoon loaded with excavators. No side trim. State 2.....</i>	<i>32</i>
<i>Figure 13. Uncontrolled tilt of the pontoon due to transverse shifting of the excavators.....</i>	<i>33</i>
<i>Figure 14. The T-6 pontoon loaded with excavators. The pontoon with 1.7° tilt. State 2A.....</i>	<i>34</i>
<i>Figure 15. The T-6 pontoon loaded with excavators with water inside the hold. State 3.....</i>	<i>35</i>
<i>Figure 16. Moment of tilting due to uncontrolled shifting of the excavators.....</i>	<i>37</i>
<i>Figure 17. State 3A. The pontoon with 1.9° tilt.....</i>	<i>38</i>
<i>Figure 18. The pontoon without tilt. State 4.....</i>	<i>39</i>
<i>Figure 19. State 3A. The pontoon with 2.5° tilt.....</i>	<i>41</i>
<i>Figure 20. State 5. The pontoon without tilt.....</i>	<i>42</i>
<i>Figure 21. State 5A. The pontoon with 3.2° tilt.....</i>	<i>44</i>
<i>Figure 22. State 6. The pontoon without tilt.....</i>	<i>45</i>
<i>Figure 23. State 6A. The pontoon capsized due to transversal shifting of the centre of mass.....</i>	<i>47</i>
<i>Figure 24. State 7. The pontoon capsized due to excessive trim $t = -5.65$ m.....</i>	<i>48</i>
<i>Figure 25. The T-6 pontoon, loaded state, no longitudinal sway. Tilt 4.9°. Water enters the hold at the stern.....</i>	<i>52</i>
<i>Figure 26. The T-6 pontoon capsizing scenario.....</i>	<i>53</i>



Figure 27. State 7. The T-6 pontoon after capsizing and losing the load..... 53
Figure 28. Draught = 0..... 61

9. List of Photographs

Photograph 1. The „Zeus” tugboat..... 6
Photograph 2. Position of the excavators on deck..... 11
Photograph 3. Position of the excavators on deck..... 12
Photograph 4. Fastened arm of one of the excavators (Photograph taken by LTSA inspectors)
..... 16
Photograph 5. Position of the excavators on the pontoon without fixing (Photograph taken by
LTSA inspectors)..... 16

10. List of Tables

Table 1. Characteristic data of the T-6 pontoon obtained from measurements and
photographs..... 9
Table 2. Models assumed for hold flooding simulation 22
Table 3. Data obtained from moulding of the shape and weight of the load placed on deck of
the T-6 pontoon 27
Table 4. Mass table. State 1. The pontoon with the load of excavators..... 27
Table 5. Righting arms and work of GZ. State 1 28
Table 6. Righting arms; work of GZ. State 1A 31
Table 7. Mass table. State 2. The pontoon with the load of excavators 31
Table 8. Parameters of the loaded pontoon with 20 t of water in the hold 32
Table 9. Righting arms, work of righting arms. State 2 33
Table 10. Mass table. State 3 35
Table 11. Parameters of the loaded pontoon with 40 t of water in the hold..... 36
Table 12. Righting arms, work of righting arms. State 3 36
Table 13. Righting arms, work of righting arms 38
Table 14. Mass table. State 4 39
Table 15. Parameters of the pontoon with 60 t of water in the hold. State 4..... 40
Table 16. Righting arms, work of GZ. State 4..... 40



<i>Table 17. Righting arms, work of righting arms. State 4A.....</i>	<i>41</i>
<i>Table 18. Mass table. State 5.....</i>	<i>42</i>
<i>Table 19. Parametres of the pontoon with 60 t of water in the hold. State 5.....</i>	<i>43</i>
<i>Table 20. Righting arms, work of righting arms. State 5.....</i>	<i>43</i>
<i>Table 21. Righting arms, work of righting arms. State 5A.....</i>	<i>44</i>
<i>Table 22. Mass table. State 6.....</i>	<i>45</i>
<i>Table 23. Parametres of the pontoon with 90 t of water in the hold. State 6.....</i>	<i>46</i>
<i>Table 24. Righting arms, work of righting arms. State 6.....</i>	<i>46</i>
<i>Table 25. Righting arms, work of righting arms. State 6.....</i>	<i>47</i>
<i>Table 26. Mass table. State 1.The pontoon with the load of excavatars witout water in the hold.....</i>	<i>49</i>
<i>Table 27. Parametres of the loaded pontoon. State 1.....</i>	<i>49</i>
<i>Table 28. Righting arms, work of GZ. State 1.....</i>	<i>50</i>
<i>Table 29. Criteria ICS'2008.....</i>	<i>50</i>

11. Information Sources

Notification of the accident

Documents of the *Zeus* tugboat and registration documents of the *T-6* pontoon

Towing contract

Documents received from the representative of the Lithuanian Commission for Investigation of Marine Accidents

Photographs taken by the SMAIC representatives

Measurements of the *T-6* pontoon during on-site verification

Hearings of the SMAIC

Expert opinion of Jarosław Soliwoda, PhD

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: Tadeusz Wojtasik– the Chairman of the SMAIC,

the team member: Jarosław Soliwoda – the Expert of the SMAIC.



