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# *Model tests on Meyer Turku RoPax – for Benchmarking and further Development of Numerical Codes*

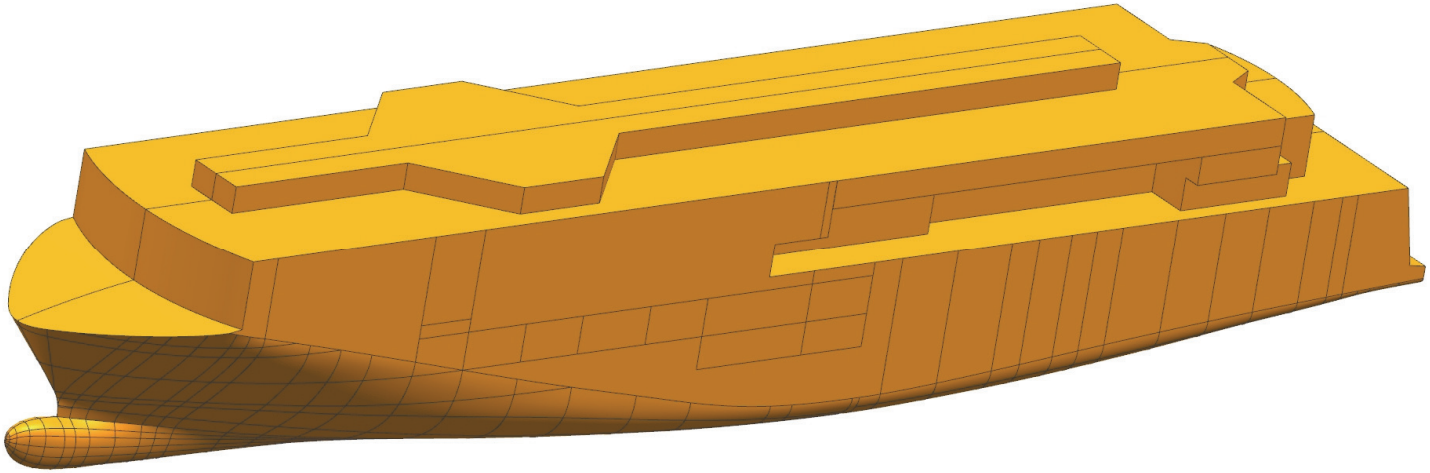
| | | |
|---|---|---|
| *Benchmark tests – Low/Realistic GM* | *- Gradual flooding in (low + high) beam seas*<br>*- Free-drifting vs. soft-moored*<br>*- Damage on the wave side vs. on the lee side*<br>*- In long-crested vs. short-crested beam seas* | **(June-August 2020)** |
| *Benchmark tests – Low GM* | *- Transient flooding in calm water and in (low) beam seas using different damage opening times* | **(August 2020)** |

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 (Flare Ship #6)-Model:*



| | | |
|---|---|---|
| MT RoPaX = Unbuilt Ship Design for FLARE by Meyer Turku Shipyard | | |
| Model scale: | | 28 |
| HSVA Model no. | | 5460 |
| Length between perpend. | Lpp | = 146.72 m |
| Breadth moulded | Bmld | = 28.00 m |
| Draught | T | = 6.1m |
| Metacentric height | GM | = 3.25 m |

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# *MT RoPax-Benchmarking Model Tests:*

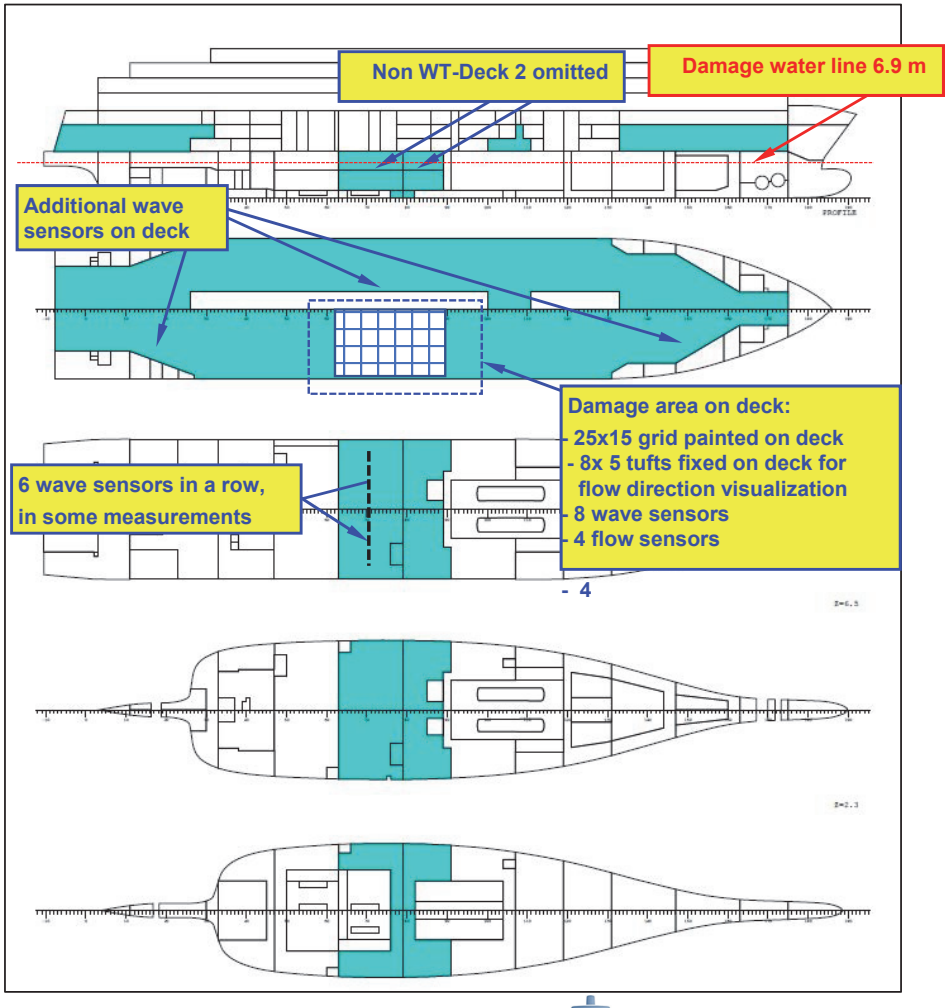
**2-Compartment damage between frames #63 and #91, center-line at frame #79:**

Width of the damage opening on the trailer deck = 14.66 m,
Width of the opening to lower compartments 9.15 m.
Reduction of intact GM to 3.25 m. [With GM 3.25 m and intact draught 6.1 m, the ship is exactly at the GM-limit curve]

- The damage opening extends from the BL to unlimited height.
- The damage opening has zero penetration, only the ship shell was removed.

**Measurements:**

- Ship motions
- Average ship drift
- Undisturbed wave elevation at centerline behind the ship
- On Trailer deck: altogether 15 wave sensors, 4 flow sensors, in selected tests.
- In compartment #63-#79: 6 wave sensors for water motion, in selected tests.

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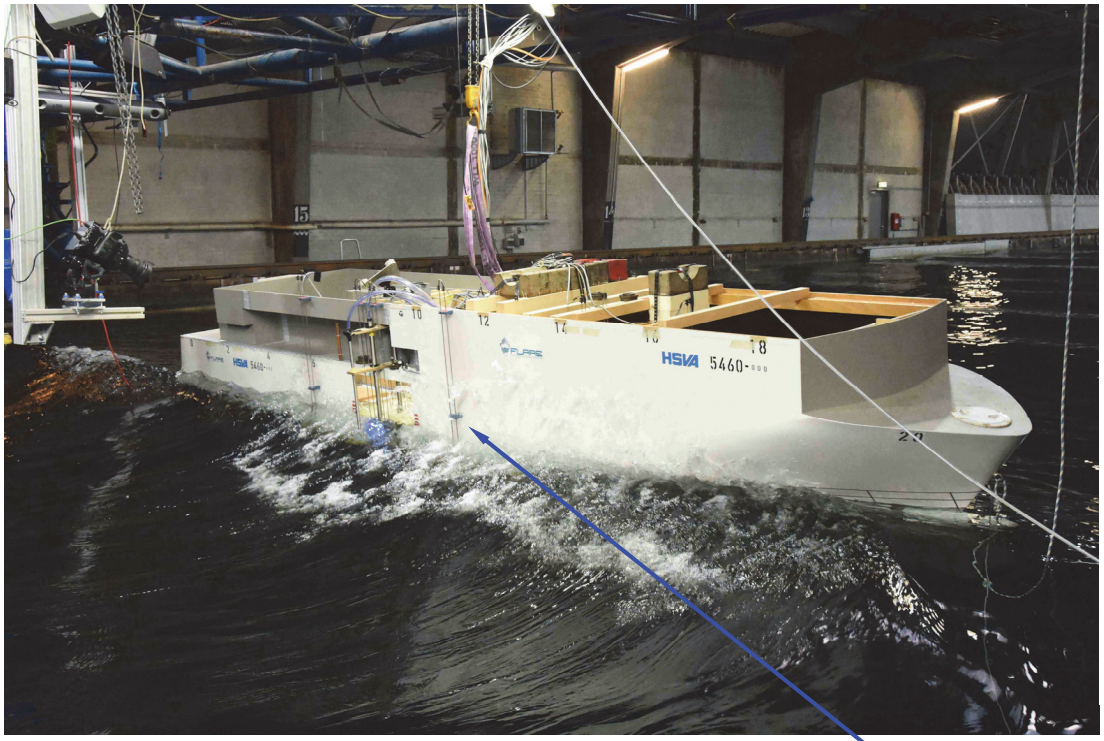
# MT RoPax- Model Tests on CW23: Gradual flooding in beam seas






