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FLARE
FLOODING ACCIDENT RESPONSE

Flooding Mitigation measures on Meyer Turku RoPaX: simulations and model tests

Flooding mitigation tests: MSRC Damage Case 2 with counter flooding **(October 2021)**
MSRC Damage Case 4 with deployment of a watertight barrier on the trailer deck **(November 2021)**
MSRC Damage Case 4 with recovery of lost buoyancy **(November 2021)**

FLARE 3rd Webinar
Numerical Flooding Simulation Tools in Realistic Large-Scale Flooding
3 March 2022

Petri Valanto
HSVA, Germany

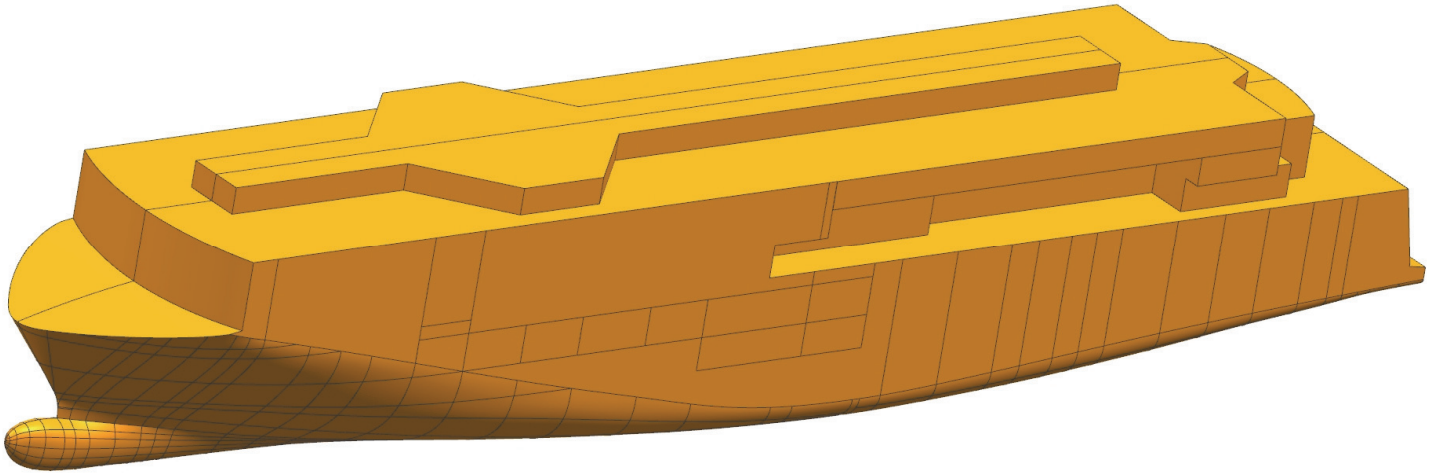
The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.: 814753)

MT RoPax Model tests on Flooding Mitigation

MT RoPaX = Unbuilt Ship Design for FLARE by Meyer Turku Shipyard

Model scale:	**28**	
HSVA Model no.	**5539**	
Length between perpend.	**Lpp**	**= 146.72 m**
Breadth moulded	**Bmld**	**= 28.00 m**
Draught	**T**	**= 6.3m**
Metacentric height	**GM**	**= 3.25 m**

A ship subdivision version modified by MSRC was used in the mitigation study.



As part of FLARE WP5, MSRC has defined six MT RoPax damage cases for forensic analysis. Two of these Damage Cases (DC2, DC4) were selected for studying flooding mitigation efforts, first with numerical simulation with HSVA Rolls, and later with model tests:

DC2 with counter flooding,

DC4 with recovery of lost buoyancy in damaged compartments and

DC4 also with deployment of a watertight barrier on the trailer deck to prevent progressive flooding.

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Flooding Mitigation with Counter Flooding (CF) in Damage Case 2 of the MT RoPaX Model

The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.: 814753)

MT RoPaX MSRC WP5DC2 CF - Simulation with and w/o Mitigation

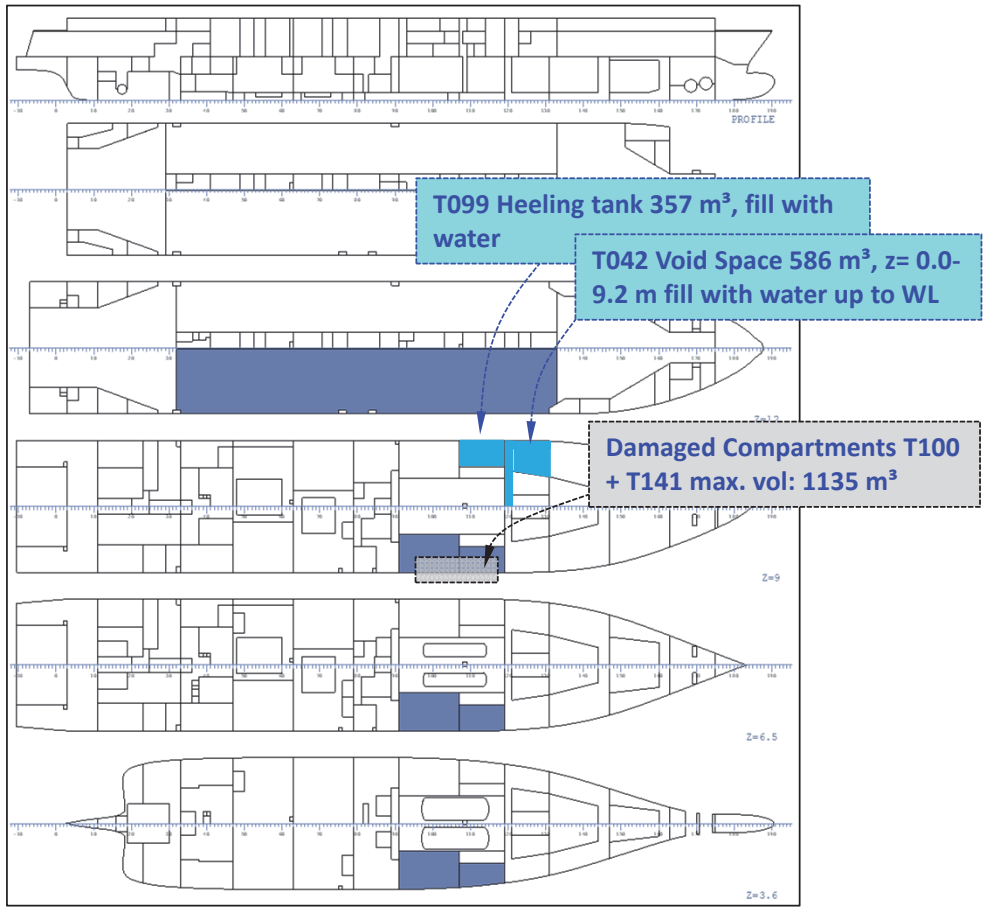

Figure 8 Damage Case 2: The grey rectangle shows the damage penetration. The damaged compartments are shown with dark blue-grey, and the compartments for counter flooding with light blue.

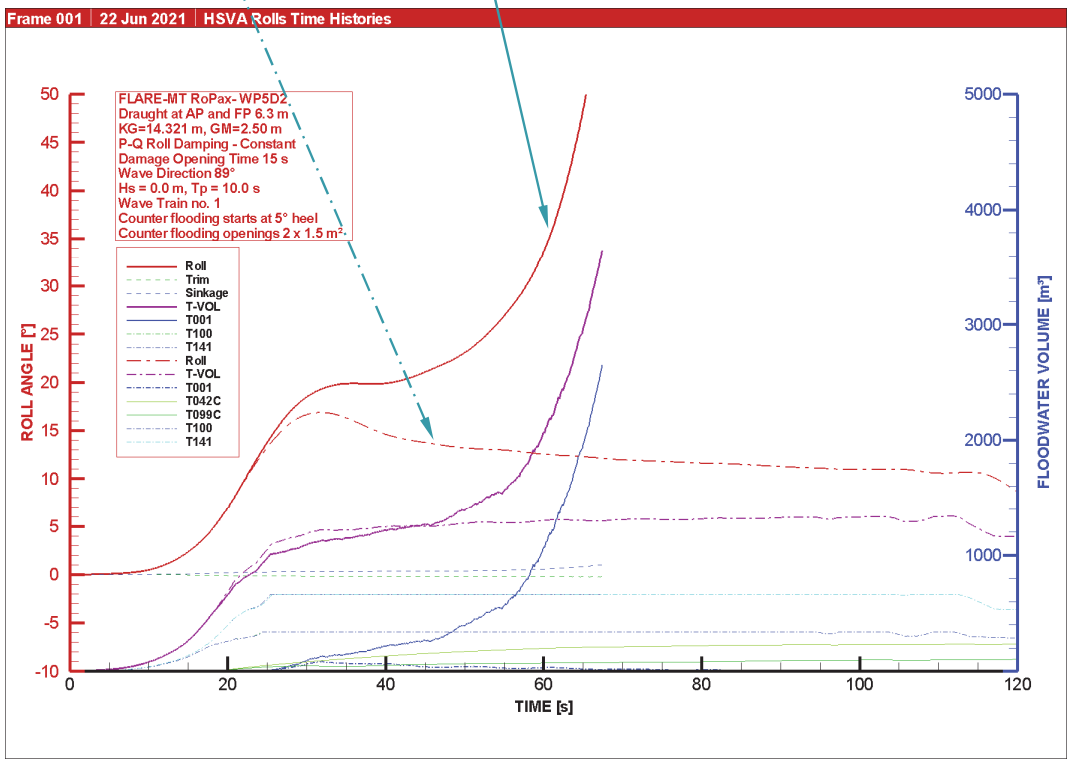

Figure 9 Counter Flooding with damage opening time 15 s: The roll angle (red) and water volumes on trailer deck and in damaged compartments (bluish) and in those for counter flooding (green). T-VOL is the total volume of the flood water in ship, T001 the water volume on the trailer deck.