13. Appendices

13.1. Appendix 1 - Requirements of the Intact Stability Code 2008 Regarding Pontoons

INTACT STABILITY CODE 2008 Stability Criteria

The provisions given hereunder apply to seagoing pontoons. A pontoon is considered to be normally:

- .1 non self-propelled;
- .2 unmanned;
- .3 carrying only deck cargo;
- .4 having a block coefficient of 0.9 or greater;
- .5 having a breadth/depth ratio of greater than 3; and
- .6 having no hatchways in the deck except small manholes closed with gasketed covers.

The following guidance is suggested:

1. no account should be taken of the buoyancy of deck cargo (except buoyancy credit for adequately secured timber);
2. consideration should be given to such factors as water absorption (e.g., timber), trapped water in cargo (e.g., pipes) and ice accretion;
3. in performing wind heel calculations:
 - 3.1 the wind pressure should be constant and for general operations be considered to act on a solid mass extending over the length of the cargo deck and to an assumed height above the deck;
 - 3.2. the centre of gravity of the cargo should be assumed at a point mid-height of the cargo;
 - 3.3. the wind lever should be taken from the centre of the deck cargo to a point at one half the mean draught.

Intact stability criteria

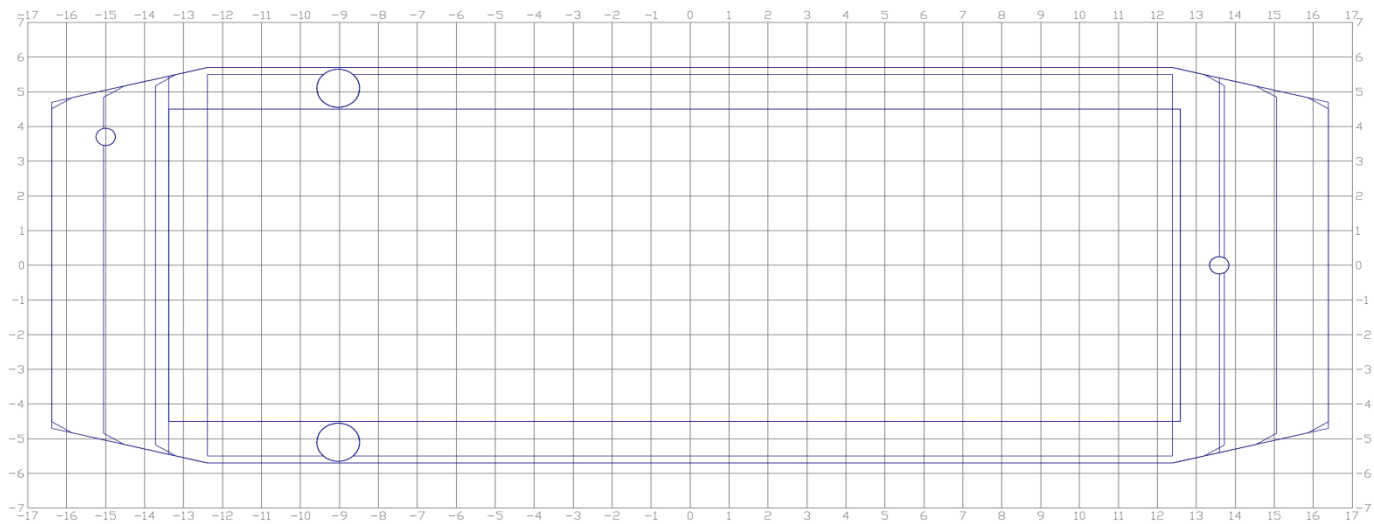
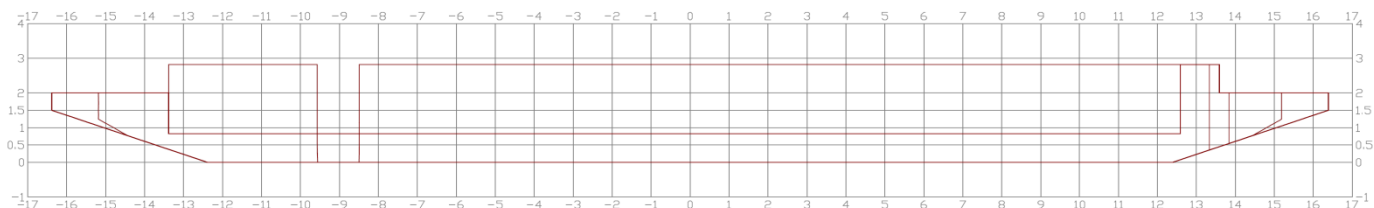
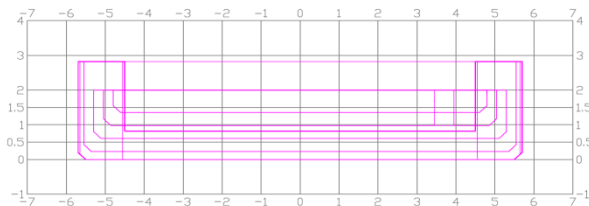
1. The area under the righting lever curve up to the angle of maximum righting lever should not be less than 0.08 metre-radians.



2. The static angle of heel due to a uniformly distributed wind load of 540 Pa (wind speed 30 m/s) should not exceed an angle corresponding to half the freeboard for the relevant loading condition, where the lever of wind heeling moment is measured from the centroid of the windage area to half the draught.
3. The minimum range of stability should be:
 - for $L \leq 100$ m: 20° ;
 - for $L \geq 150$ m: 15° ;
 - for intermediate length: by interpolation.