MEASUREMENT OF FLOW SPEED AND LOCAL WATER ELEVATION

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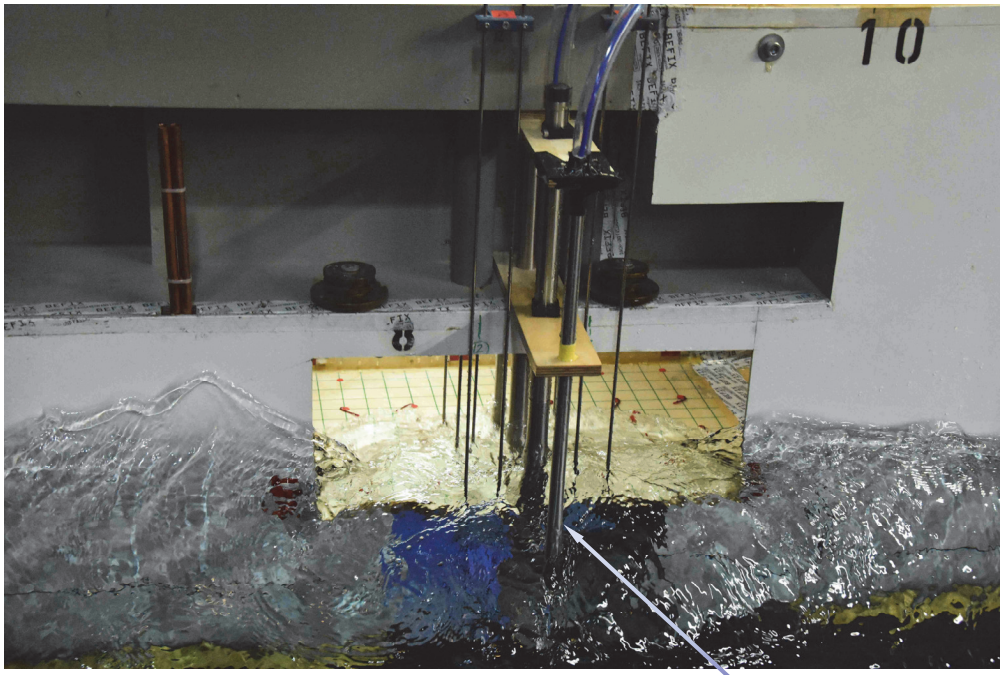
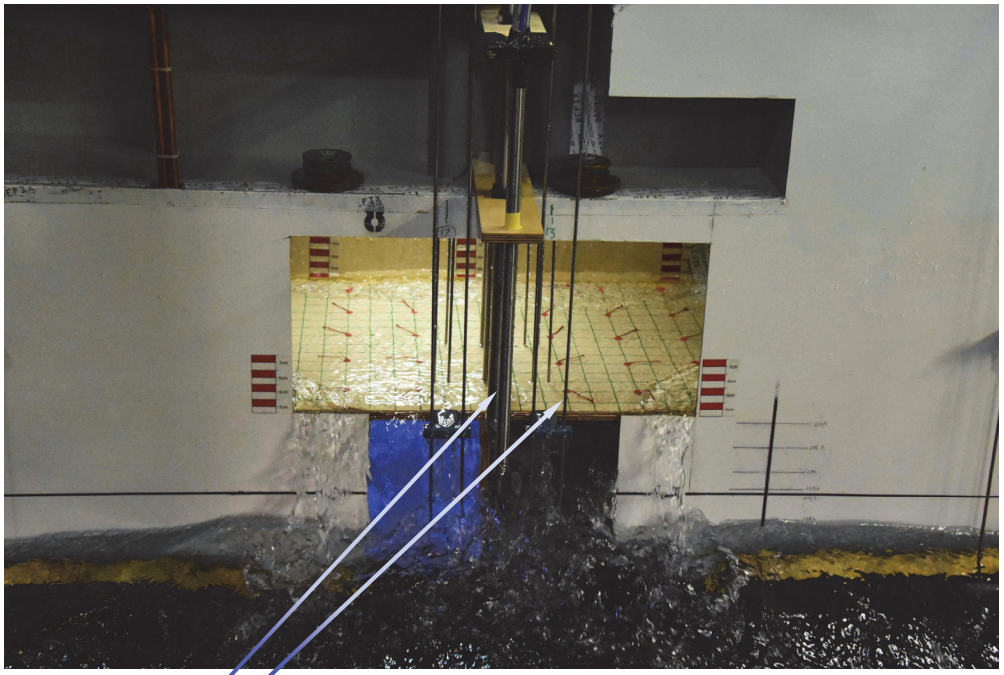
# MT RoPax- Model Tests on CW23: Gradual flooding in beam seas



WATER FLOWS IN

MEASUREMENT OF FLOW SPEED AND LOCAL WATER ELEVATION

WATER FLOWS OUT

THE FLOW IN THE DAMAGE OPENING CAN BE VERY UNSTEADY!

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# MT RoPax- Model Tests on CW23 Run 23: Gradual flooding in beam seas

*(Example for illustration)*



A FEW VIDEO FRAMES SHOWING WATER RUSHING ON THE TRAILER DECK, HITTING THE CENTER CASING AND SPREADING ON THE DECK

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# *MT RoPax- Model Tests on CW23 Run 23: Gradual flooding in beam seas*

***(Example for illustration)***



**THE FLOW DIRECTION CHANGES IN EVERY 5 - 8 s IN FULL SCALE!**

**A SHORT VIDEO OF THE SAME CASE …**

**ALSO IN GRADUAL FLOODING CASE THE FLOW THROUGH THE DAMAGE OPENING IS VERY UNSTEADY. BUT MOST SIMULATION CODES USE BERNOULLI EQUATION FOR MODELING THIS FLOW:**

**THE PROBLEM IS THAT BERNOULLI EQUATION DESCRIBES STEADY FLOW IN AN INERTIAL FRAME OF REFERENCE (BUT THE FLOW IS NOT STEADY, AND THE SHIP IS NOT INERTIAL FRAME OF REF)**

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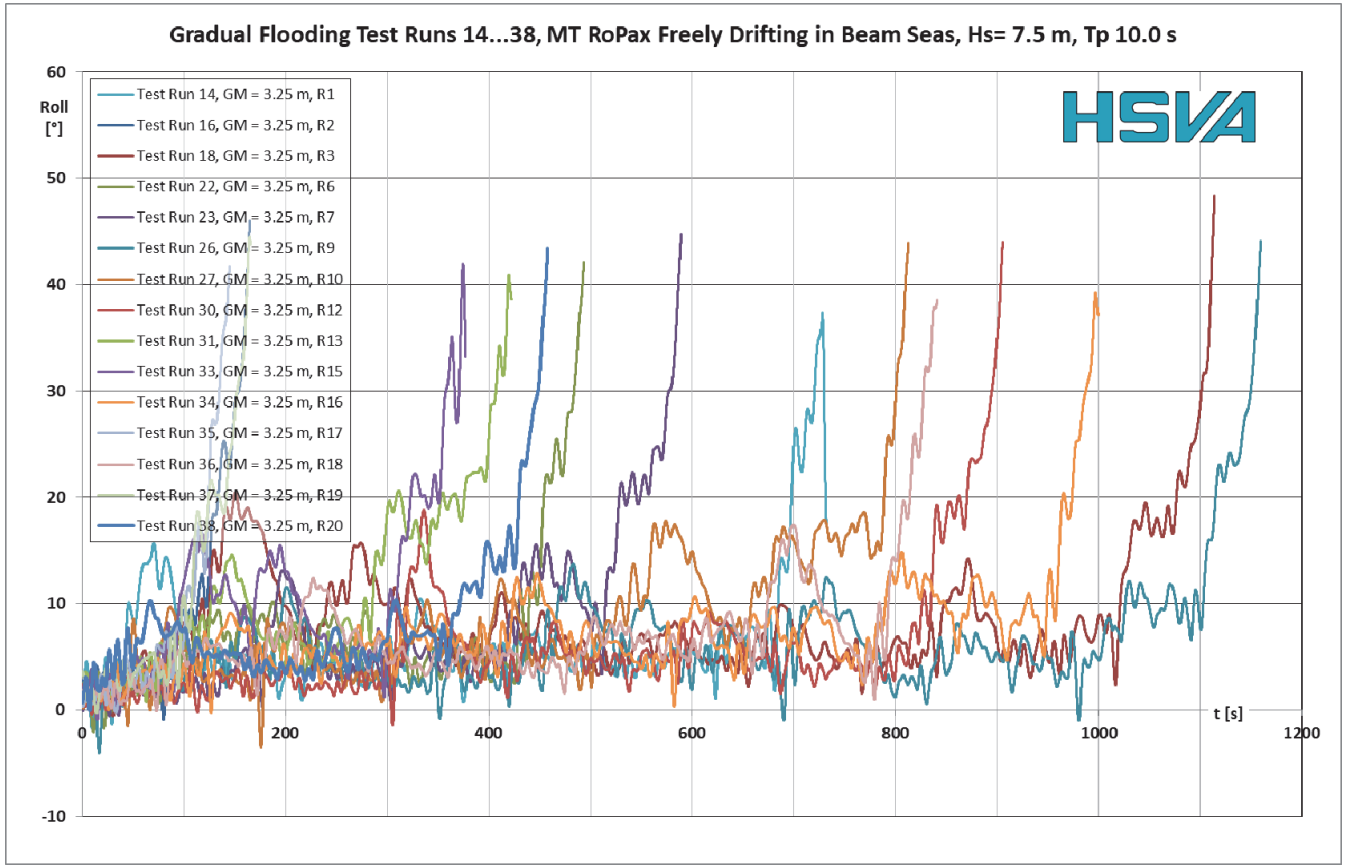
# MT RoPaX- Model Tests on CW23/34: Gradual flooding in beam seas

*(Capsize Rate)*




**TEST RUNS IN $H_S$ 7.5 m FOR BENCHMARK-TASK 3b**
**CAPSIZE RATE 15/20 = 75 %**

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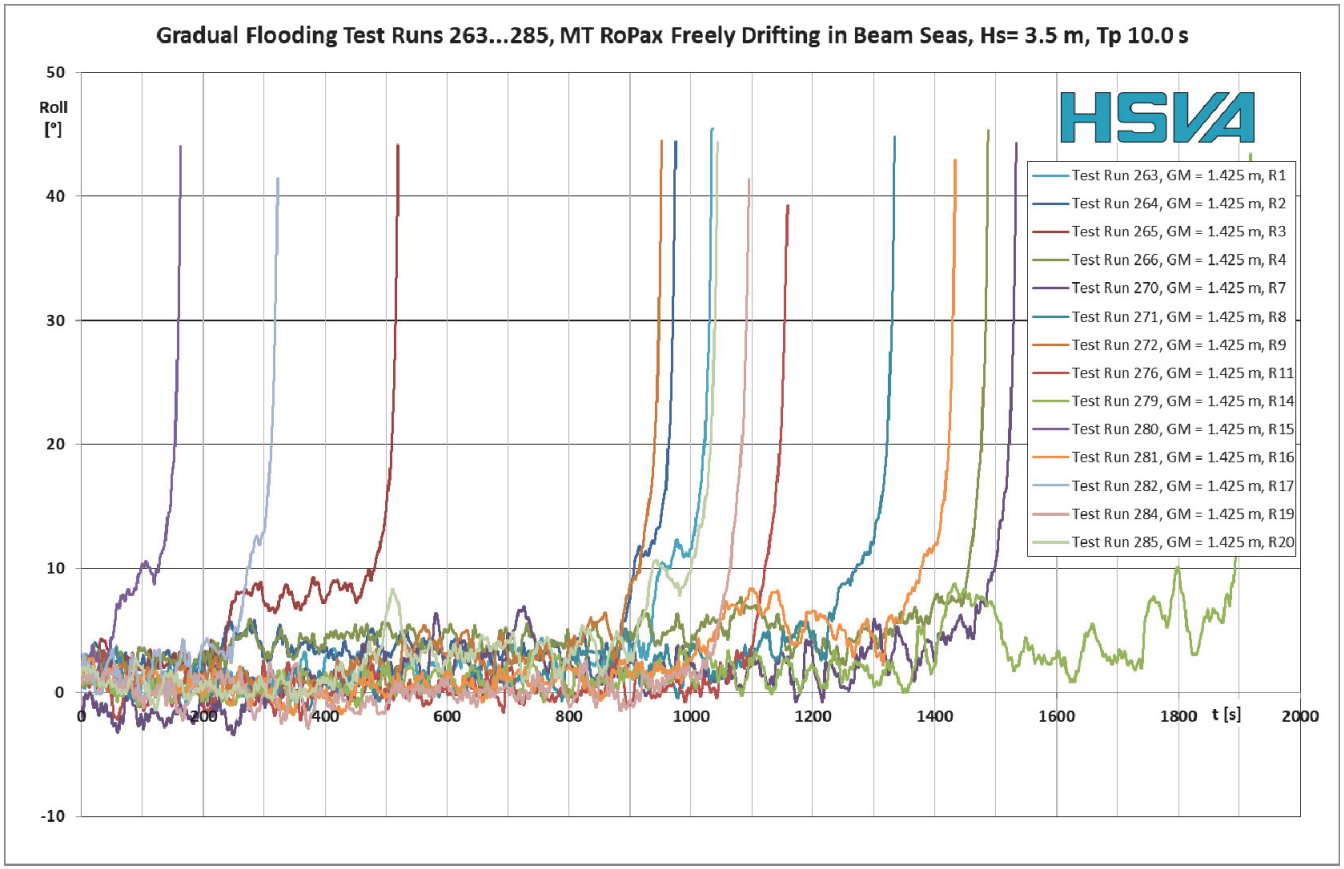
# MT RoPaX- Model Tests on CW23/34: Gradual flooding in beam seas