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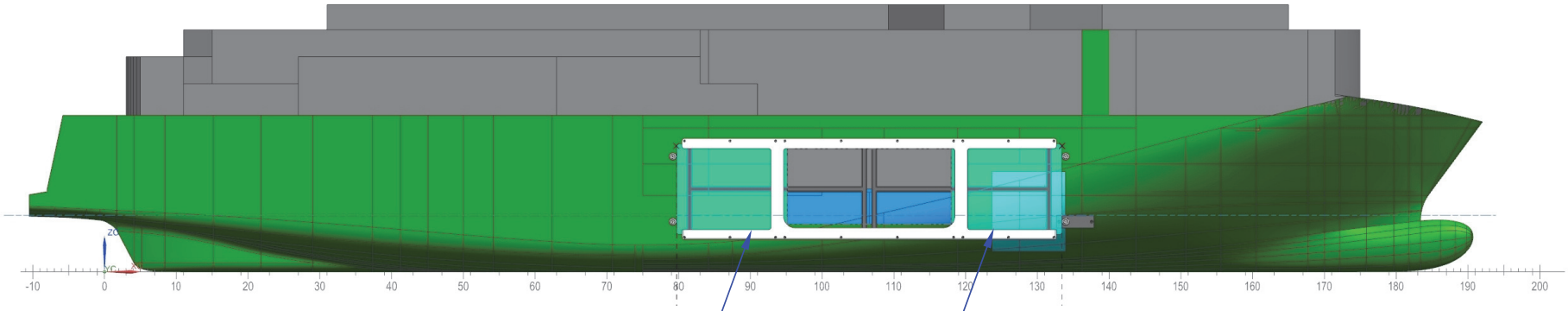
MT RoPaX-MSRC WP5DC2 CF - Model with the Damage Opening



DAMAGE OPENING WIDTH 18.26 m, HEIGHT 8.38 m, PENETRATION DEPTH 3.0 m. z= 5.3 m … 13.68 m
=> LOWER EDGE OF DAMAGE LIES 1.0 m BELOW DWL AT 6.3 m

SLIDING DOORS ON BOTH SIDES OF THE DAMAGE OPENING ONTO THE TRAILER DECK AND INTO COMPARTMENTS T141 AND T100
DAMAGE OPENING TIME CA. 15 s (30 s) in F.SC.

DAMAGE CASE 2 EXTENSIONS

DAM ID	X1 [m]	X2 [m]	Y1 [m]	Y2 [m]	Z1 [m]	Z2 [m]
DMC0569	76.12	94.38	-50.00	-11.00	5.30	13.68

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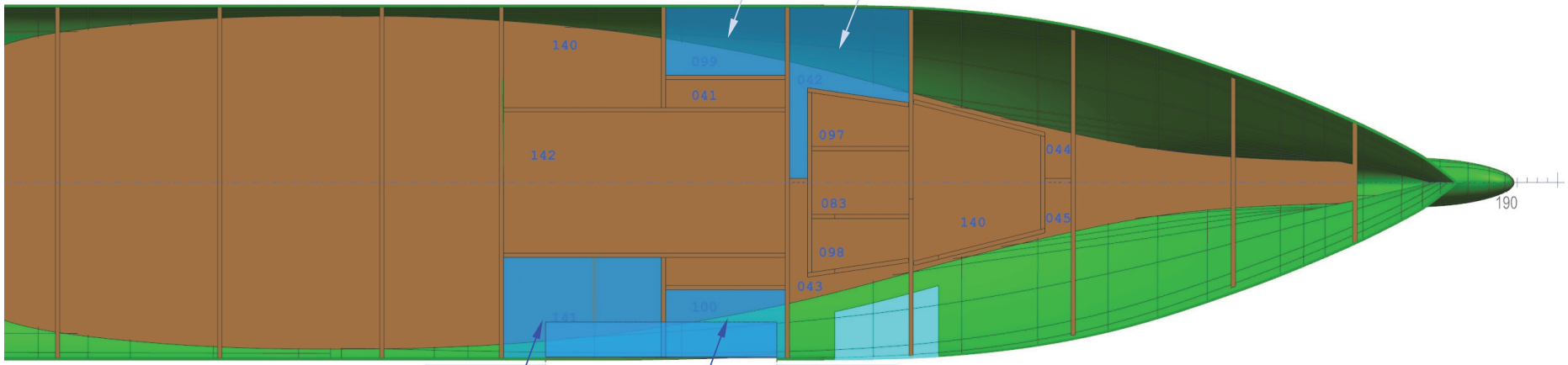
MT RoPaX-MSRC WP5DC2 CF - Model with relevant internal compartments



DAMAGE CASE 2 EXTENSIONS

DAM ID	X1 [m]	X2 [m]	Y1 [m]	Y2 [m]	Z1 [m]	Z2 [m]
DMC0569	76.12	94.38	-50.00	-11.00	5.30	13.68

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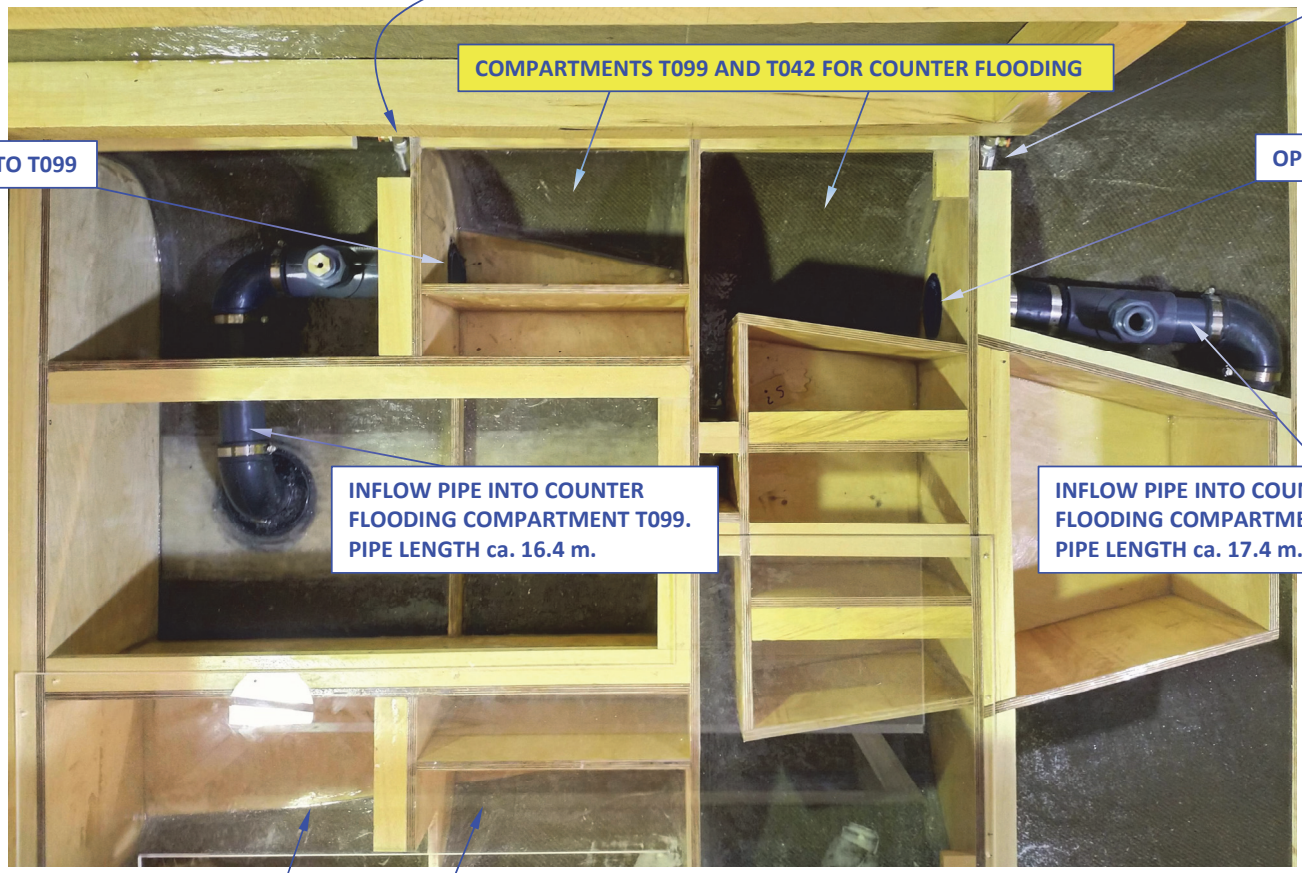
MT RoPaX-MSRC WP5DC2 CF - Model





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MT RoPaX- Flooding Mitigation Model Tests:

October 2021: Flooding Mitigation: Damage Case 2, Counter Flooding

DC2: 2-Compartment damage between frames #91 and #119:

(1) **Transient Flooding in calm water:** Reduction of intact GM to 3.018 m => The ship capsizes in calm water w/o flooding mitigation, but should survive with mitigation.

The effectiveness of the counter flooding in calm water was tested with realistic damage opening times (DOT) of 15 s and 30 s. The video recordings taken demonstrate its effectiveness.

(1) **Gradual Flooding in beam seas:** Further model tests with GM 3.48 m in beam seas at Hs 3.5 m and 5.0 m, Tp 10.0 s using the DOT of 15 s.

The effectiveness of the mitigation was tested at moderate sea states with the GM-value of 3.48 m. The flooding mitigation in beam seas can (a) prevent or (b) postpone capsize, thus making evacuation unnecessary or providing more time for it.
This effect, however, is expected to diminish with increasing wave height.

WHAT HAPPENS IN THE TRANSIENT PHASE? IS THE MITIGATION SYSTEM EFFECTIVE/RAPID ENOUGH TO PREVENT CAPSIZE JUST AFTER DAMAGE OPENING?

HOW DOES THE DAMAGED SHIP SURVIVE GRADUAL FLOODING IN BEAM SEAS AFTER FLOODING MITIGATION?