13.2. Appendix 2 – Body Lines of the T-6 Pontoon



13.3. Appendix 3 – Hydrostatic Data of the T-6 Pontoon

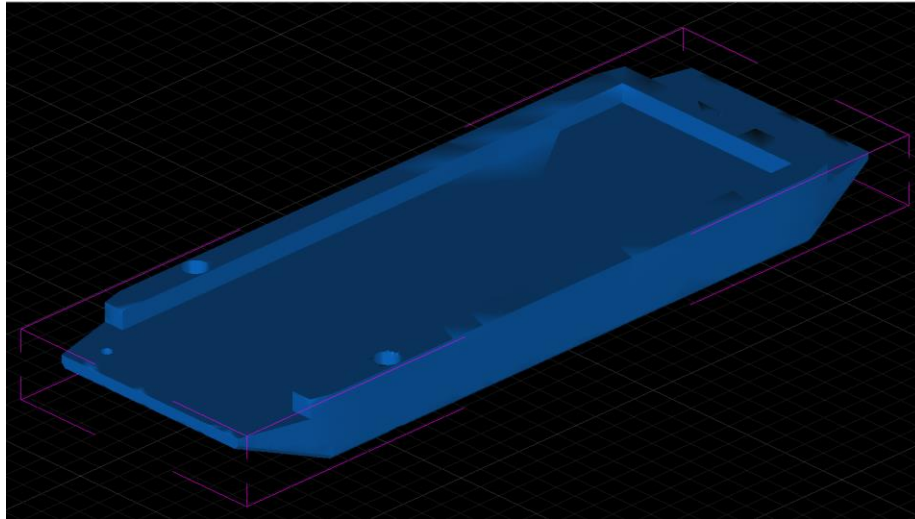


Figure 28. Draught = 0

Skróty:

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 AP,
VCB [m]	- vertical centre of buoyancy from BP,
KMT [m]	- height of the transverse metacentre from BP,
WPA [m ²]	- surface of the actual waterline,
LCF [m]	- longitudinal centre of flotation,
TPC [t/cm]	- increase in displacement per 1 cm of draught,
C _b [-]	- block coefficient of the hull,
C _w [-]	- block coefficient of the actual waterline,
BMT [m]	- transverse metacentric radius,
BML [m]	- longitudinal metacentric radius,
MCT [tm/cm]	- moment to change trim per 1 cm.



T	Disp	Vol.	LCB	VCB	KMT	WPA	LCF	TPC	Cb	Cwp	BMT	BML	MCT
[m]	[t]	[m³]	[m]	[m]	[m]	[m²]	[m]	[t/cm]	[-]	[-]	[m]	[m]	[tm/cm]
0.50	147.5	147.5	-0.001	0.255	22.960	311.12	-0.024	3.11	0.943	0.995	22.70	134.95	7.270
0.51	150.6	150.6	-0.001	0.261	22.521	311.51	-0.032	3.12	0.943	0.994	22.26	132.64	7.283
0.52	153.8	153.8	-0.001	0.266	22.099	311.88	-0.041	3.12	0.942	0.993	21.83	130.39	7.294
0.53	156.9	156.9	-0.001	0.271	21.691	312.21	-0.052	3.12	0.941	0.992	21.42	128.19	7.303
0.54	160.0	160.0	-0.001	0.276	21.297	312.52	-0.064	3.13	0.940	0.991	21.02	126.03	7.310
0.55	166.6	166.6	-0.001	0.276	20.560	314.27	-0.011	3.14	0.959	0.995	20.28	123.05	7.418
0.56	169.8	169.8	-0.001	0.282	20.215	314.74	-0.016	3.15	0.958	0.995	19.93	121.30	7.437
0.57	172.9	172.9	-0.001	0.287	19.883	315.24	-0.019	3.15	0.957	0.994	19.60	119.64	7.458
0.58	176.1	176.1	-0.001	0.292	19.565	315.76	-0.020	3.16	0.956	0.994	19.27	118.07	7.481
0.59	179.3	179.3	-0.001	0.297	19.259	316.32	-0.021	3.16	0.955	0.994	18.96	116.58	7.506
0.60	182.4	182.4	-0.001	0.302	18.964	316.90	-0.020	3.17	0.954	0.994	18.66	115.17	7.532
0.61	185.6	185.6	-0.001	0.307	18.681	317.51	-0.018	3.18	0.953	0.994	18.37	113.84	7.562
0.62	188.8	188.8	-0.001	0.313	18.408	318.15	-0.015	3.18	0.951	0.994	18.10	112.59	7.593
0.63	192.0	192.0	-0.001	0.318	18.145	318.82	-0.010	3.19	0.950	0.994	17.83	111.41	7.626
0.64	191.7	191.7	-0.002	0.328	18.217	319.46	-0.007	3.19	0.932	0.994	17.89	112.26	7.657
0.65	194.9	194.9	-0.003	0.333	17.954	320.02	-0.007	3.20	0.931	0.994	17.62	110.98	7.683
0.66	198.1	198.1	-0.003	0.338	17.700	320.58	-0.007	3.21	0.931	0.994	17.36	109.75	7.708
0.67	201.3	201.3	-0.003	0.344	17.453	321.14	-0.007	3.21	0.930	0.994	17.11	108.55	7.734
0.68	204.5	204.5	-0.003	0.349	17.215	321.70	-0.007	3.22	0.929	0.994	16.87	107.40	7.760
0.69	207.7	207.7	-0.003	0.354	16.984	322.26	-0.007	3.22	0.928	0.994	16.63	106.28	7.786
0.70	211.0	211.0	-0.003	0.359	16.759	322.82	-0.007	3.23	0.927	0.993	16.40	105.19	7.812
0.71	214.2	214.2	-0.003	0.364	16.541	323.38	-0.007	3.23	0.927	0.993	16.18	104.13	7.838
0.72	217.4	217.4	-0.003	0.370	16.329	323.94	-0.007	3.24	0.926	0.993	15.96	103.11	7.864
0.73	220.7	220.7	-0.003	0.375	16.123	324.50	-0.007	3.24	0.925	0.993	15.75	102.11	7.890
0.74	227.5	227.5	-0.002	0.375	15.675	325.05	-0.007	3.25	0.939	0.993	15.30	99.56	7.916
0.75	230.7	230.7	-0.002	0.380	15.485	325.60	-0.007	3.26	0.938	0.993	15.11	98.65	7.942