*(Capsize Rate)*




**TEST RUNS IN $H_S$ 3.5 m FOR BENCHMARK-TASK 3a**
**CAPSIZE RATE 13/20 = 65 %**

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# *MT RoPaX- Gradual flooding – Benchmarking – How good are the numerical predictions?*

THIS VALUE ≈ A GOOD ESTIMATE OF THE REAL CAPSIZE RATE

SIMULATIONS MIGHT GIVE THIS

SIMULATIONS MIGHT GIVE THIS

**Ruponen et. al., Applied Ocean Research 2022(?):**

**Capsize rate in 20 repetitions with different wave realizations in model tests and in simulations**

| GM [m] | $H_S$ [m] | $T_P$ [s] | Model tests | Sim. Code 1 | Sim. Code 2 | Sim. Code 3 | Sim. Code 4 |
|---|---|---|---|---|---|---|---|
| 1.425 | 3.5 | 10 | 65 % | 75% | 0% | 90% | 25% |
| 3.25 | 7.5 | 10 | 75 % | 90% | 40% | 30% | 95% |

**=> THE ACCURACY OF THE NUMERICAL PREDICTIONS FOR ROPAX ~~COULD~~ SHOULD BE BETTER !**

**POTENTIAL WEAK POINTS IN THE NUMERICAL CODES FOR SHIP DAMAGE SURVIVABILITY:**

- **MODELING THE FLOOD WATER MOTION IN THE SHIP AND DAMPING IN THE NUMERICAL MODEL OF THE INTERNAL WATER MOTION**
- **HORIZONTAL MOTION OF THE DAMAGE OPENING (SHIP DRIFT, SWAY, HORIZONTAL MOTION DUE TO SHIP ROLL MOTION)**
- **THE USE OF BERNOULLI EQUATION (FOR STEADY FLOW) FOR THE MOSTLY UNSTEADY FLOOD WATER FLOW IN THE DAMAGE OPENING.**

**=> THERE IS STILL SOME WORK TO DO!**

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# *MT RoPax- Tests: Gradual flooding => Difference in horizontal motion – comparison of tests with a free-drifting vs. soft-moored ship model*

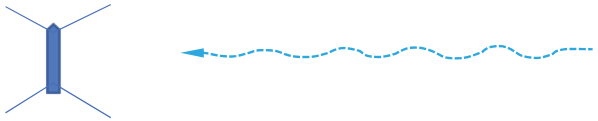
**The lowest GM on the limit curve 3.25 m was used in the test in order to have realistic test conditions on long-crested beam seas. Large damage on the wave side.**

**The GM of the vessel was reduced to 1.425 m in order to provide a capsize boundary in reasonable wave heights.**

**Free-drifting, just the direction occasionally corrected**



**Soft-moored: no drift, but sway allowed**



| IRREGULAR SEAS | | CAPSIZE RATE | | CAPSIZE BOUNDARY [m] | |
|---|---|---|---|---|---|
| GM [m] | $H_S$ [m] | FREE-DRIFTING | SOFT-MOORED | FREE-DRIFTING | SOFT-MOORED |
| 1.425 | 3.5 | 70 % | 100 % | ca. 3.0-3.5 | 2.5 - (3.0) |
| 3.25 | 7.5 | 75 % | 100 % | ca. 7.0-7.5 | 4.5 - 5.0 |

| | CAPSIZE BOUNDARY IN REGULAR WAVES $H_W$ [m] | |
|---|---|---|
| GM [m] | FREE-DRIFTING | SOFT-MOORED |
| 1.425 | ca. 6.0 | ca. 4.5 |
| 3.25 | ca. 6.0 | ca. 4.5 |

**Conclusion: The presence or absence of drift appears to have a clear effect on the water ingress leading to capsize!**

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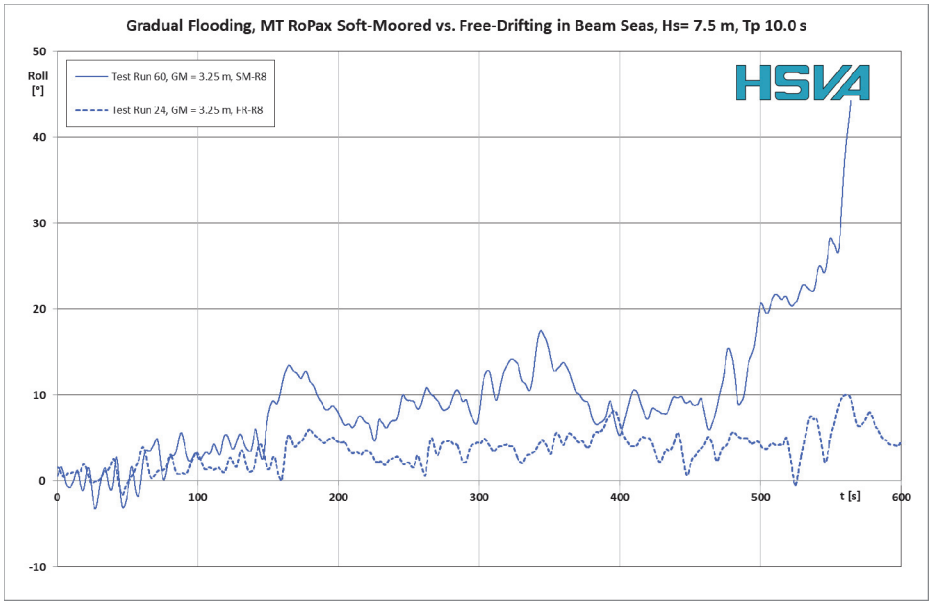
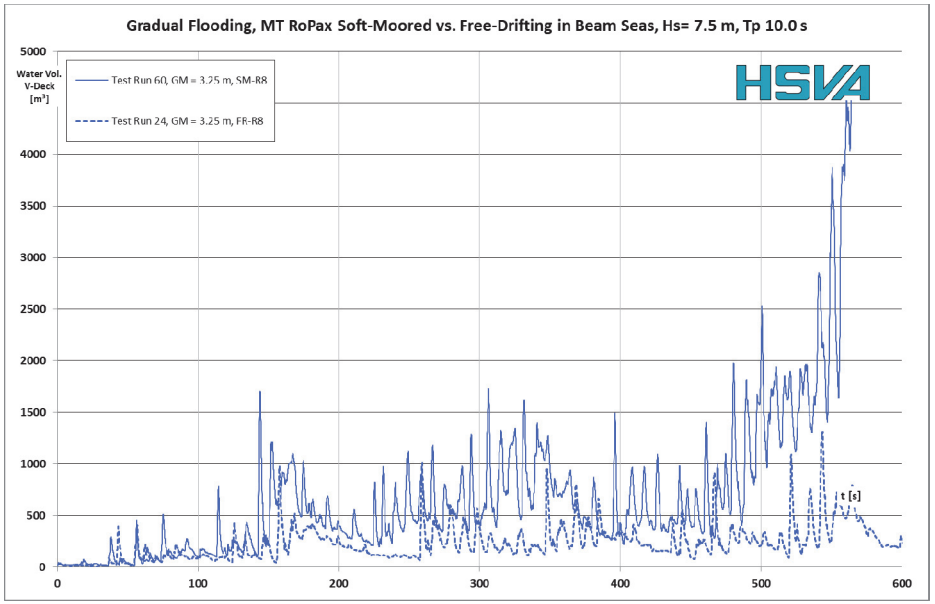
# *MT RoPaX- Model Tests on CW23: Floodwater ingress on trailer deck in Soft-Moored (SM, no drift) vs. Free-Drifting (FR, drifting) case using the same wave train.*

## Heeling (roll) angle




## Water volume on the trailer deck




Solid Line = Soft-moored (SM)
Dashed Line = Free-drifting (FR)
The water volume shown is calculated based on 11 wave heights at sensor positions and roll angle.
Note that the water flow onto the trailer deck is much higher in the soft-moored case, accordingly the roll angle grows much faster.