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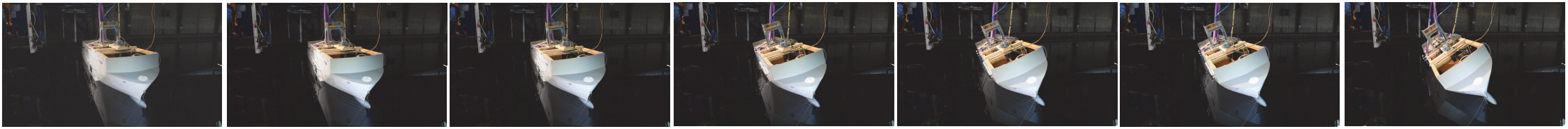
MT RoPaX-MSRC WP5DC2 CF - Model tests 13.10.21 *GM=3.125 m, Damage opening time 30 s, 1° Start criterion for counter flooding*

Test run no: 16: Video 0009.MOV–FRAMES **W/O COUNTER FLOODING => CAPSIZE**

F.SC. SECONDS

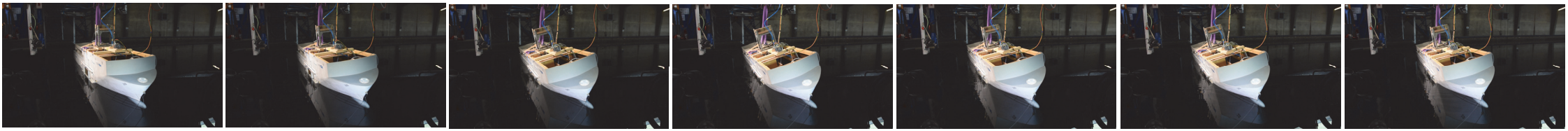
0 S (DAMAGE OPENS) **8.8 s** **17.6 s** **26.5 s** **35.3 s** **44.1 s** **53.0 s (CAPSIZE)**



Test run no: 15: Video 0008.MOV–FRAMES **WITH COUNTER FLOODING => SURVIVAL**

F.SC. SECONDS

0 S (DAMAGE OPENS) **8.8 s** **17.6 s** **26.5 s** **35.3 s** **44.1 s** **53.0 s (STABLE SHIP)**



TWO COUNTER FLOODING VALVES OPEN AUTOMATICALLY AT 1° HEELING ANGLE (INCREASE)

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MT RoPaX Model tests no. 15-16 on Flooding Mitigation on DC2



GM = 3.125 m
Damage length on the ship side = 18.26 m.
Damage opening time ca. 30 s.
Counter flooding start at 1° heeling angle (change).
Without counter flooding the ship capsizes in ca. 65 s.
With counter flooding it survives.

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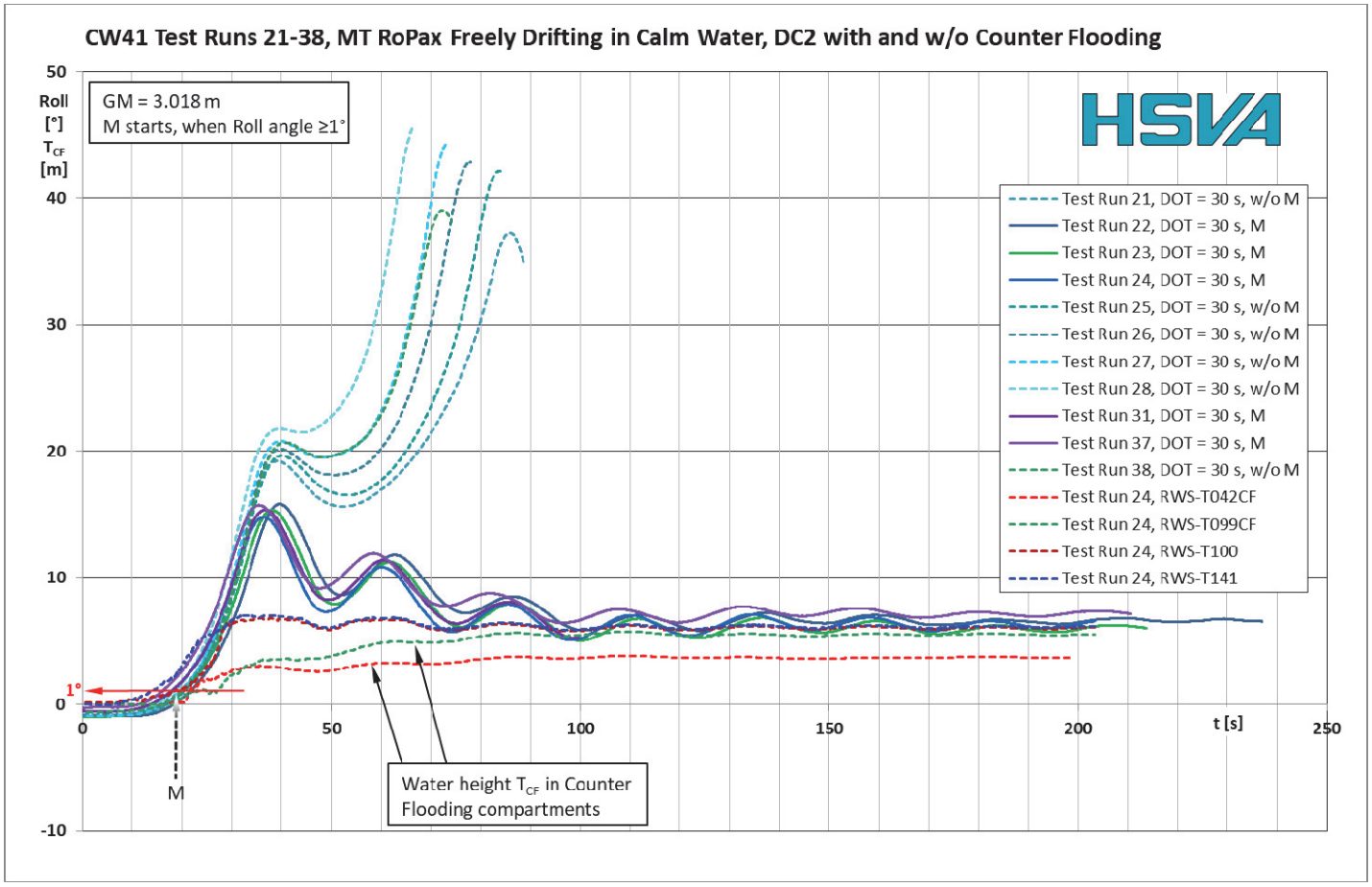
MT RoPaX-MSRC WP5DC2 CF - Model tests on 13-15.10.21 in calm water and in waves

GM=3.018 m, Damage opening time 30 s, Start criterion for counter flooding (CF) is 1° heeling angle. Opening to the CF-Compartments through 2 x 1.5 m² pipes CF = Counter Flooding, DOT = Damage Opening Time.



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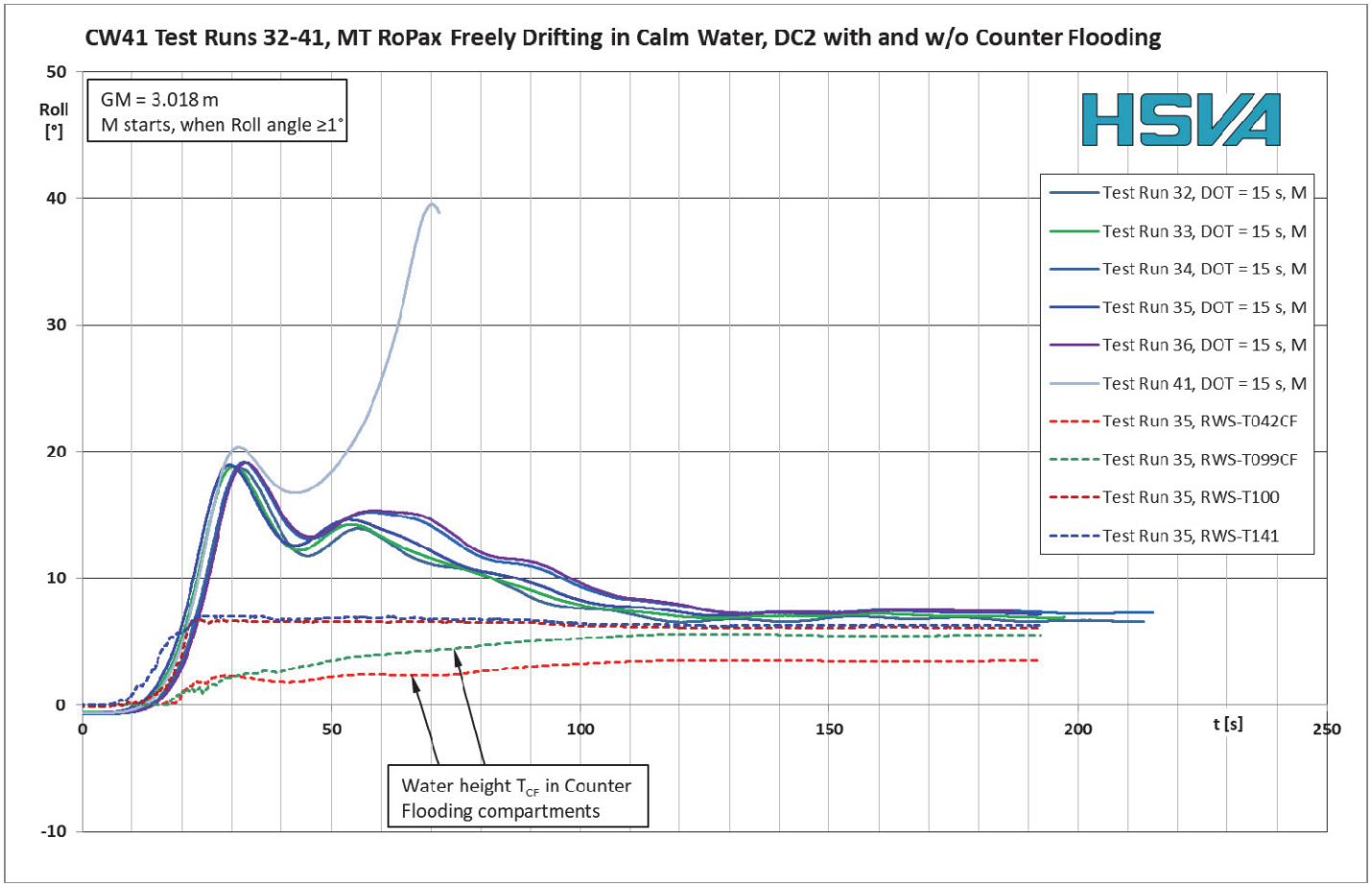
MT RoPaX-MSRC WP5DC2 CF - Model tests on 13-15.10.21 in calm water and in waves

GM=3.018 m, Damage opening time 15 s, Start criterion for counter flooding (CF) is 1° heeling angle. Opening to the CF-Compartments through 2 x 1.5 m² pipes CF = Counter Flooding, DOT = Damage Opening Time.