FINAL REPORT 45/18



SMAIC
STATE MARINE ACCIDENT
INVESTIGATION COMMISSION

0.76	234.0	234.0	-0.002	0.386	15.301	326.16	-0.007	3.26	0.937	0.993	14.92	97.76	7.968
0.77	237.3	237.3	-0.002	0.391	15.121	326.71	-0.007	3.27	0.936	0.992	14.73	96.90	7.994
0.78	240.5	240.5	-0.002	0.396	14.947	327.26	-0.007	3.27	0.935	0.992	14.55	96.06	8.020
0.79	243.8	243.8	-0.002	0.401	14.777	327.81	-0.007	3.28	0.934	0.992	14.38	95.24	8.046
0.80	247.1	247.1	-0.002	0.406	14.611	328.37	-0.007	3.28	0.933	0.992	14.20	94.45	8.072
0.81	250.4	250.4	-0.002	0.412	14.449	328.92	-0.007	3.29	0.932	0.992	14.04	93.67	8.098
0.82	253.7	253.7	-0.002	0.417	14.292	329.47	-0.007	3.29	0.931	0.992	13.88	92.92	8.124
0.83	257.0	257.0	-0.002	0.422	14.138	330.03	-0.007	3.30	0.930	0.992	13.72	92.18	8.151
0.84	260.3	260.3	-0.002	0.427	13.987	330.57	-0.007	3.31	0.929	0.991	13.56	91.45	8.176
0.85	263.6	263.6	-0.002	0.433	13.841	331.12	-0.007	3.31	0.928	0.991	13.41	90.75	8.202
0.86	266.9	266.9	-0.002	0.438	13.697	331.66	-0.007	3.32	0.927	0.991	13.26	90.06	8.228
0.87	270.2	270.2	-0.002	0.443	13.557	332.21	-0.007	3.32	0.926	0.991	13.11	89.39	8.254
0.88	273.6	273.6	-0.003	0.448	13.420	332.76	-0.007	3.33	0.926	0.991	12.97	88.73	8.280
0.89	276.9	276.9	-0.003	0.454	13.286	333.30	-0.007	3.33	0.925	0.991	12.83	88.09	8.306
0.90	280.3	280.3	-0.003	0.459	13.156	333.85	-0.007	3.34	0.924	0.990	12.70	87.46	8.333
0.91	283.6	283.6	-0.003	0.464	13.028	334.39	-0.007	3.34	0.923	0.990	12.56	86.85	8.359
0.92	286.9	286.9	-0.003	0.470	12.904	334.94	-0.007	3.35	0.922	0.990	12.43	86.26	8.385
0.93	290.3	290.3	-0.003	0.475	12.781	335.48	-0.007	3.35	0.921	0.990	12.31	85.67	8.412
0.94	293.7	293.7	-0.003	0.480	12.661	336.02	-0.007	3.36	0.920	0.990	12.18	85.09	8.437
0.95	297.0	297.0	-0.003	0.485	12.543	336.55	-0.007	3.37	0.919	0.989	12.06	84.52	8.462
0.96	300.4	300.4	-0.003	0.491	12.427	337.08	-0.007	3.37	0.918	0.989	11.94	83.96	8.488
0.97	303.8	303.8	-0.003	0.496	12.314	337.61	-0.006	3.38	0.917	0.989	11.82	83.42	8.513
0.98	307.2	307.2	-0.003	0.501	12.203	338.14	-0.006	3.38	0.917	0.989	11.70	82.89	8.539
0.99	310.6	310.6	-0.003	0.506	12.095	338.67	-0.006	3.39	0.916	0.989	11.59	82.37	8.564
1.00	314.0	314.0	-0.003	0.512	11.989	339.19	-0.006	3.39	0.915	0.988	11.48	81.85	8.590
1.01	317.4	317.4	-0.003	0.517	11.885	339.72	-0.006	3.40	0.914	0.988	11.37	81.35	8.615
1.02	320.8	320.8	-0.003	0.522	11.783	340.25	-0.006	3.40	0.913	0.988	11.26	80.86	8.641
1.03	324.2	324.2	-0.003	0.528	11.683	340.77	-0.006	3.41	0.912	0.988	11.16	80.38	8.666
1.04	327.6	327.6	-0.003	0.533	11.585	341.30	-0.006	3.41	0.911	0.987	11.05	79.91	8.692