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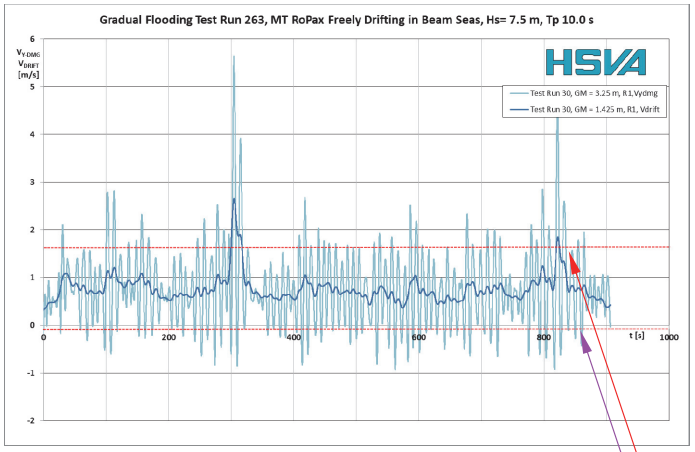
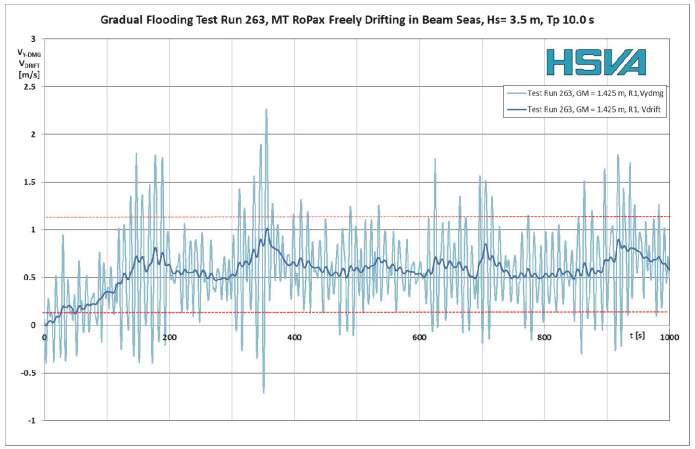
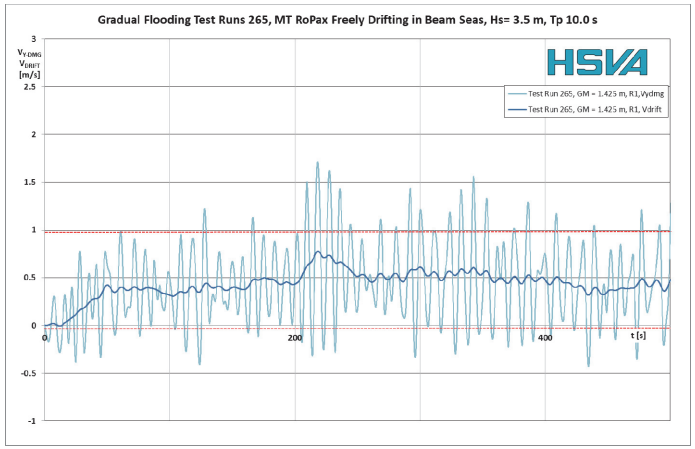
# MT RoPaX: Freely drifting ship model in beam seas: $v_{DRIFT}$ and $v_{Y\text{-}DMG}$




$V_{DRIFT}$ = Drifting speed

$V_{Y\text{-}DMG}$= Lateral speed of the damage opening

$$V_{MAX} \approx V_{DRIFT} + V_{MAX\text{-}SWAY}$$
$$V_{MIN} \approx 0$$

$$|V_{MAX}| >> |V_{MIN}|$$

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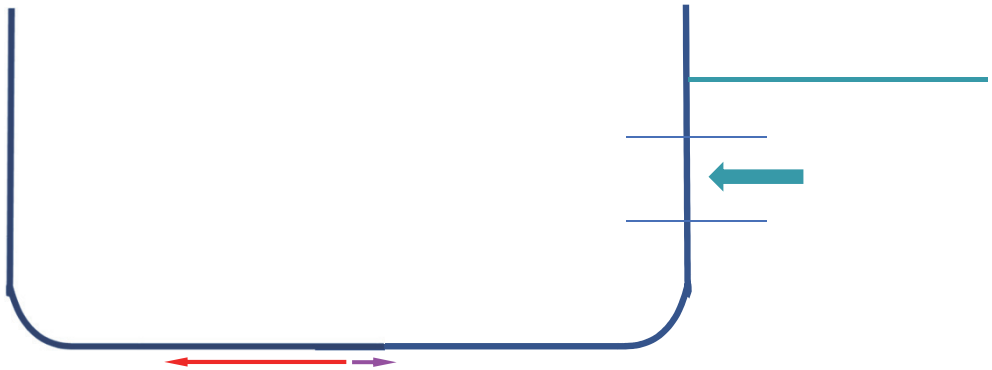
# MT RoPaX- Model Tests on CW23 and CW34: $V_{DRIFT}$ and $V_{Y\text{-}DMG}$

***Do we need an improved formulation for water flow in the damage opening?***



What happens at the inlet, when the ship moves?
Should we take the $V_{Y\text{-}DMG}$ into account in Bernoulli equation?

Should we apply "dynamic orifice equation" instead, because the flow is mostly unsteady?

$V_{Y\text{-}SHIP}$: the motion is not symmetric and there is a phase difference between $V_{Y\text{-}DMG}$ and the wave elevation at damage opening

$V_{MAX} \approx V_{DRIFT} + V_{MAX\text{-}SWAY}$
$V_{MIN} \approx 0$

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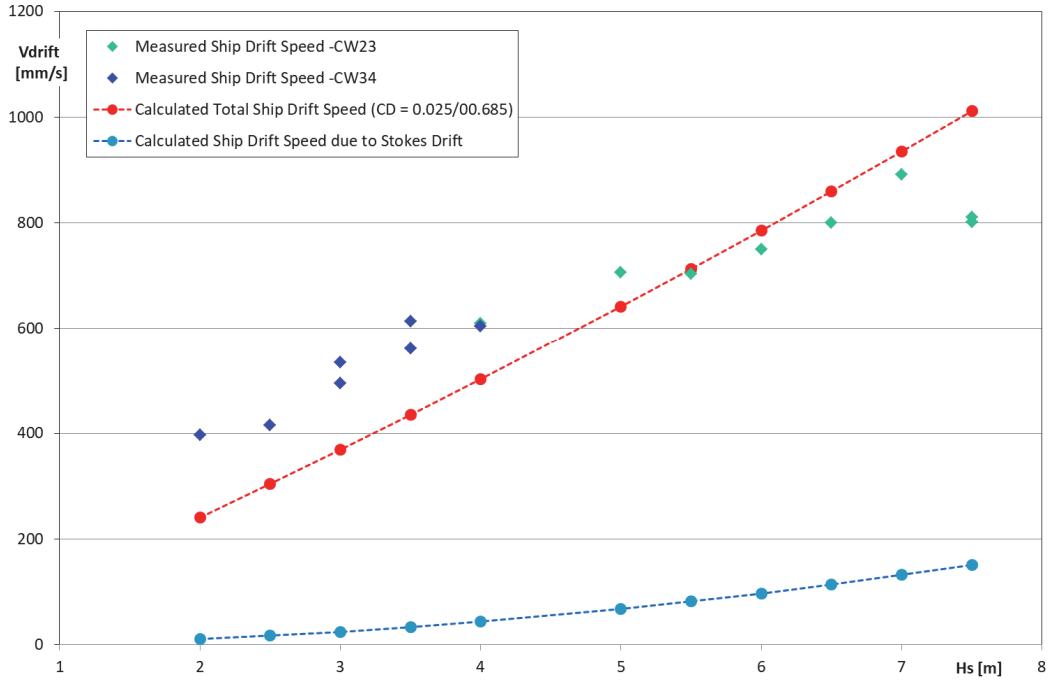
# MT RoPaX- Drift in Model Tests – Drift in numerical models

**A fairly simple theoretical – semi-empirical expression to describe the ship drift in a numerical model was tested in HSVA Rolls:**

**=> One can correct the sea spectrum (input) to better correspond with the encounter spectrum using the determined drift speed.**

**=> One can improve the modeling of the flow in the damage opening in the numerical model.**




Lateral ship speed due to Stokes Drift:

$$v = \frac{1}{d}\int_0^\infty \omega S(\omega)(1 - e^{-2(\omega^2/g)d})d\omega \quad .$$

Mean sway force due to waves:

$$F_Y = C_{D-SF}(\lambda / L_{pp})\rho g \zeta_A^2 L_{PP}$$

Drag of the ship hull due to lateral motion:

$$F_Y = C_{D-SV}(hull\ form)\frac{1}{2}\rho v_y^2 L_{PP} T, \quad \text{solve for} \quad v_y$$

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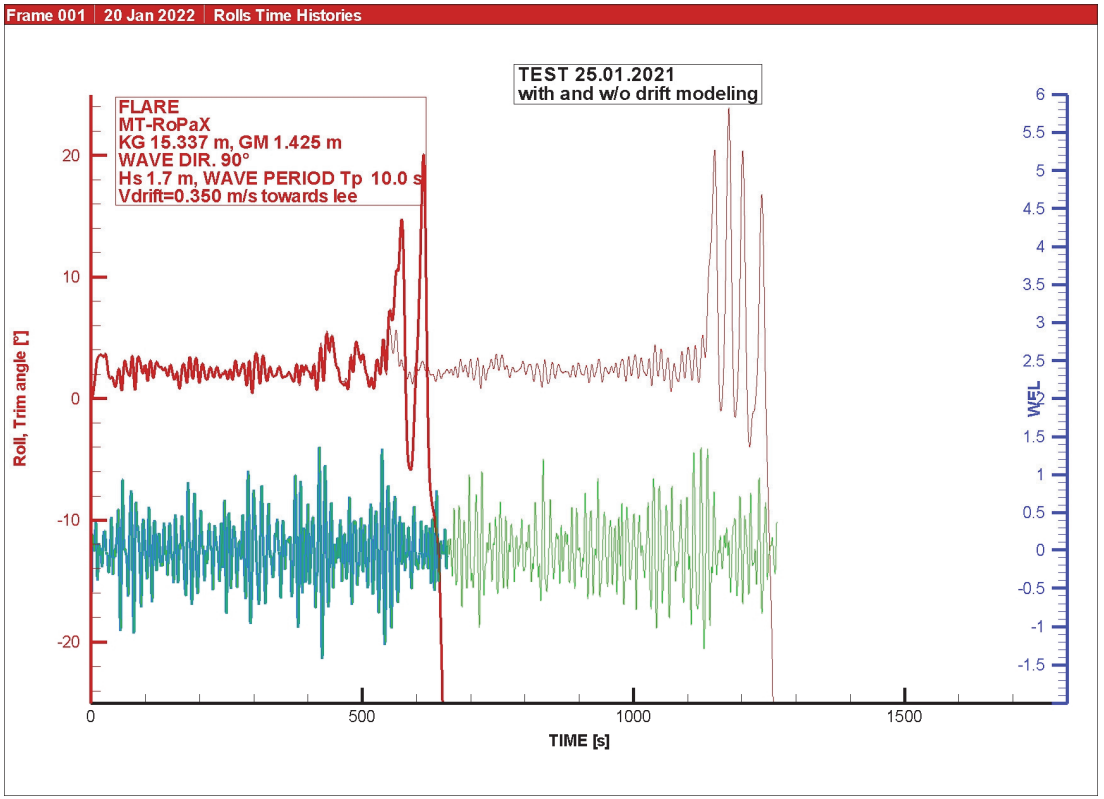
# *MT RoPaX- Drift in Model Tests – Drift in numerical models of the water inflow/outflow*

**First try: with $v_y$ thus obtained the drift speed and sway were taken into account in the flow model (Bernoulli) at the damage opening. => It has a significant effect on the Time to Capsize TTC. => We have made a start, one should continue to study this further!**