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MT RoPaX-MSRC WP5DC2 CF - Model tests on 13-15.10.21 in calm water and in waves

GM=3.018/3.48 m, Damage opening time 30°, Start criterion for counter flooding (CF) is 1° heeling angle. Opening to the CF-Compartments 2 x 1.5 m²
CF = Counter Flooding, DOT = Damage Opening Time.

Summary of the preliminary experimental results of the Damage Case 2

Calm Water: GM 3.018 m

- The ship capsized in 5/5 cases with DOT 30s, w/o CF => 0 % survival rate
- The ship capsized in 1/5 cases with DOT 30s, with CF start at 1° => 100 % survival rate
- The ship capsized in 1/6 cases with DOT 15 s, with CF start at 1° => 83 % survival rate

Sea States: GM 3.48 m, DOT 15 s, T_P = 10.0 s

- The ship capsized in H_S = 3.5 m in 8/10 cases w/o CF => 20 % survival rate
  ↓
- The ship capsized in H_S = 3.5 m in 0/10 cases with CF => 100 % survival rate
- The ship capsized in H_S = 5.0 m in 10/10 cases w/o CF => 0 % survival rate
  ↓
- The ship capsized in H_S = 5.0 m in 0/10 cases with CF => 100 % survival rate

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Flooding Mitigation with Deployment of a Watertight Barrier (WTB) on the Trailer Deck in Damage Case 4 of the MT RoPaX Model

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FLOODING ACCIDENT RESPONSE

MT RoPaX MSRC WP5DC4 WTB- Simulation with and w/o Mitigation

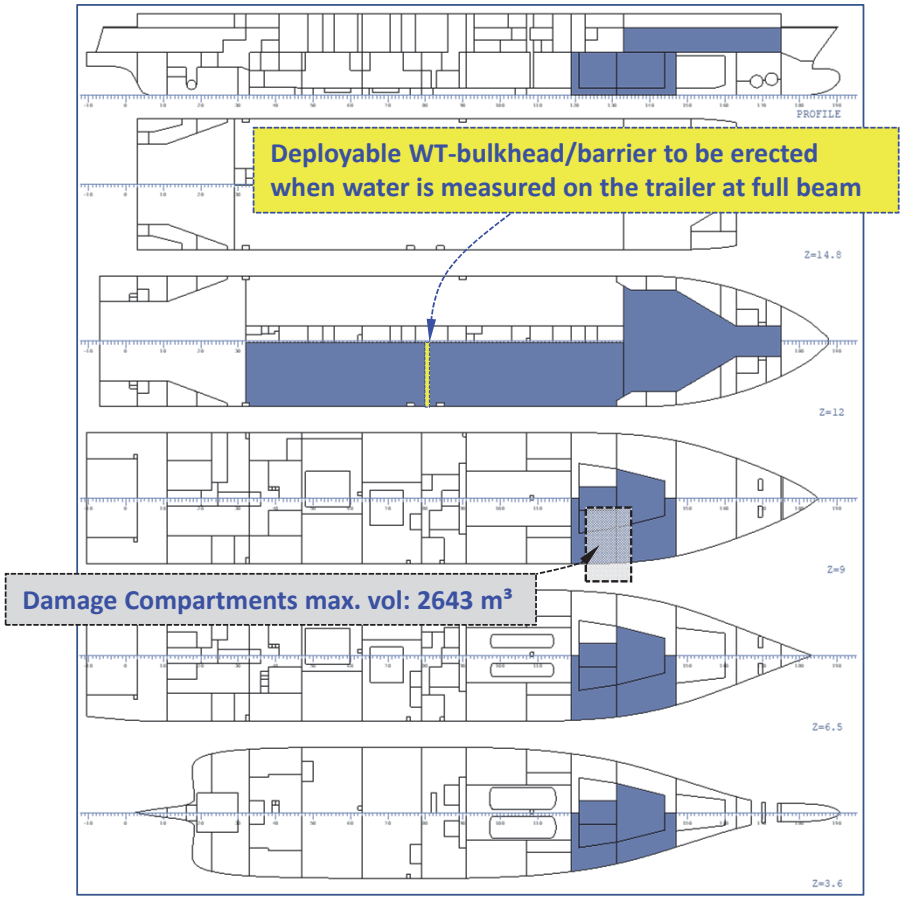

Figure 22 Damage Case 4 WTB: The grey rectangle shows the damage penetration. The damaged compartments are shown with dark blue-grey, the barrier to block the flood water spreading on the trailer deck with yellow.

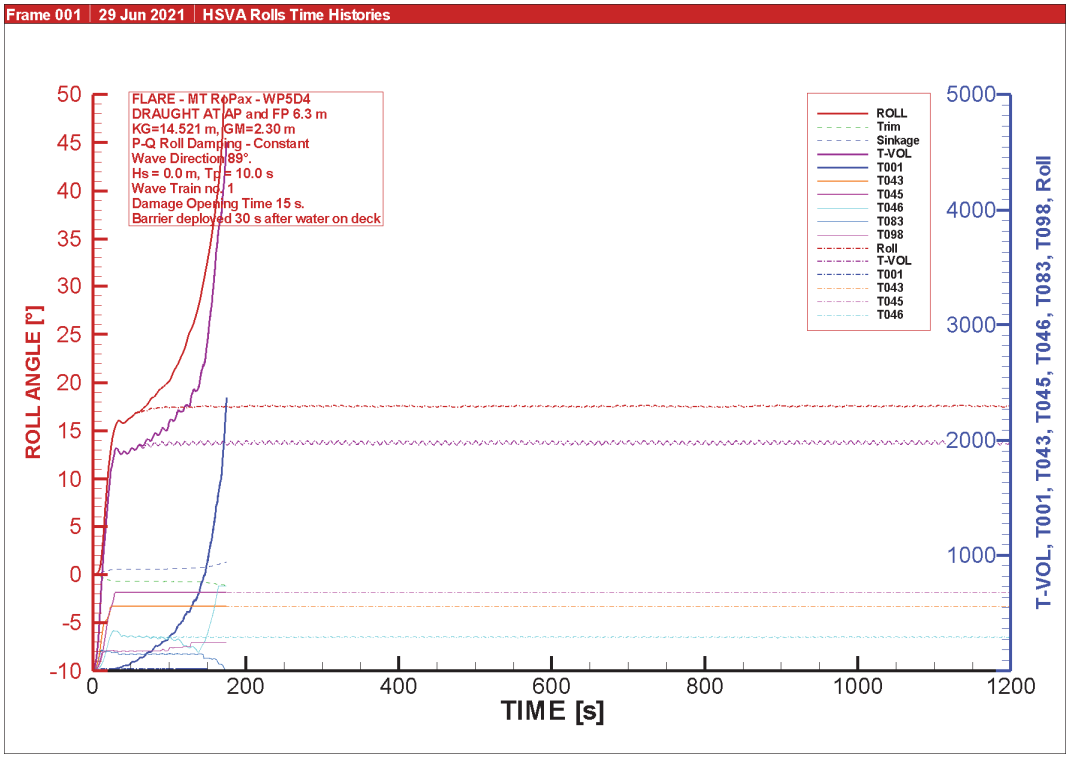

Figure 23 Deployable barrier (30 s): The roll angle (red) and water volumes on trailer deck (deep blue) and in damaged compartments. The solid curves show the situation without the deployed barrier, the dash-dotted ones the results with the barrier.

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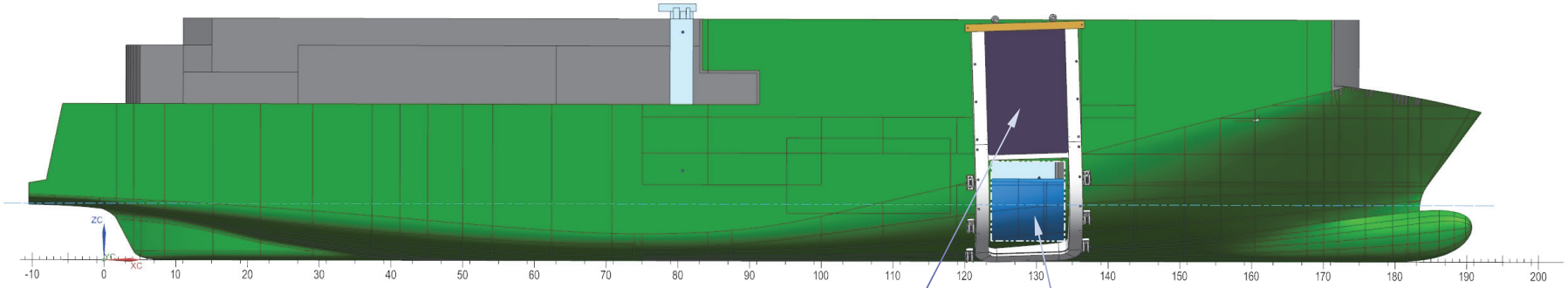
FLOODING ACCIDENT RESPONSE

MT RoPaX-MSRC WP5DC4 WTB + RLB - Model with the Damage Opening



DAMAGE OPENING WIDTH 18.26 m, HEIGHT 8.38 m, PENETRATION DEPTH 3.0 m. z= 5.3 m … 13.68 m
=> LOWER EDGE OF DAMAGE LIES 1.0 m BELOW DWL AT 6.3 m

VERTICAL SLIDING DOOR OF THE DAMAGE OPENING ONTO THE TRAILER DECK AND INTO COMPARTMENTS T083, T098, T043, T046, T045 + TRAILER DECK T001
DAMAGE OPENING TIME CA. 15 s (30 s) in F.SC.