FINAL REPORT 45/18



SMAIC
STATE MARINE ACCIDENT
INVESTIGATION COMMISSION

1.05	331.0	331.0	-0.003	0.538	11.488	341.82	-0.006	3.42	0.911	0.987	10.95	79.45	8.717
1.06	334.4	334.4	-0.003	0.543	11.394	342.34	-0.006	3.42	0.910	0.987	10.85	78.99	8.743
1.07	337.9	337.9	-0.003	0.549	11.302	342.87	-0.006	3.43	0.909	0.987	10.75	78.55	8.768
1.08	341.3	341.3	-0.003	0.554	11.211	343.39	-0.006	3.43	0.908	0.987	10.66	78.11	8.794
1.09	344.8	344.8	-0.003	0.559	11.122	343.91	-0.006	3.44	0.907	0.986	10.56	77.68	8.819
1.10	348.2	348.2	-0.003	0.565	11.035	344.43	-0.006	3.44	0.906	0.986	10.47	77.26	8.845
1.11	351.7	351.7	-0.003	0.570	10.949	344.95	-0.006	3.45	0.905	0.986	10.38	76.85	8.870
1.12	351.3	351.3	-0.005	0.580	10.981	345.47	-0.006	3.45	0.895	0.986	10.40	77.27	8.896
1.13	354.8	354.8	-0.005	0.586	10.896	345.99	-0.006	3.46	0.894	0.985	10.31	76.86	8.922
1.14	358.3	358.3	-0.005	0.591	10.813	346.49	-0.006	3.46	0.894	0.985	10.22	76.45	8.946
1.15	361.7	361.7	-0.005	0.596	10.732	346.99	-0.006	3.47	0.893	0.985	10.14	76.04	8.970
1.16	365.2	365.2	-0.005	0.601	10.651	347.47	-0.006	3.47	0.892	0.985	10.05	75.63	8.993
1.17	368.7	368.7	-0.005	0.607	10.573	347.94	-0.006	3.48	0.891	0.984	9.97	75.22	9.015
1.18	372.2	372.2	-0.005	0.612	10.495	348.39	-0.006	3.48	0.891	0.984	9.88	74.81	9.036
1.19	375.7	375.7	-0.005	0.617	10.418	348.83	-0.006	3.49	0.890	0.983	9.80	74.40	9.056
1.20	379.2	379.2	-0.005	0.623	10.343	349.27	-0.006	3.49	0.889	0.983	9.72	73.99	9.076
1.21	382.7	382.7	-0.005	0.628	10.269	349.68	-0.006	3.50	0.888	0.982	9.64	73.58	9.094
1.22	386.2	386.2	-0.005	0.633	10.196	350.09	-0.006	3.50	0.888	0.982	9.56	73.16	9.111
1.23	389.7	389.7	-0.005	0.639	10.124	350.49	-0.006	3.50	0.887	0.981	9.49	72.75	9.128
1.24	393.2	393.2	-0.005	0.644	10.053	350.87	-0.006	3.51	0.886	0.981	9.41	72.34	9.143
1.25	396.7	396.7	-0.005	0.649	9.984	351.24	-0.006	3.51	0.886	0.980	9.33	71.92	9.158
1.26	400.3	400.3	-0.005	0.655	9.915	351.60	-0.006	3.52	0.885	0.979	9.26	71.50	9.171
1.27	403.8	403.8	-0.005	0.660	9.847	351.94	-0.006	3.52	0.884	0.979	9.19	71.09	9.184
1.28	407.3	407.3	-0.005	0.665	9.780	352.28	-0.006	3.52	0.883	0.978	9.12	70.67	9.195
1.29	410.9	410.9	-0.005	0.671	9.714	352.60	-0.006	3.53	0.883	0.977	9.04	70.25	9.206
1.30	414.4	414.4	-0.005	0.676	9.650	352.91	-0.006	3.53	0.882	0.976	8.97	69.83	9.216
1.31	418.0	418.0	-0.005	0.681	9.586	353.21	-0.006	3.53	0.881	0.976	8.90	69.41	9.225
1.32	421.5	421.5	-0.005	0.687	9.521	353.46	-0.006	3.53	0.881	0.975	8.83	68.97	9.231
1.33	425.1	425.1	-0.005	0.692	9.457	353.71	-0.006	3.54	0.880	0.974	8.77	68.53	9.235