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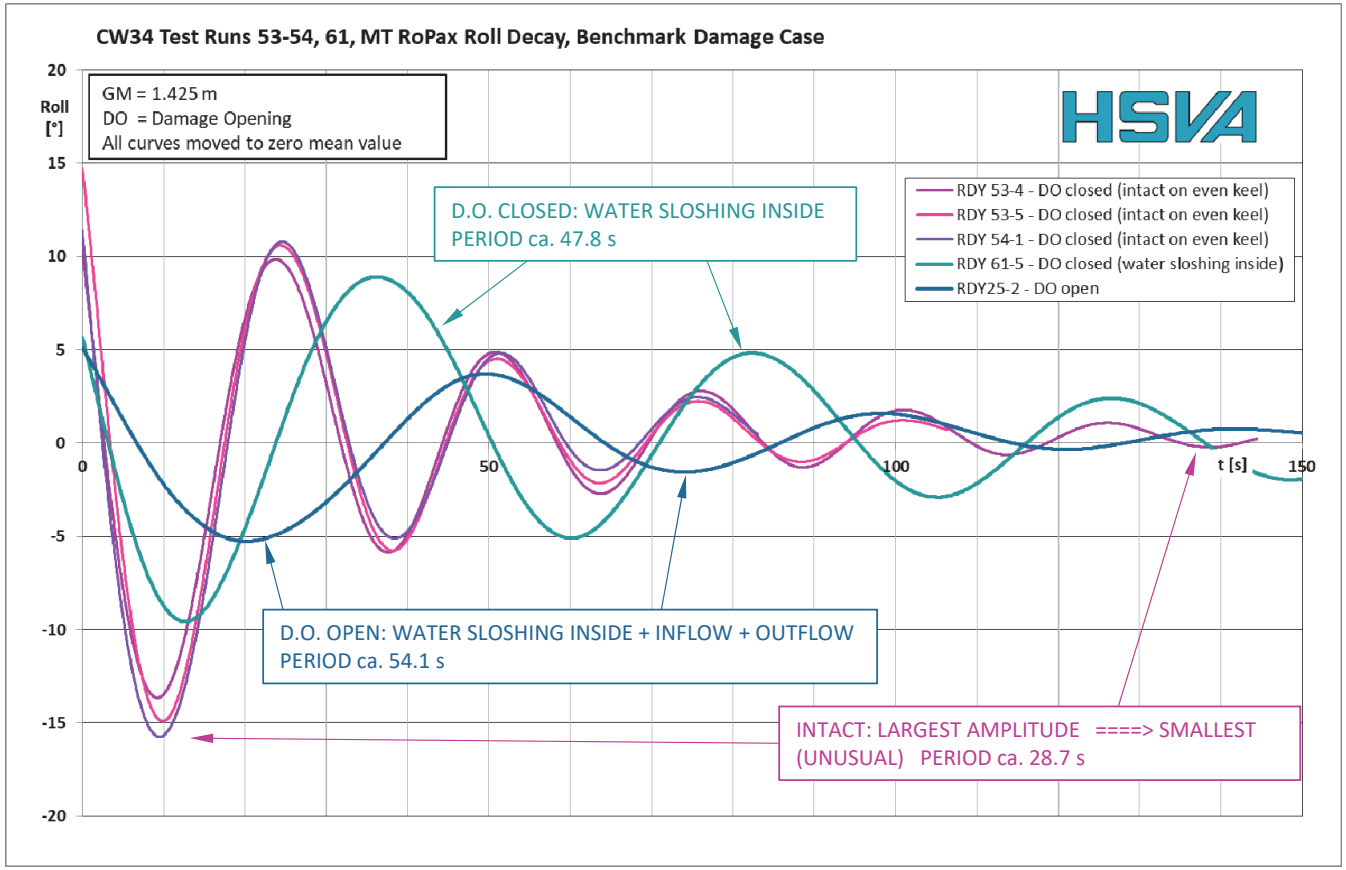
# MT RoPaX- Roll Decay – Roll Damping due to flood water




The roll damping (or excitation) introduced by the flood water depends on the ship internal flooded geometry, flood water mass and distribution, ship roll period/ wave excitation period, the floating position…

It is not really possible to use some simple ship roll damping coefficients to take the effect of the flood water into account on a general basis.

Need to have proper numerical model for the ship flood water system, particularly for:

- The internal water motion
- The inflow/outflow through the D.O.

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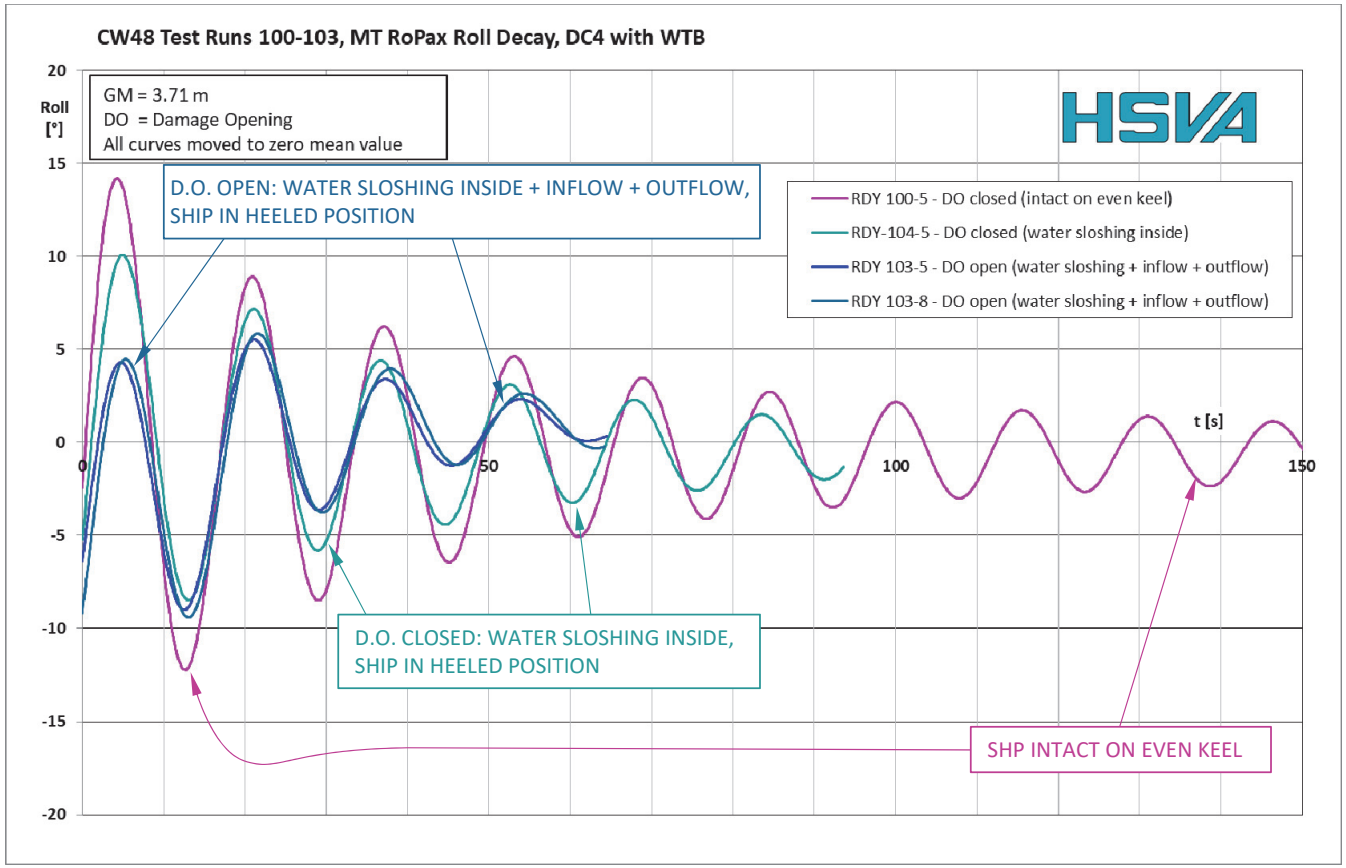


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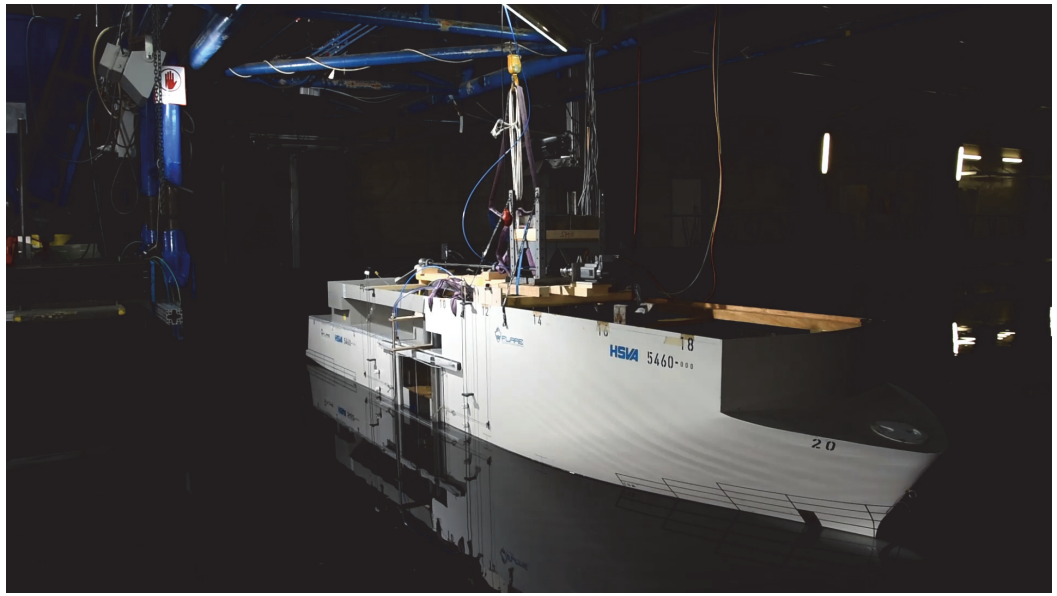
# *MT RoPax- Model Tests on CW34: Transient flooding*

The GM of the vessel was reduced to 1.3 m .. 1.5 m in order to provide a clear ship response to the damage opening in calm water and in waves of moderate height. At the lowest GM 3.25 m on the limit curve nothing would happen.