DAMAGE CASE 4 EXTENSIONS						
DAM ID	X1 [m]	X2 [m]	Y1 [m]	Y2 [m]	Z1 [m]	Z2 [m]
DMC0385	98.95	107.14	-50.00	-1.30	2.29	11.14

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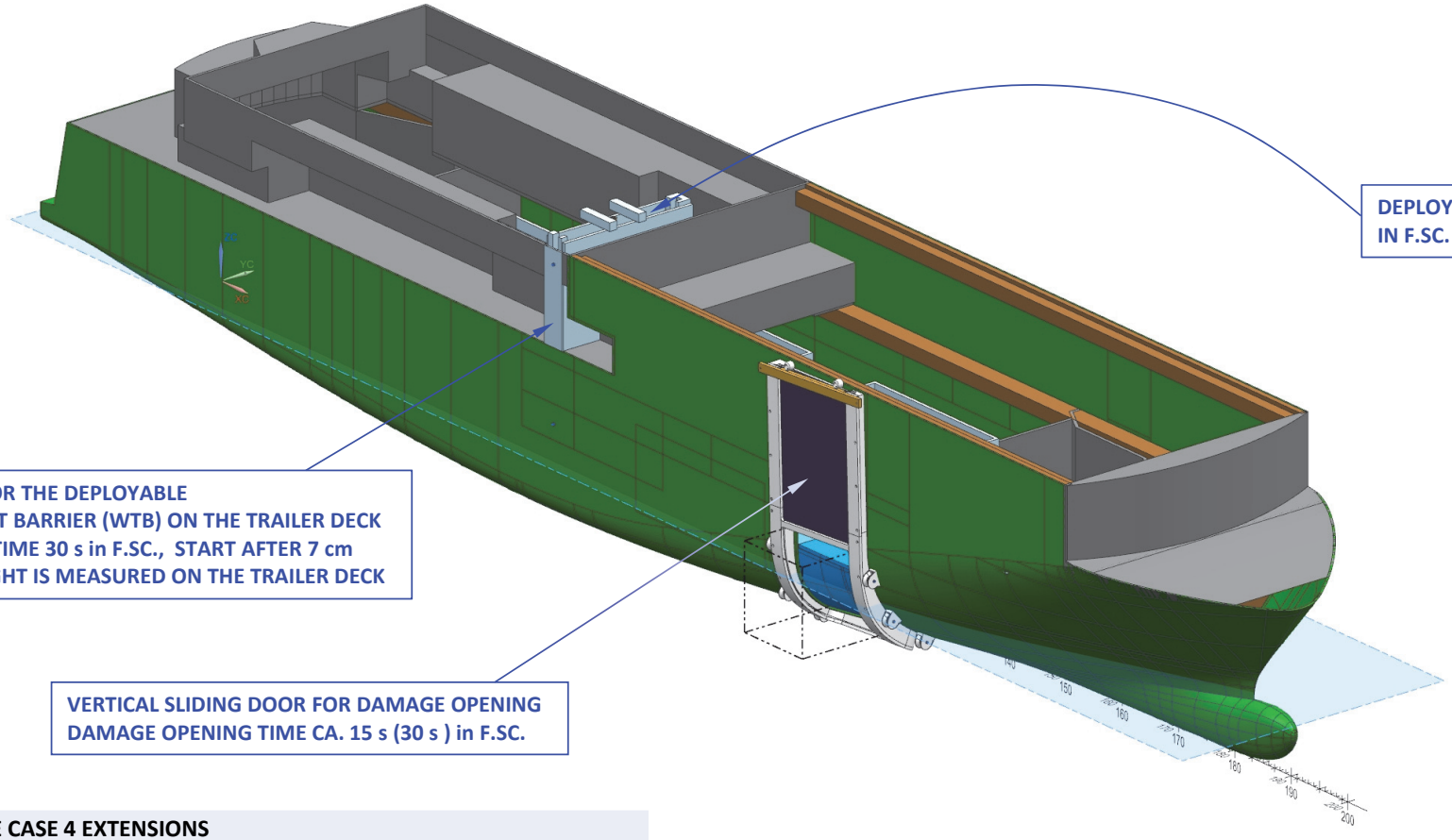
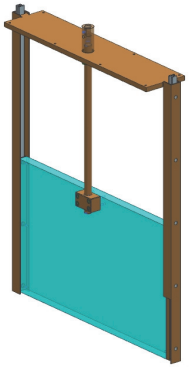
MT RoPaX-MSRC WP5DC4 WTB + RLB - Model with the Damage Opening





DAMAGE CASE 4 EXTENSIONS

DAM ID	X1 [m]	X2 [m]	Y1 [m]	Y2 [m]	Z1 [m]	Z2 [m]
DMC0385	98.95	107.14	-50.00	-1.30	2.29	11.14

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MT RoPaX Model tests 11,15 on Deployment of a Watertight Barrier (WTB)



GM = 3.30 m
Damage length on the ship side = 8.19 m.
Damage opening time ca. 15 s.
Deployment of the Roll-Up-Door starts when 7 cm water column is measured on the trailer deck.
Deplyment time ca. 27 s.
Without deployment of the roll-up-door the ship capsizes in ca. 90 s.
With deployment of the roll-up-door it survives.

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FLOODING ACCIDENT RESPONSE

MT RoPaX Model tests 11,15 on Deployment of a Watertight Barrier (WTB)



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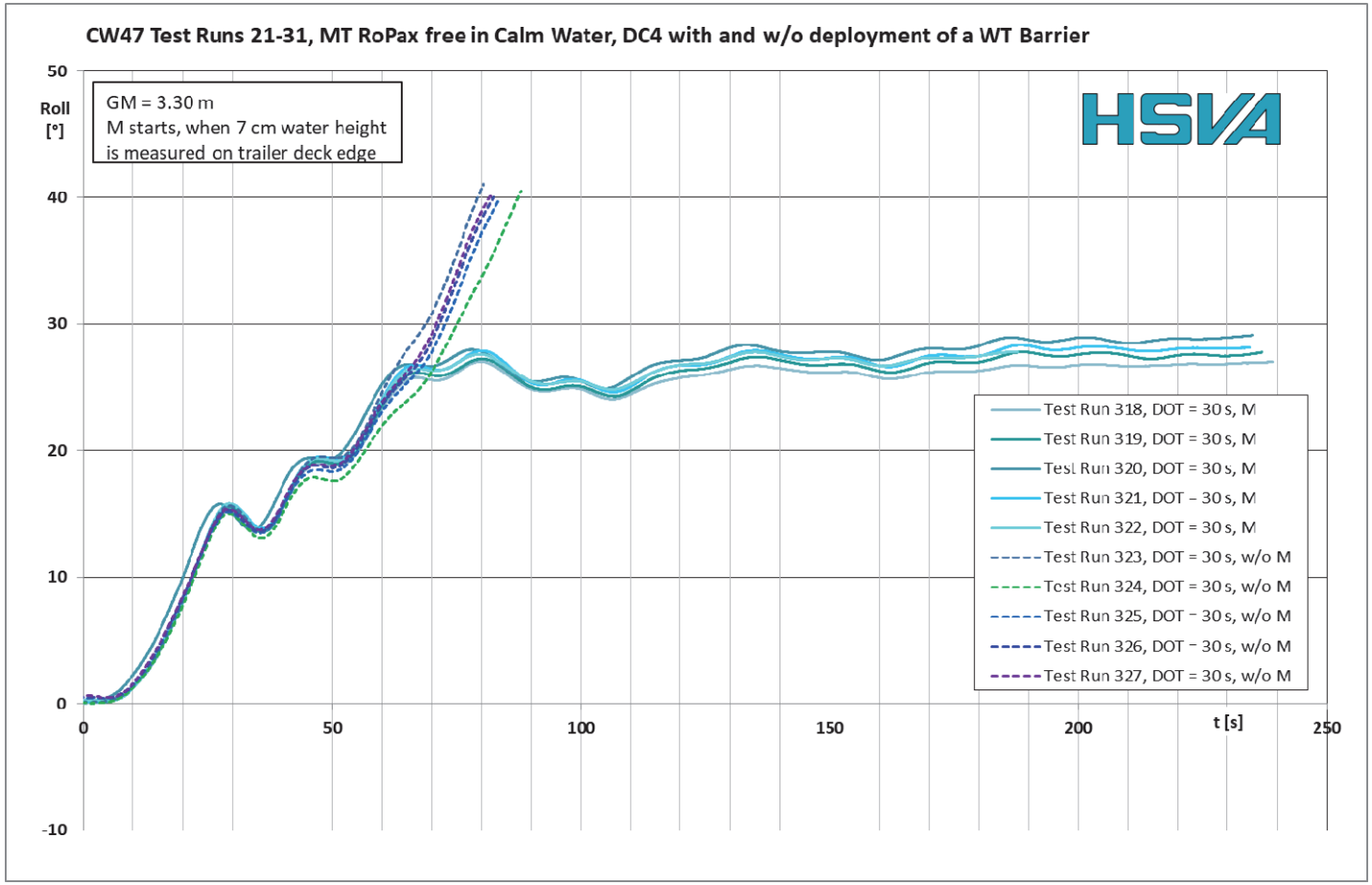
MT RoPaX-MSRC WP5DC4 WTB - Model tests on 26-30.11.21 in calm water and in waves

GM=3.30 m, Damage opening time 30 s, Start criterion for deployment of watertight barrier (WTB) is 7 cm water on the trailer deck. Duration of deployment ca. 27 s. WTB = Watertight Barrier, DOT = Damage Opening Time.