FINAL REPORT 45/18



SMAIC
STATE MARINE ACCIDENT
INVESTIGATION COMMISSION

1.34	428.7	428.7	-0.005	0.698	9.394	353.93	-0.006	3.54	0.879	0.973	8.70	68.09	9.238
1.35	432.2	432.2	-0.005	0.703	9.331	354.15	-0.006	3.54	0.878	0.972	8.63	67.65	9.241
1.36	435.8	435.8	-0.005	0.708	9.270	354.35	-0.006	3.54	0.878	0.971	8.56	67.20	9.242
1.37	439.4	439.4	-0.005	0.714	9.209	354.54	-0.006	3.55	0.877	0.969	8.50	66.76	9.242
1.38	443.0	443.0	-0.005	0.719	9.149	354.71	-0.006	3.55	0.876	0.968	8.43	66.31	9.241
1.39	446.6	446.6	-0.005	0.724	9.089	354.88	-0.006	3.55	0.876	0.967	8.37	65.86	9.239
1.40	450.2	450.2	-0.005	0.730	9.031	355.03	-0.006	3.55	0.875	0.966	8.30	65.41	9.236
1.41	453.8	453.8	-0.005	0.735	8.973	355.16	-0.006	3.55	0.874	0.965	8.24	64.96	9.231
1.42	457.4	457.4	-0.005	0.740	8.915	355.28	-0.006	3.55	0.874	0.964	8.18	64.50	9.226
1.43	461.0	461.0	-0.005	0.746	8.859	355.39	-0.006	3.55	0.873	0.962	8.11	64.05	9.220
1.44	464.6	464.6	-0.005	0.751	8.803	355.49	-0.006	3.55	0.872	0.961	8.05	63.59	9.212
1.45	468.3	468.3	-0.005	0.757	8.747	355.57	-0.006	3.56	0.872	0.960	7.99	63.13	9.203
1.46	471.9	471.9	-0.005	0.762	8.693	355.64	-0.006	3.56	0.871	0.958	7.93	62.67	9.193
1.47	475.5	475.5	-0.006	0.767	8.639	355.70	-0.006	3.56	0.870	0.957	7.87	62.20	9.182
1.48	479.2	479.2	-0.006	0.773	8.585	355.74	-0.006	3.56	0.869	0.955	7.81	61.74	9.170
1.49	482.8	482.8	-0.006	0.778	8.533	355.77	-0.006	3.56	0.869	0.954	7.76	61.27	9.157
1.50	486.5	486.5	-0.006	0.783	8.480	355.78	-0.006	3.56	0.868	0.952	7.70	60.81	9.143
1.51	490.1	490.1	-0.006	0.789	8.557	365.04	-0.006	3.65	0.869	0.977	7.77	65.43	9.903
1.52	493.8	493.8	-0.006	0.794	8.506	365.06	-0.006	3.65	0.870	0.977	7.71	64.95	9.907
1.53	497.4	497.4	-0.006	0.800	8.456	365.09	-0.006	3.65	0.870	0.977	7.66	64.49	9.910
1.54	501.1	501.1	-0.006	0.805	8.406	365.10	-0.006	3.65	0.871	0.977	7.60	64.03	9.913
1.55	504.7	504.7	-0.006	0.810	8.357	365.12	-0.006	3.65	0.872	0.977	7.55	63.57	9.917
1.56	508.4	508.4	-0.006	0.816	8.309	365.14	-0.006	3.65	0.872	0.977	7.49	63.13	9.920
1.57	512.0	512.0	-0.006	0.821	8.262	365.16	-0.006	3.65	0.873	0.977	7.44	62.69	9.923
1.58	515.7	515.7	-0.006	0.826	8.215	365.18	-0.006	3.65	0.874	0.978	7.39	62.25	9.927
1.59	519.3	519.3	-0.006	0.832	8.169	365.20	-0.006	3.65	0.874	0.978	7.34	61.83	9.930
1.60	523.0	523.0	-0.006	0.837	8.124	365.22	-0.006	3.65	0.875	0.978	7.29	61.41	9.933
1.61	526.6	526.6	-0.006	0.842	8.080	365.24	-0.006	3.65	0.876	0.978	7.24	60.99	9.937
1.62	530.3	530.3	-0.006	0.848	8.036	365.26	-0.006	3.65	0.876	0.978	7.19	60.58	9.940