**In calm water:**




**=> transient capsize or survival**

**In beam seas:**




**=> gradual capsize in waves or survival**

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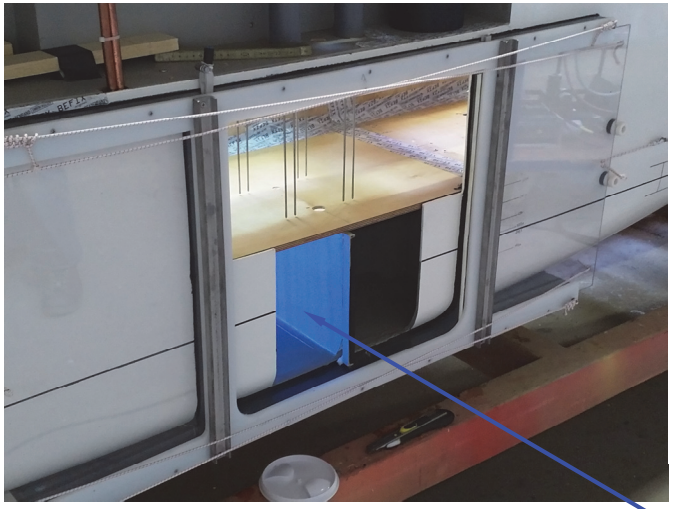
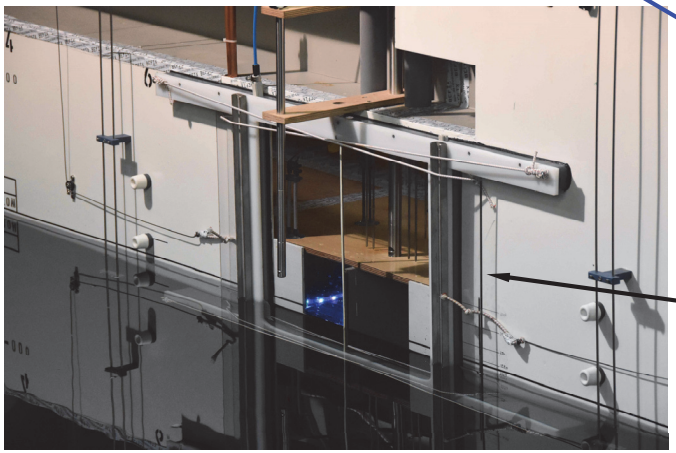
# MT RoPax- Tests on CW34: Transient flooding in calm water/ in beam seas







'BLUE' COMPARTMENT: WINDOW + VIDEO CAMERA + OPENINGS FOR 6 SENSORS FOR WATER LEVEL MEASUREMENT

SLIDING DOORS FOR THE DAMAGE OPENING IN A TRANSIENT FLOODING CASE

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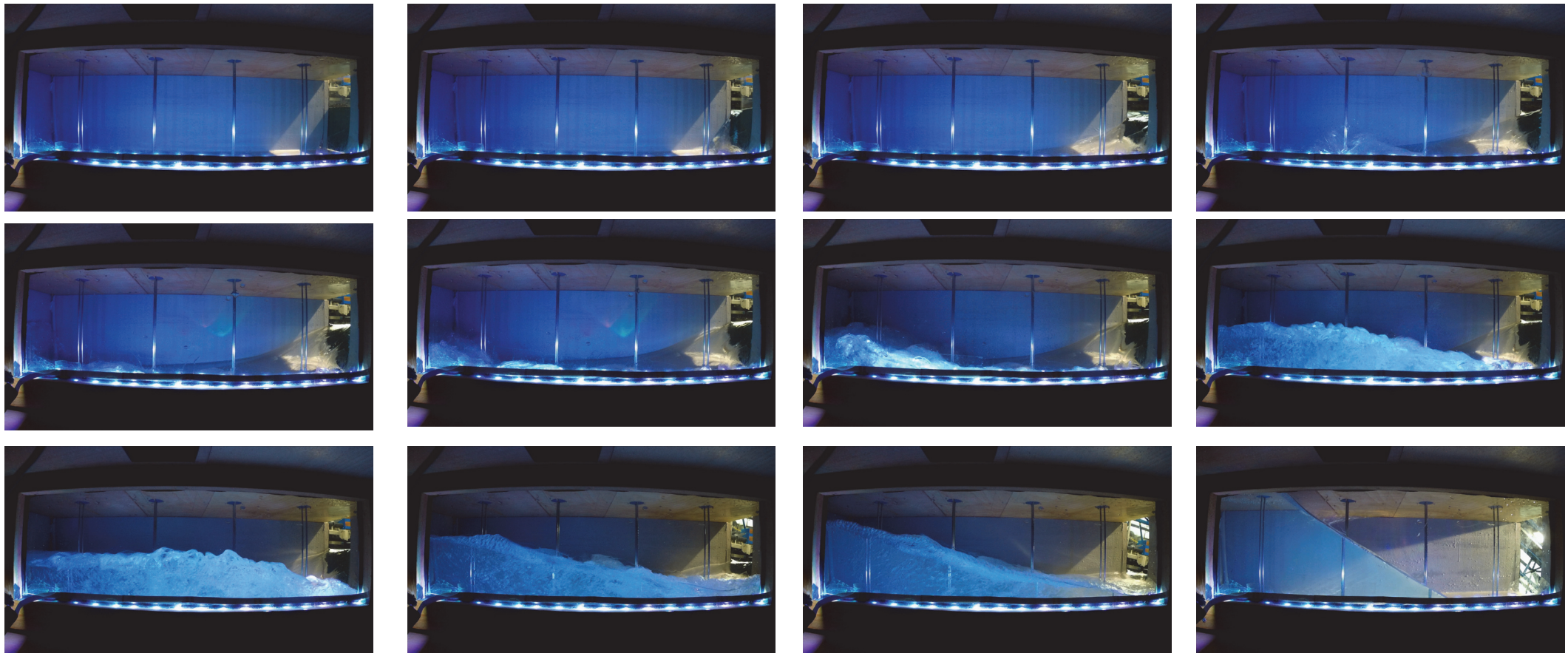
# MT RoPax - Test run 7 in calm water: Transient flooding of an internal compartment - frames



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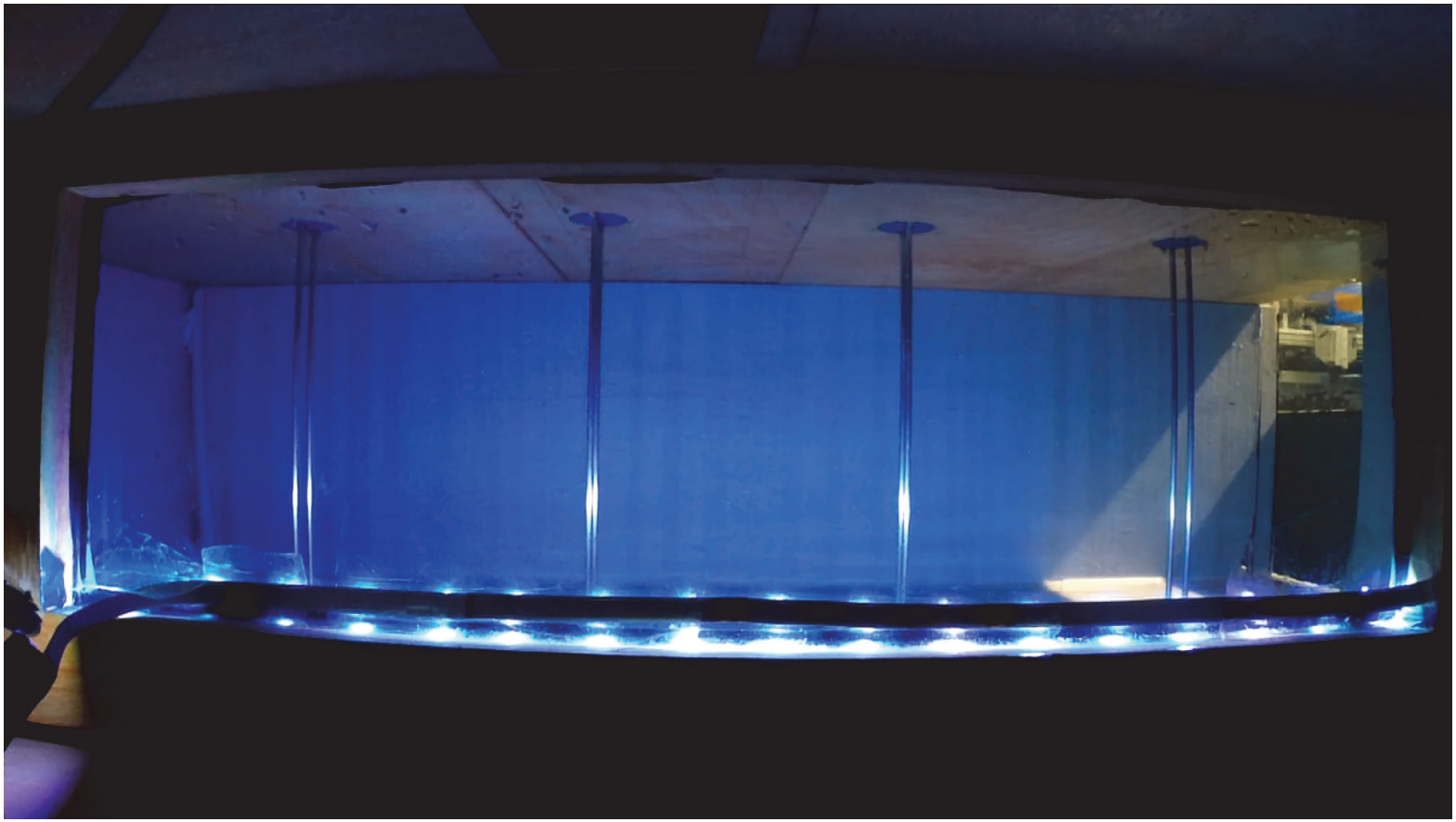
# MT RoPax - Test run 7 in calm water: Transient flooding of an internal compartment - video