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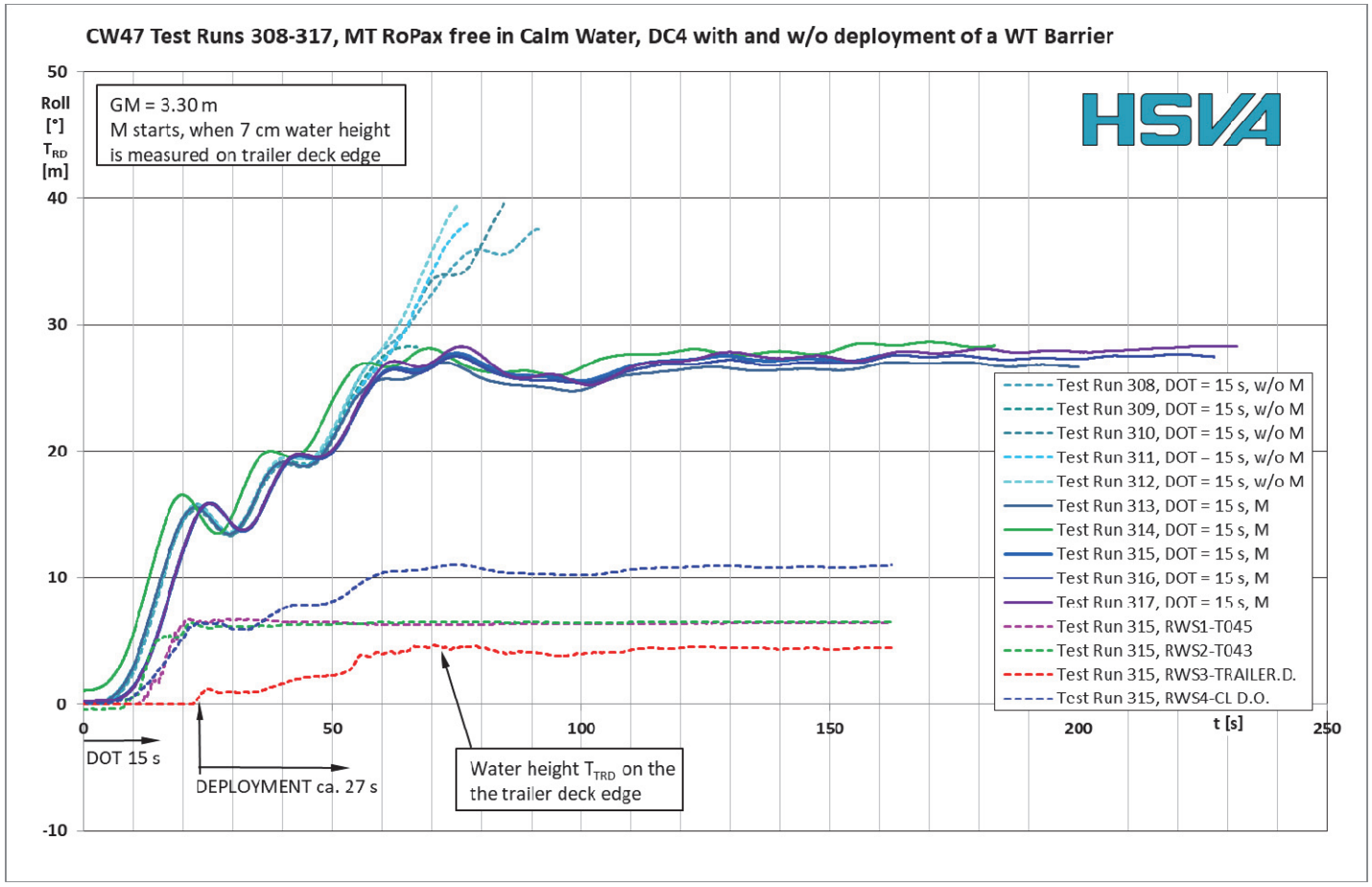
MT RoPaX-MSRC WP5DC4 WTB - Model tests on 26-30.11.21 in calm water and in waves

GM=3.30 m, Damage opening time 30 s, Start criterion for deployment of watertight barrier (WTB) is 7 cm water on the trailer deck. Duration of deployment ca. 27 s. WTB = Watertight Barrier, DOT = Damage Opening Time.



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MT RoPaX-MSRC WP5DC4 WTB - Model tests on 26-30.11.21 in calm water and in waves

GM=3.30/3.71 m, Damage opening time 15/30 s, Start criterion for deployment of watertight barrier (WTB) is 7 cm water on the trailer deck. Duration of deployment ca. 27 s. WTB = Watertight Barrier, DOT = Damage Opening Time.

Summary of the preliminary experimental results of the Damage Case 4

Calm Water: GM 3.3 m

- The ship capsized in 5/5 cases with DOT 30s, w/o WTB => 0 % survival rate
- The ship capsized in 0/5 cases with DOT 30s, with WTB => 100 % survival rate
- The ship capsized in 5/5 cases with DOT 15 s, w/o WTB => 0 % survival rate
- The ship capsized in 0/5 cases with DOT 15 s, with WTB => 100 % survival rate

Sea States: GM 3.71 m, DOT 15 s, T_P = 10.0 s

- The ship capsized in H_S = 2.5 m in 10/10 cases w/o WTB => 0 % survival rate
- The ship capsized in H_S = 2.5 m in 0/10 cases with WTB => 100 % survival rate
- The ship capsized in H_S = 4.0 m in 10/10 cases w/o WTB => 0 % survival rate
- The ship capsized in H_S = 4.0 m in 0/10 cases with WTB => 100 % survival rate

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Flooding Mitigation with Recovery of Lost Buoyancy (RLB) in Damage Case 4 of the MT RoPaX Model

The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.: 814753)

MT RoPaX MSRC WP5DC4 RLB- Simulation with and w/o Mitigation

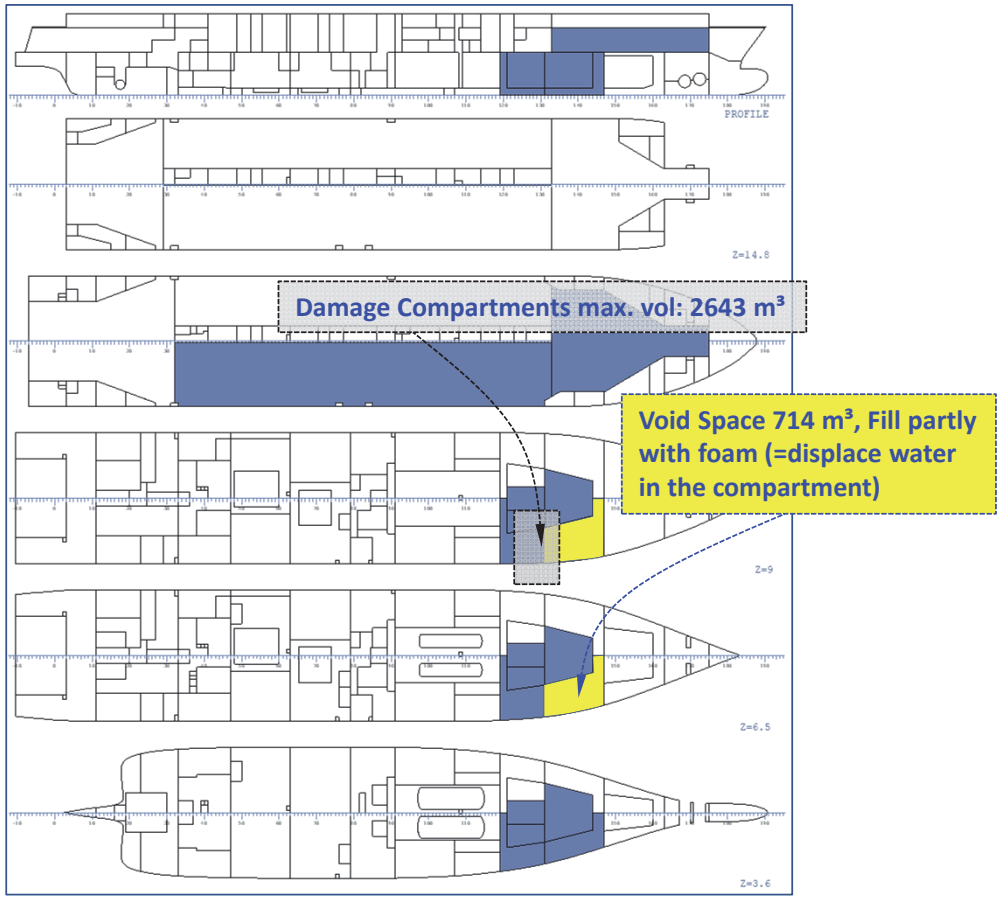

Figure 15 Damage Case 4 RLB: The grey rectangle shows the damage penetration. The damaged compartments are shown with dark blue-grey, the compartments for counter flooding with light blue, and those for recovery of lost buoyancy through flood water displacement with yellow.

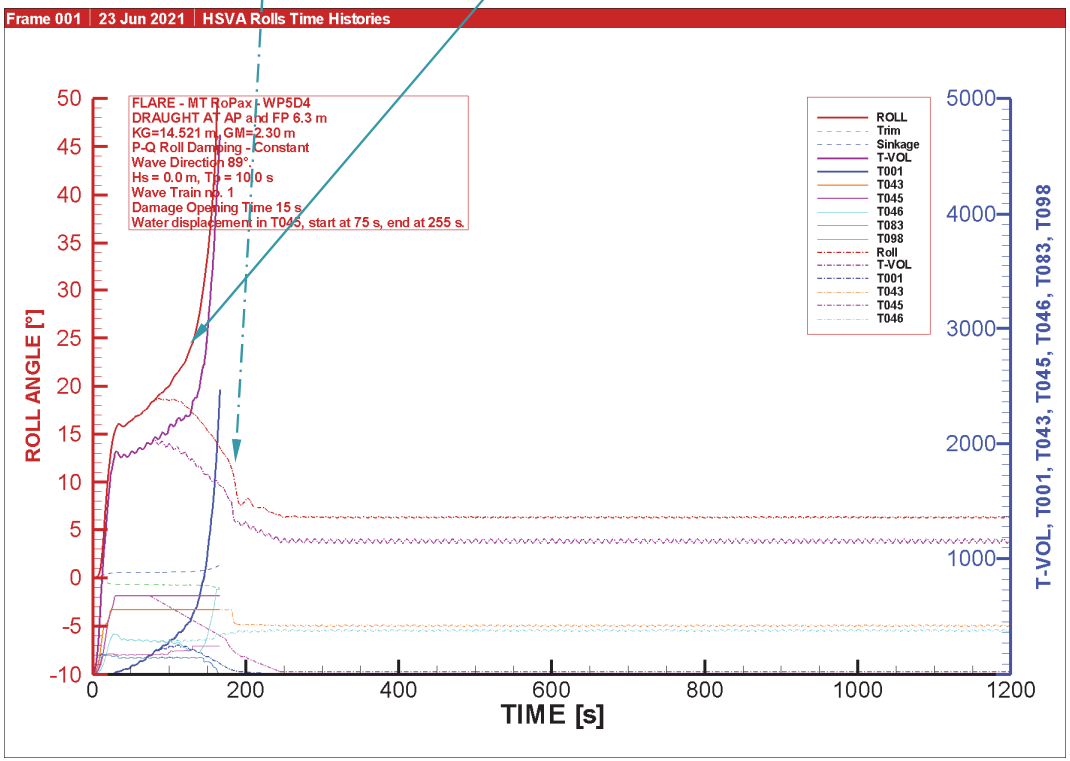

Figure 17 Recovery of lost buoyancy (RLB): The roll angle (red) and water volumes on trailer deck (blue) and in damaged compartments (bluish, reddish, deep yellow) and in the one (T045, pink solid/dash-dotted curve) chosen for mitigation by displacing flood water. T-VOL is the total volume of the flood water in ship, T001 the water volume on the trailer deck.