FINAL REPORT 45/18



SMAIC
STATE MARINE ACCIDENT
INVESTIGATION COMMISSION

1.63	533.9	533.9	-0.006	0.853	7.993	365.28	-0.006	3.65	0.877	0.978	7.14	60.17	9.944
1.64	537.6	537.6	-0.006	0.858	7.951	365.30	-0.006	3.65	0.877	0.978	7.09	59.78	9.947
1.65	541.3	541.3	-0.006	0.864	7.909	365.32	-0.006	3.65	0.878	0.978	7.05	59.38	9.951
1.66	544.9	544.9	-0.006	0.869	7.868	365.34	-0.006	3.65	0.879	0.978	7.00	58.99	9.954
1.67	548.6	548.6	-0.006	0.874	7.827	365.36	-0.006	3.65	0.879	0.978	6.95	58.61	9.958
1.68	552.2	552.2	-0.006	0.879	7.787	365.38	-0.006	3.65	0.880	0.978	6.91	58.23	9.961
1.69	555.9	555.9	-0.006	0.885	7.748	365.40	-0.006	3.65	0.880	0.978	6.86	57.86	9.964
1.70	559.5	559.5	-0.006	0.890	7.709	365.41	-0.006	3.65	0.881	0.978	6.82	57.49	9.967
1.71	563.2	563.2	-0.006	0.895	7.670	365.41	-0.006	3.65	0.882	0.978	6.77	57.11	9.969
1.72	566.8	566.8	-0.006	0.901	7.631	365.41	-0.006	3.65	0.882	0.978	6.73	56.74	9.971
1.73	570.5	570.5	-0.006	0.906	7.594	365.41	-0.006	3.65	0.883	0.978	6.69	56.38	9.973
1.74	574.1	574.1	-0.006	0.911	7.556	365.41	-0.006	3.65	0.883	0.978	6.65	56.02	9.975
1.75	577.8	577.8	-0.006	0.916	7.519	365.41	-0.006	3.65	0.884	0.978	6.60	55.67	9.977
1.76	581.4	581.4	-0.006	0.922	7.483	365.41	-0.006	3.65	0.884	0.978	6.56	55.32	9.979
1.77	585.1	585.1	-0.006	0.927	7.448	365.41	-0.006	3.65	0.885	0.978	6.52	54.97	9.981
1.78	588.8	588.8	-0.006	0.932	7.412	365.41	-0.006	3.65	0.885	0.978	6.48	54.63	9.983
1.79	592.4	592.4	-0.006	0.937	7.378	365.41	-0.006	3.65	0.886	0.978	6.44	54.29	9.985
1.80	596.1	596.1	-0.006	0.943	7.343	365.41	-0.006	3.65	0.886	0.978	6.40	53.96	9.987
1.81	599.7	599.7	-0.006	0.948	7.310	365.41	-0.006	3.65	0.887	0.978	6.36	53.63	9.989
1.82	603.4	603.4	-0.006	0.953	7.276	365.41	-0.006	3.65	0.887	0.978	6.32	53.31	9.991
1.83	607.0	607.0	-0.006	0.959	7.244	365.41	-0.006	3.65	0.888	0.978	6.29	52.99	9.993
1.84	610.7	610.7	-0.006	0.964	7.211	365.41	-0.006	3.65	0.888	0.978	6.25	52.67	9.995
1.85	614.3	614.3	-0.006	0.969	7.179	365.41	-0.006	3.65	0.889	0.978	6.21	52.36	9.997
1.86	618.0	618.0	-0.006	0.974	7.148	365.41	-0.006	3.65	0.889	0.978	6.17	52.05	9.999
1.87	621.6	621.6	-0.006	0.979	7.117	365.41	-0.006	3.65	0.890	0.978	6.14	51.74	10.001
1.88	625.3	625.3	-0.006	0.985	7.086	365.41	-0.006	3.65	0.890	0.978	6.10	51.44	10.003
1.89	628.9	628.9	-0.006	0.990	7.056	365.41	-0.006	3.65	0.891	0.978	6.07	51.14	10.005
1.90	632.6	632.6	-0.006	0.995	7.026	365.41	-0.006	3.65	0.891	0.978	6.03	50.84	10.007
1.91	636.3	636.3	-0.006	1.000	6.997	365.41	-0.006	3.65	0.892	0.978	6.00	50.55	10.009



FINAL REPORT 45/18



SMAIC
STATE MARINE ACCIDENT
INVESTIGATION COMMISSION

1.92	639.9	639.9	-0.006	1.006	6.968	365.41	-0.006	3.65	0.892	0.978	5.96	50.26	10.011
1.93	643.6	643.6	-0.006	1.011	6.939	365.41	-0.006	3.65	0.893	0.978	5.93	49.98	10.014
1.94	647.2	647.2	-0.006	1.016	6.911	365.41	-0.006	3.65	0.893	0.978	5.90	49.70	10.016
1.95	650.9	650.9	-0.006	1.021	6.883	365.41	-0.006	3.65	0.893	0.978	5.86	49.42	10.018
1.96	654.5	654.5	-0.006	1.026	6.855	365.41	-0.006	3.65	0.894	0.978	5.83	49.14	10.020
1.97	658.2	658.2	-0.006	1.032	6.828	365.41	-0.006	3.65	0.894	0.978	5.80	48.87	10.022
1.98	661.8	661.8	-0.006	1.037	6.801	365.41	-0.006	3.65	0.895	0.978	5.77	48.60	10.025
1.99	665.5	665.5	-0.006	1.042	6.775	365.41	-0.006	3.65	0.895	0.978	5.73	48.33	10.027
2.00	669.1	669.1	-0.006	1.047	6.749	365.41	-0.006	3.65	0.896	0.978	5.70	48.07	10.029



13.4. Appendix 4 – Righting Arms

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	2.00
Angle of flooding [°]	40.90	28.30	22.60	18.10	15.20	13.20	11.60	10.30	9.00	7.60	6.30	5.10	3.80	2.40	1.10	0.00
tilt [°]	Righting arm [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	0.000
5	1.991	1.659	1.465	1.276	1.149	1.048	0.966	0.904	0.846	0.794	0.749	0.708	0.656	0.582	0.487	0.380
10	3.132	2.874	2.682	2.459	2.269	2.088	1.929	1.804	1.675	1.544	1.412	1.279	1.147	1.002	0.808	0.595
15	3.629	3.435	3.290	3.122	2.975	2.824	2.660	2.505	2.324	2.117	1.878	1.629	1.389	1.156	0.926	0.695
20	3.901	3.750	3.636	3.497	3.359	3.210	3.029	2.831	2.579	2.319	2.053	1.782	1.518	1.264	1.021	0.782
25	4.053	3.936	3.843	3.715	3.564	3.366	3.129	2.912	2.662	2.405	2.143	1.877	1.611	1.350	1.100	0.861
30	4.126	4.037	3.953	3.797	3.601	3.376	3.144	2.932	2.689	2.440	2.187	1.930	1.673	1.416	1.168	0.932
35	4.140	4.064	3.959	3.765	3.555	3.337	3.115	2.911	2.679	2.441	2.199	1.955	1.711	1.466	1.224	0.995
40	4.100	4.009	3.882	3.669	3.468	3.262	3.051	2.859	2.639	2.415	2.188	1.958	1.729	1.499	1.270	1.050
50	3.839	3.709	3.561	3.371	3.196	3.019	2.837	2.674	2.486	2.296	2.103	1.909	1.715	1.521	1.326	1.136
60	3.385	3.234	3.110	2.955	2.814	2.671	2.527	2.397	2.249	2.099	1.947	1.794	1.642	1.490	1.337	1.187
70	2.772	2.650	2.556	2.442	2.340	2.237	2.135	2.043	1.939	1.834	1.728	1.622	1.516	1.410	1.305	1.204
80	2.065	1.981	1.921	1.851	1.791	1.733	1.675	1.625	1.567	1.511	1.454	1.398	1.342	1.287	1.232	1.188