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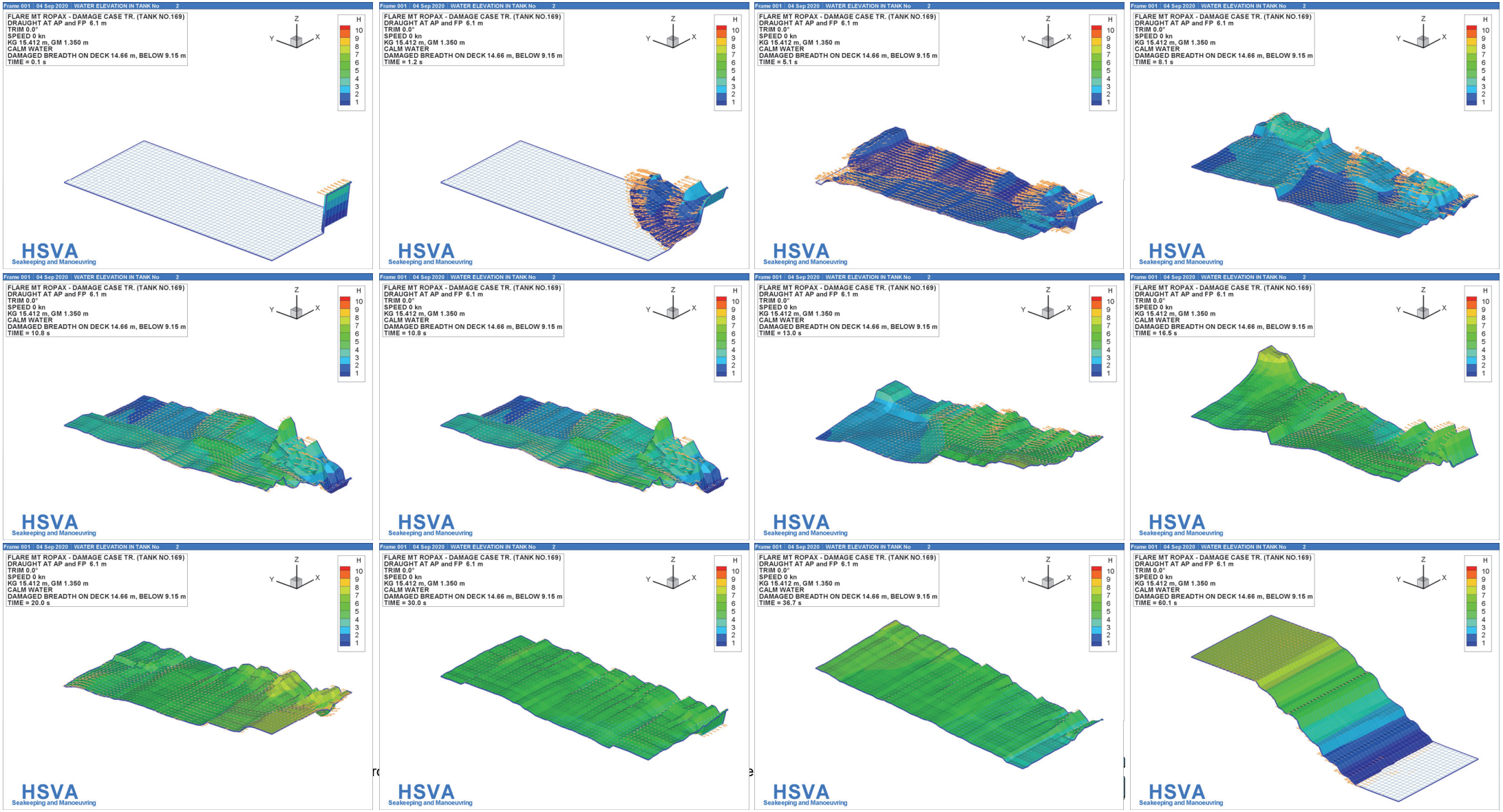
# Test Run 7: Transient flooding - Simulation with shallow-water-equations

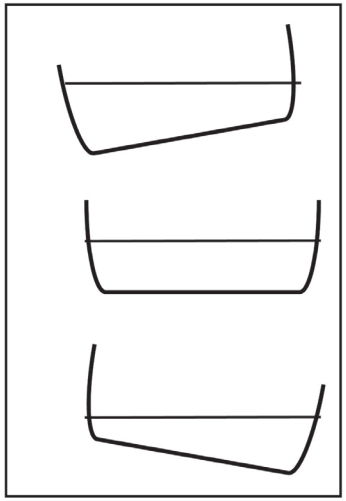


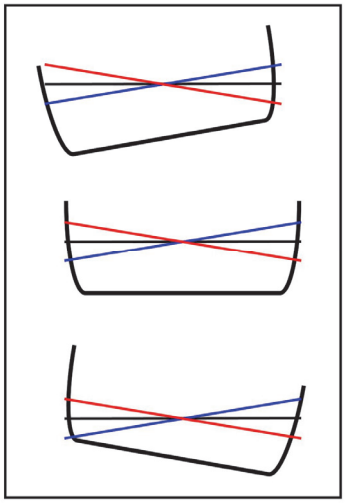


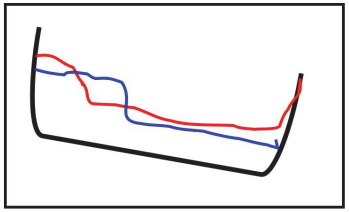
# *Damage Survivability Simulation Tools*

**Typical Floodwater Free Surface Modelling**

- Plane and horizontal
- Plane and free movable
- Free movable (e.g. shallow water equations)
- CFD? ‘RANSE’, ‘SPH’ =>
  sofar too elaborate and time-consuming







*It is essential for the correct modeling of the time-dependent heeling moment on the ship that the flood water distribution is correct at every moment of time, that is, the right amount of flood water is at the right place at the right moment of time. The more dynamics the ship system has the more important this becomes.*

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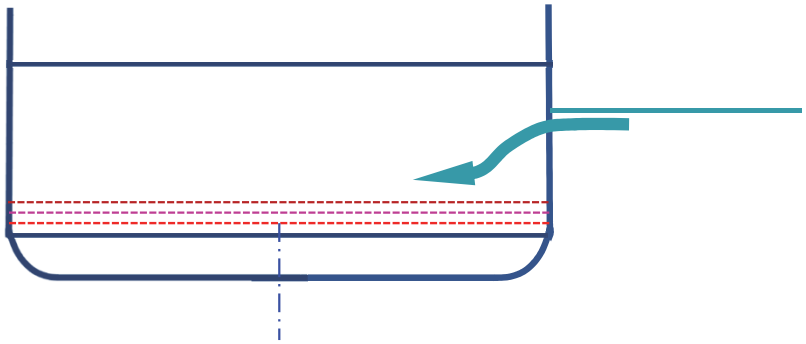
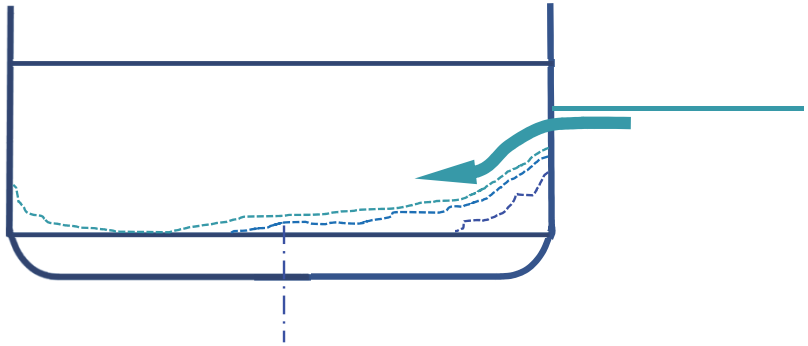
# Flood water distribution models for simulation tools

*Improved formulation for water flow into the compartment should be used?*
*In transient case the flood water should be in the right spot at the right time.*



*Quasi-static flood water distribution*

*Flood water c.o.g. initially at centerline, moves in transverse direction only when the ship heels.*



*Dynamic flood water distribution*

*Flood water c.o.g. initially at the damage side => moves towards intact side => moves back towards the centerline. Moves in transverse direction depending on the actual distribution.*

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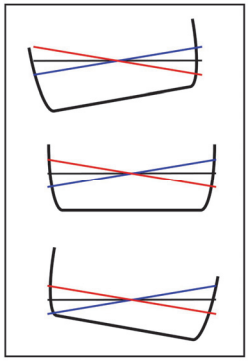
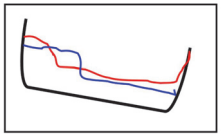
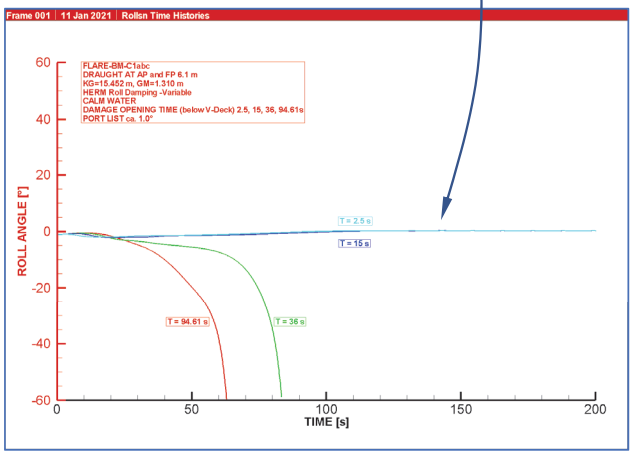
# MT RoPaX- Computing transient flooding in calm water using different flooding models

Transient ship flooding cases computed with HSVA Rolls with a quasi-hydrostatic model for the water in the damaged compartments. => water spreads instantly and evenly in the compartments, the water surface remains always a plane.

The transient ship flooding cases computed anew with HSVA Rolls using shallow-water-equations for the water behavior in the damaged compartments.








**OPENING TIMES:**

**(A) FASTEST POSSIBLE IN MODEL TESTS ~ 2.5 s in F.SC.**
**(B) REALISTIC (ca. 6 x "A") ~ 15 s in F.SC.**
**(C) LONGER (ca. 15 x "A") ~ 36 s in F.SC.**
**(D) MUCH LONGER (ca. 40 x "A") ~ 95 s in F.SC.**

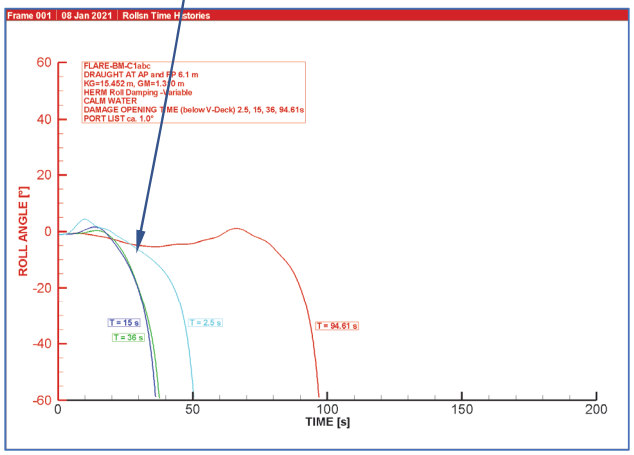



**Figure 2** Time-history of roll computed using quasi-hydrostatic model (water surface modeled as an inclined plane) for the flood water behavior in the damaged compartments.

**Figure 3** Time-history of roll computed using shallow-water-equations for the flood water behavior in the damaged compartments.