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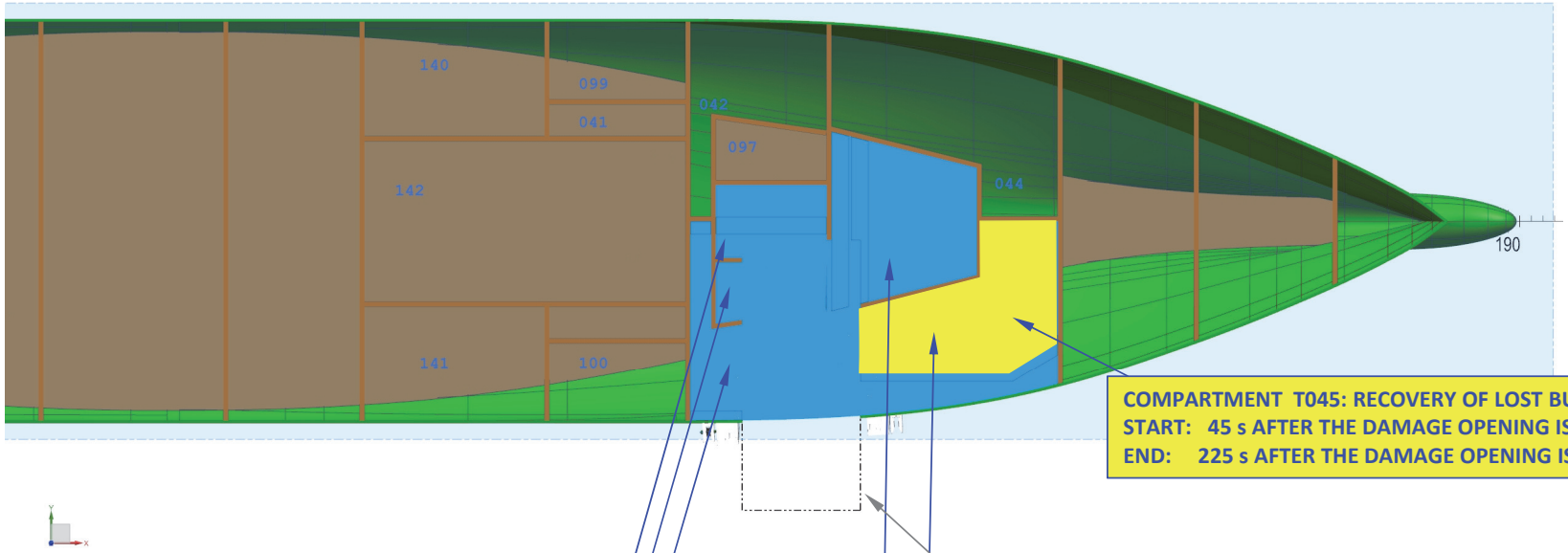
MT RoPaX-MSRC WP5DC4 RLB - Model with relevant internal compartments



DAMAGE CASE 4 EXTENSIONS

DAM ID	X1 [m]	X2 [m]	Y1 [m]	Y2 [m]	Z1 [m]	Z2 [m]
DMC0385	98.95	107.14	-50.00	-1.30	2.29	11.14

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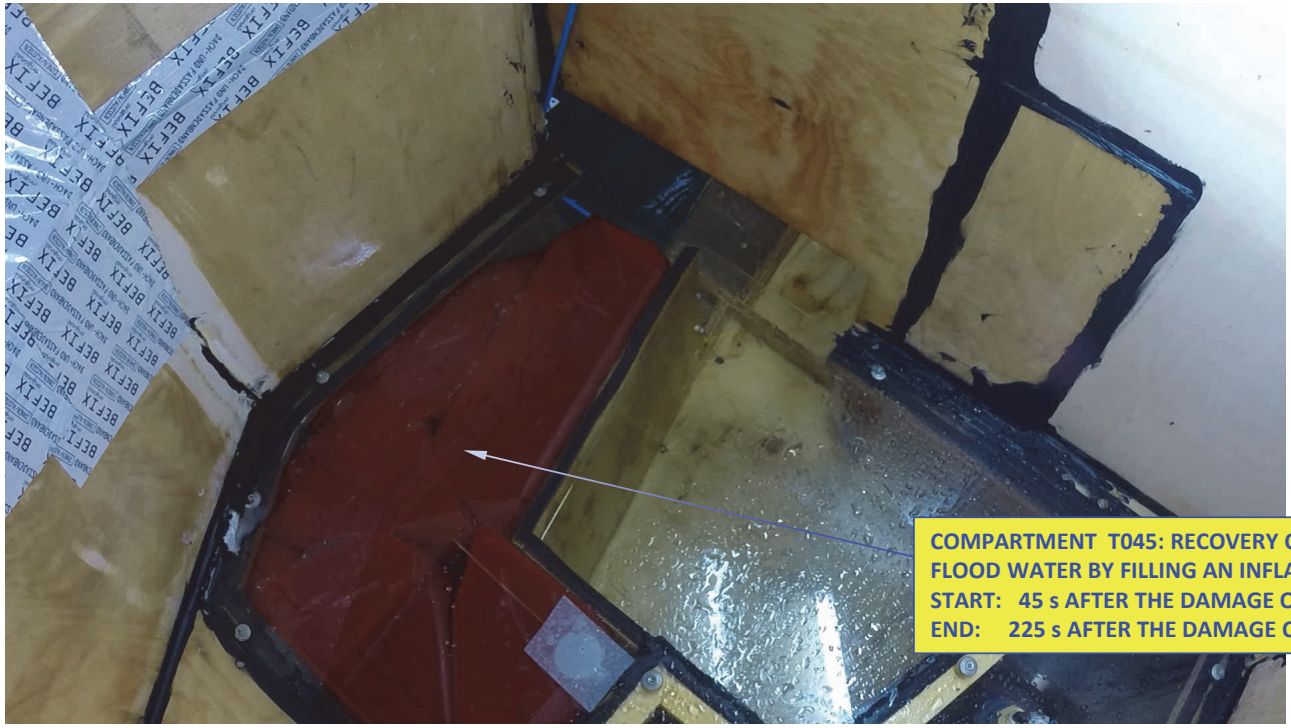
MT RoPaX-MSRC WP5DC4 RLB - Model with damaged compartment T045 – displacement of floodwater by filling an inflatable container with air



COMPARTMENT T045: RECOVERY OF LOST BUOYANCY BY DISPLACING FLOOD WATER BY FILLING AN INFLATABLE CONTAINER WITH AIR.
START: 45 s AFTER THE DAMAGE OPENING IS COMPLETED
END: 225 s AFTER THE DAMAGE OPENING IS COMPLETED

DAMAGE CASE 4 EXTENSIONS

DAM ID	X1 [m]	X2 [m]	Y1 [m]	Y2 [m]	Z1 [m]	Z2 [m]
DMC0385	98.95	107.14	-50.00	-1.30	2.29	11.14

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MT RoPaX Model tests no.135,148 on Recovery of Lost Buoyancy



GM = 3.71 m
Damage length on the ship side = 8.19 m.
Damage opening time ca. 30 s.
Recovery of the Lost Buoyancy in a damaged compartment starts 30 s after the damage has completely opened.
The recovery is carried out with an inflatable container displacing flood water in the compartment.
Without mitigation the ship capsizes in ca. 160 s.
With the recovery of the lost buoyancy it survives.

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MT RoPaX Model tests no. 135,148 on Recovery of Lost Buoyancy



GM = 3.71 m
Damage length on the ship side = 8.19 m.
Damage opening time ca. 30 s.
Recovery of the Lost Buoyancy in a damaged compartment starts 30 s after the damage has completely opened.
The recovery is carried out with a red inflatable container displacing flood water in the compartment.
Without mitigation the ship capsizes in ca. 160 s.
With the recovery of the lost buoyancy it survives.

The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.: 814753)