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	2.00
Angle of flooding [°]	23.10	18.30	15.20	13.20	11.60	10.20	8.80	7.50	6.20	5.00	3.70	2.30	1.10	0.00	0.00	0.00
Tilt [°]	Righting arm [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	0.000
5	1.940	1.640	1.432	1.272	1.158	1.055	0.970	0.900	0.840	0.787	0.738	0.684	0.621	0.547	0.481	0.424
10	3.084	2.835	2.625	2.428	2.261	2.086	1.926	1.779	1.641	1.508	1.378	1.245	1.099	0.938	0.800	0.681



FINAL REPORT 45/18



15	3.594	3.405	3.244	3.089	2.951	2.793	2.628	2.450	2.253	2.037	1.810	1.577	1.342	1.116	0.937	0.795
20	3.871	3.720	3.588	3.454	3.326	3.162	2.967	2.745	2.503	2.247	1.987	1.728	1.473	1.230	1.039	0.889
25	4.025	3.903	3.789	3.653	3.503	3.304	3.080	2.839	2.589	2.335	2.077	1.819	1.562	1.317	1.122	0.970
30	4.099	3.996	3.875	3.715	3.544	3.329	3.099	2.861	2.617	2.371	2.123	1.872	1.622	1.382	1.191	1.041
35	4.108	4.002	3.863	3.687	3.508	3.293	3.070	2.842	2.609	2.374	2.138	1.899	1.660	1.430	1.246	1.102
40	4.052	3.934	3.781	3.600	3.423	3.217	3.006	2.790	2.571	2.350	2.128	1.904	1.679	1.462	1.289	1.153
50	3.769	3.632	3.478	3.309	3.153	2.975	2.794	2.609	2.423	2.236	2.048	1.859	1.669	1.485	1.340	1.225
60	3.306	3.175	3.040	2.900	2.773	2.630	2.486	2.340	2.193	2.045	1.898	1.750	1.602	1.459	1.348	1.259
70	2.716	2.606	2.501	2.398	2.306	2.203	2.100	1.997	1.894	1.791	1.689	1.587	1.484	1.388	1.313	1.254
80	2.033	1.954	1.887	1.824	1.770	1.711	1.653	1.596	1.540	1.485	1.431	1.376	1.324	1.277	1.240	1.211

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	2.00
Angle of flooding [°]	14.60	12.90	11.40	10.00	8.70	7.40	6.10	4.90	3.60	2.30	1.00	0.00	0.00	0.00	0.00	0.00
Tilt [°]	Righting arm [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	0.000
5	1.784	1.578	1.418	1.267	1.143	1.041	0.957	0.884	0.819	0.755	0.691	0.628	0.574	0.529	0.487	0.449
10	2.914	2.717	2.543	2.355	2.178	2.011	1.853	1.704	1.562	1.426	1.285	1.149	1.028	0.922	0.820	0.729
15	3.460	3.302	3.159	2.998	2.833	2.662	2.479	2.286	2.082	1.873	1.660	1.459	1.285	1.134	0.992	0.872
20	3.749	3.618	3.493	3.341	3.170	2.978	2.768	2.547	2.316	2.079	1.838	1.615	1.423	1.257	1.105	0.977
25	3.909	3.791	3.664	3.498	3.309	3.103	2.883	2.653	2.415	2.172	1.928	1.703	1.510	1.345	1.192	1.063
30	3.972	3.853	3.715	3.540	3.345	3.134	2.913	2.684	2.449	2.212	1.975	1.756	1.569	1.408	1.260	1.134
35	3.955	3.831	3.689	3.511	3.317	3.109	2.892	2.670	2.446	2.220	1.993	1.785	1.606	1.453	1.313	1.193
40	3.874	3.749	3.607	3.432	3.242	3.042	2.834	2.624	2.413	2.201	1.988	1.793	1.626	1.483	1.352	1.240
50	3.569	3.451	3.319	3.159	2.991	2.814	2.635	2.457	2.278	2.100	1.921	1.756	1.619	1.502	1.393	1.300
60	3.120	3.018	2.905	2.772	2.633	2.491	2.348	2.207	2.067	1.927	1.787	1.662	1.559	1.471	1.388	1.317
70	2.568	2.485	2.400	2.300	2.198	2.095	1.994	1.894	1.797	1.700	1.604	1.521	1.453	1.395	1.340	1.293
80	1.936	1.882	1.828	1.767	1.707	1.648	1.591	1.537	1.484	1.432	1.383	1.342	1.309	1.279	1.254	1.232