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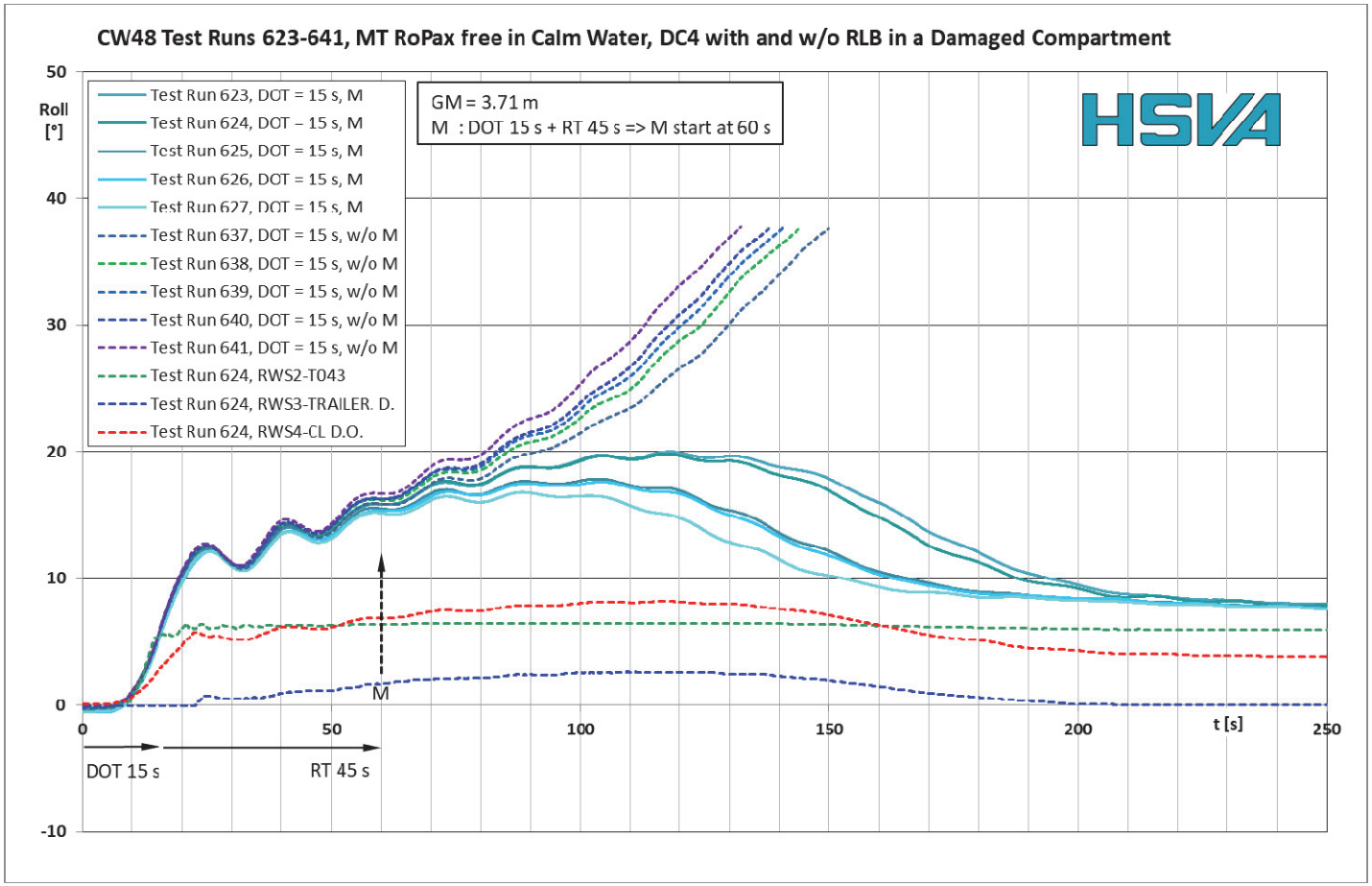
MT RoPaX-MSRC WP5DC4 RLB - Model tests on 30.11-02.12.21 in calm water and in waves

GM=3.71 m, Damage opening time 15 s, Recovery of Lost Buoyancy (RLB) starts 45 s after the damage has opened in 15 s. Duration of deployment ca. 180 s. RLB = Recovery of Lost Buoyancy, DOT = Damage Opening Time.



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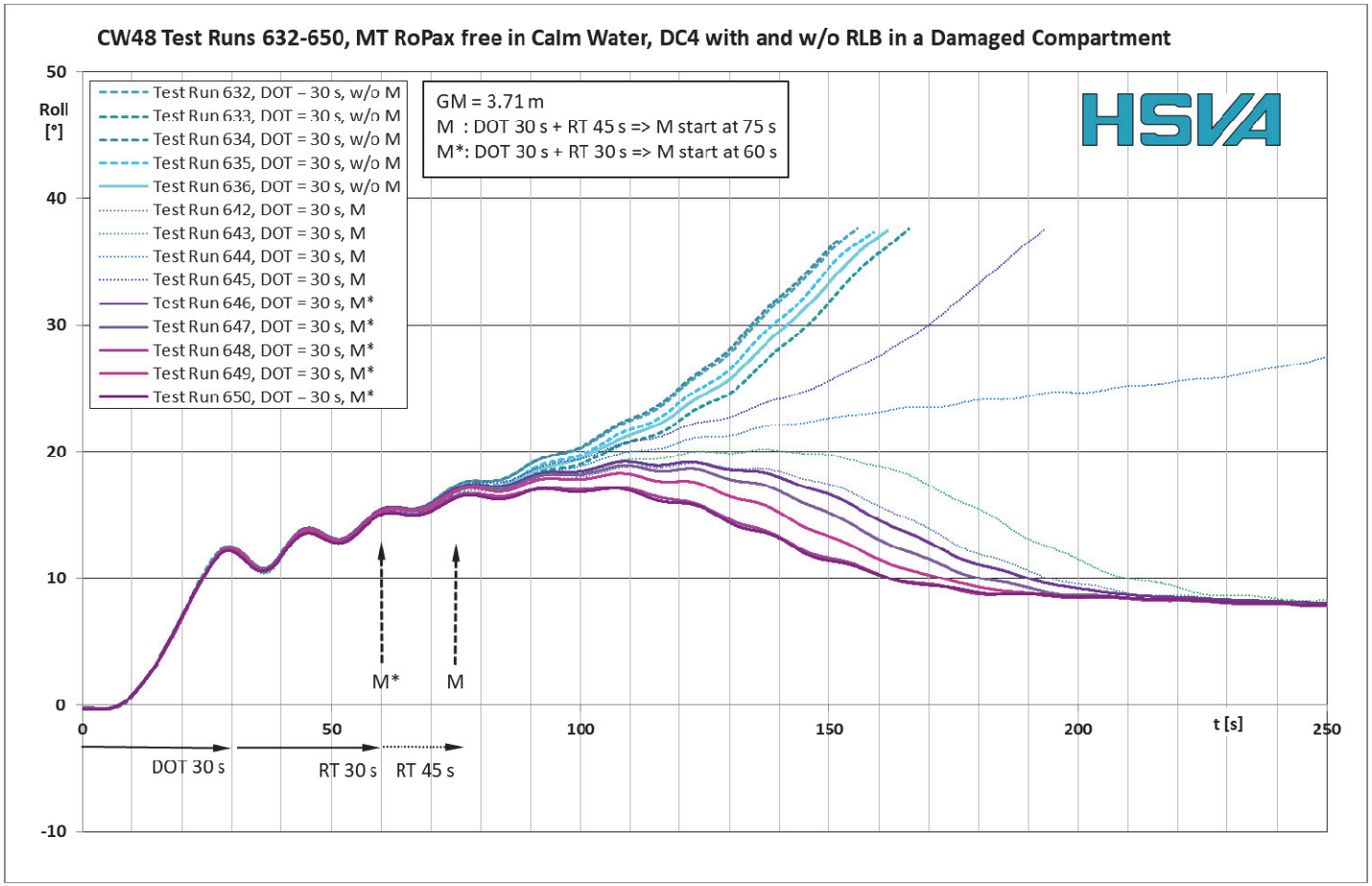
MT RoPaX-MSRC WP5DC4 RLB - Model tests on 30.11-02.12.21 in calm water and in waves

GM=3.71 m, Damage opening time 30 s, Recovery of Lost Buoyancy (RLB) starts 30 s after the damage has opened in 30 s. Duration of deployment ca. 180 s. RLB = Recovery of Lost Buoyancy, DOT = Damage Opening Time, M = Mitigation.



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MT RoPaX-MSRC WP5DC4 RLB - Model tests on 30.11-02.12.21 in calm water and in waves

GM=3.71/3.81 m, Damage opening time 15/30 s. Start of displacing flood water in compartment T045: 45s/30 s (=RT) after the damage has opened. Duration of water displacement 180 s. RLB = Recovery of lost buoyancy, DOT = Damage Opening Time, RT = Reaction Time

Summary of the preliminary experimental results of the Damage Case 4

Calm Water: GM 3.71 m

- The ship capsized in 5/5 cases with DOT 15s, RT ----, w/o RLB => 0 % survival rate
- The ship capsized in 0/5 cases with DOT 15s, RT 45s, with RLB => 100 % survival rate
- The ship capsized in 5/5 cases with DOT 30s, RT ----, w/o RLB => 0 % survival rate
- The ship capsized in 0/5 cases with DOT 30s, RT 30s, with RLB => 100 % survival rate

Sea States: GM 3.81 m, DOT 15 s, RT 45 s, T_P = 10.0 s

- The ship capsized in H_S = 2.5 m in 10/10 cases w/o RLB => 0 % survival rate
- The ship capsized in H_S = 2.5 m in 0/10 cases with RLB => 100 % survival rate
- The ship capsized in H_S = 4.0 m in 10/10 cases w/o RLB => 0 % survival rate
- The ship capsized in H_S = 4.0 m in 3/10 cases with RLB => 70 % survival rate

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Conclusions on Flooding Mitigation (1)

- Three flooding mitigation methods on two damage cases on a modern RoPax design were studied.
- All mitigation methods were programmed and simulated prior to the model tests. This was easy and very useful.
- All three mitigation methods successfully prevent or postpone ship capsize in the serious damage cases studied, and thus have a clear positive effect on the potential loss of life PLL.
- Fairly simple, but effective steering systems were used to start the mitigation automatically in the ship model:

  (1) Counter Flooding (CF) starts automatically, when the ship heel exceeds (5°)/1° towards damage side.

  (2) Recovery of Lost Buoyancy (RLB) in a damaged compartment starts 45/30 s after the damage has opened, and lasts 180 s.

  (3) The deployment of the Watertight Barrier (WTB) on the trailer deck starts automatically, when water height of 7 cm is detected by a sensor on the outer edge of the trailer deck. WTB lowering time is 30 s.

  - Not once did any of the mitigation systems fail in the tests. It is not difficult or complicated to find/use effective starting criteria.

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Conclusions on Flooding Mitigation (2)

- Implementation in a ship:

  (1) It is very straightforward to prepare few heeling or ballast tanks or void spaces for Counter Flooding (CF) on each ship side opposing the damage. CF reduces the heeling angle, which makes all tasks in the damaged ship easier.

  (2) Recovery of Lost Buoyancy (RLB) in a damaged compartment requires preparation of each such compartment in advance, which can get damaged and is relevant for the ship stability. This is a much more extensive task than the preparation for counter flooding. RLB reduces the heeling angle, which makes all tasks in the damaged ship easier.

  (3) The deployment of the Watertight Barrier (WTB), e.g. a standard Roll-gate, on the trailer deck is very straightforward also in an existing ship. WTB does not recover anything, it limits the extent of flooding. Capsize is postponed or prevented, but a large heeling angle remains, which does not make tasks in the damaged ship easier.

Altogether:

=> The three flooding mitigation methods investigated provide very promising ways to increase the safety level of both newbuildings and of the operating fleet of cruise and Ropax ships. The deployment speed of the mitigation measures has to be paid attention to.

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Thank you for your attention!

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