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# MT RoPax- Model Tests for benchmarking: Transient flooding in calm water

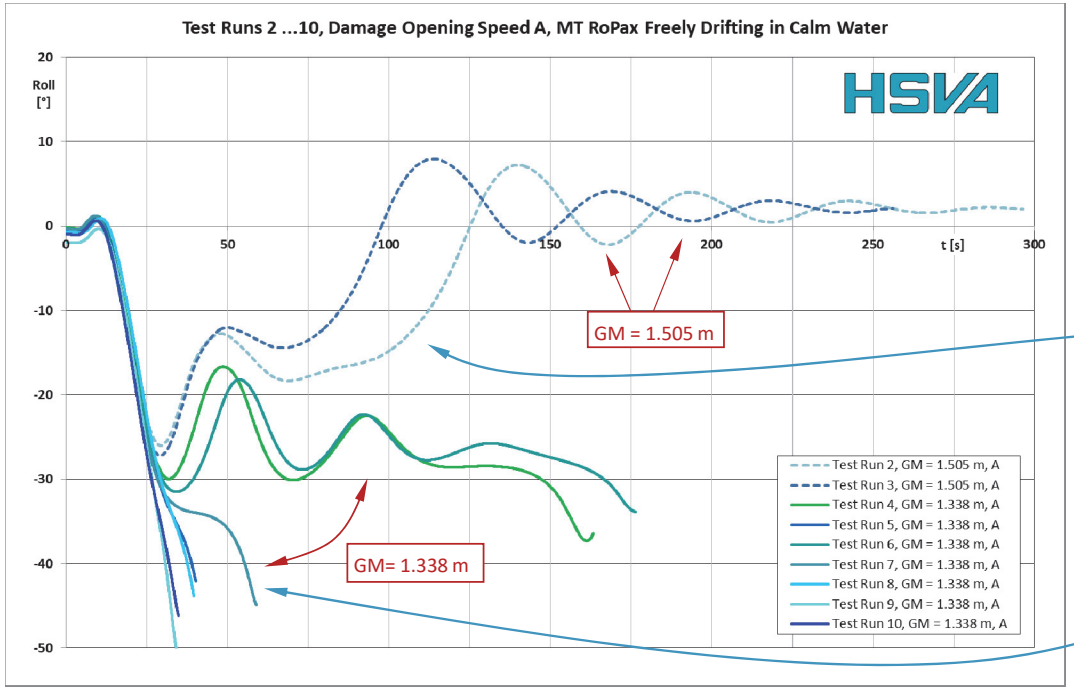


**Figure 1** Transient flooding test in calm water: Time histories of roll with different GM –values. The initial heel in runs 2 ...10 varied between -0.42° and -2.12° to port. Accordingly all capsizes took place towards port side.

**BENCHMARK-TASKS 1a, 1b:**

**COMPUTE THE TIME-HISTORY OF THE ROLL ANGLE AT THE DIFFERENT GM-VALUES AND SHOW THE DIFFERENCE IN BEHAVIOR**

**TEST RUNS 2 AND 7 WERE USED FOR BENCHMARKING**

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# MT RoPax- Model Tests on CW34: Transient flooding in calm water

**OPENING TIMES:**

**(A) FASTEST POSSIBLE IN MODEL TESTS**
**(B) REALISTIC (ca. 6 x ”A“)**
**(C) LONGER (ca. 20 x “A“)**
**(D) MUCH LONGER (ca. 40 x “A“)**

**NOTE:**

**SHIP CAPSIZES TO UNDAMAGED SIDE DUE TO SMALL INITIAL HEEL.**

**AT OPENING TIMES (A), (B), AND (C) THE DIFFERENCES IN THE RESULTING CAPSIZE TIMES ARE NOT VERY LARGE/ REALLY RELEVANT.**

**THE HYPOTHESE THAT THE SHORTEST OPENING TIME LEADS TO SHORTEST CAPSIZE TIME IS NOT REALLY SUPPORTED.**

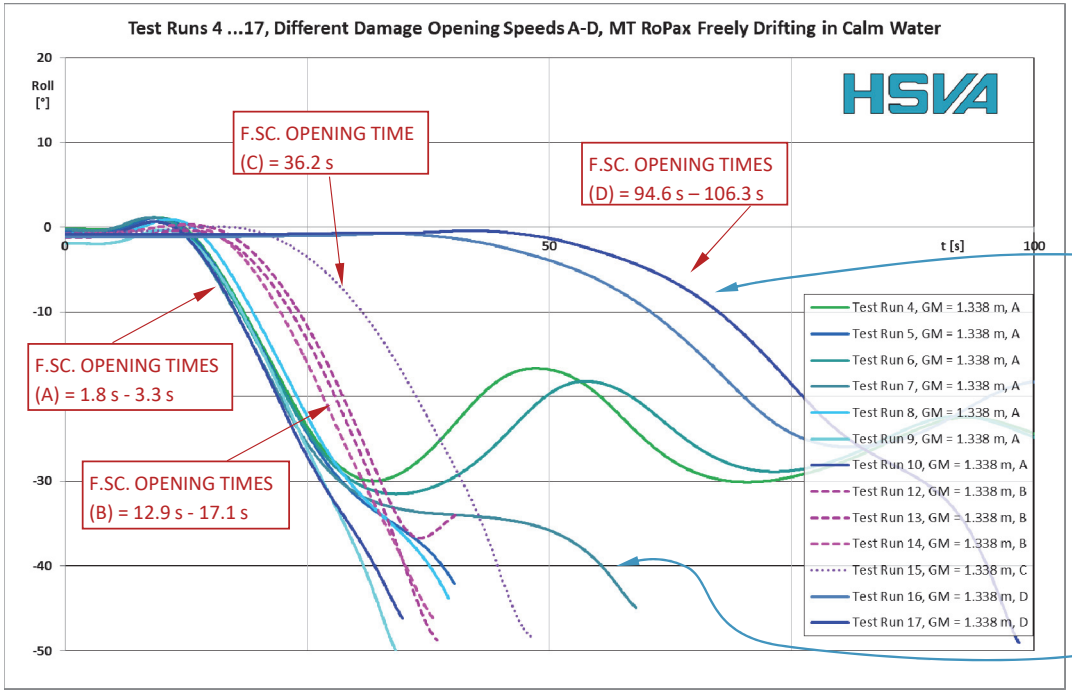


**Figure 2** Transient flooding test in calm water: Time histories of roll with different damage opening times A-D. The initial heel in test runs 4 ...17 varied between -0.42° and -2.12° to port. Accordingly all capsizes took place towards port side.

**BENCHMARK-TASKS 1b, 1c**

**COMPUTE THE TIME-HISTORY OF THE ROLL ANGLE AT THE DIFFERENT DAMAGE OPENING TIMES AND SHOW THE DIFFERENCE IN BEHAVIOR**

**TEST RUNS 7 AND 17 WERE USED FOR BENCHMARKING**

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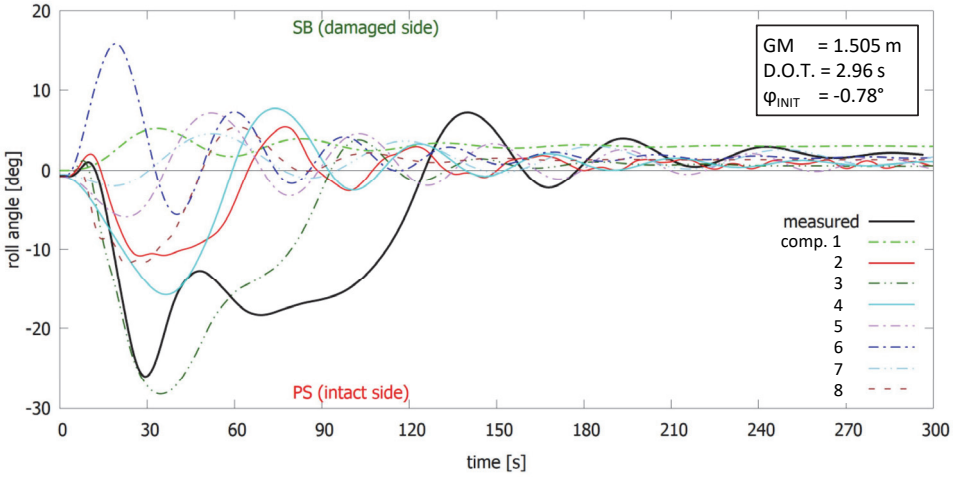
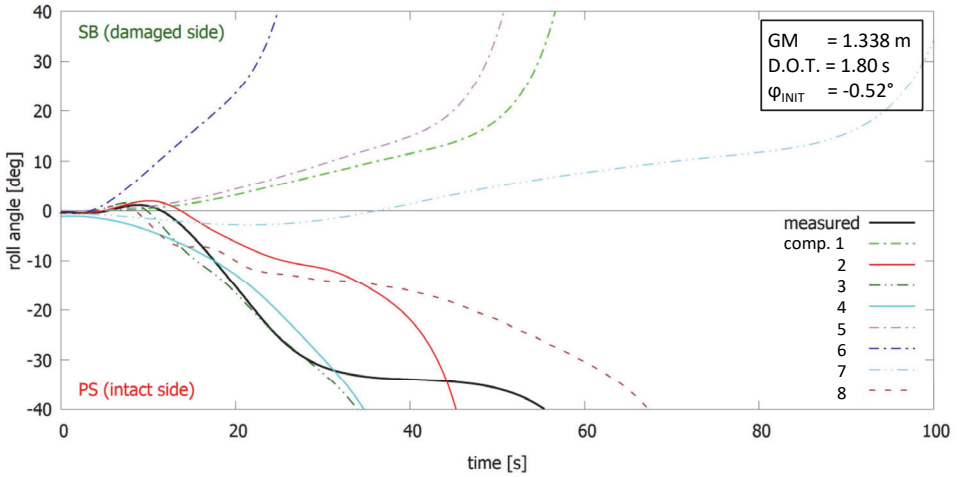
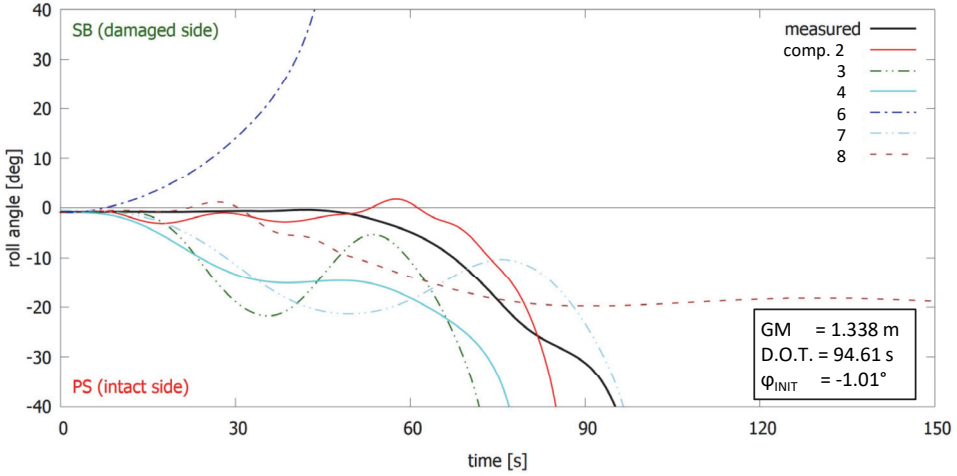
# MT RoPaX- Transient flooding – Benchmarking – How good are the numerical predictions?

**Ruponen et. al., Applied Ocean Research 2022(?):**




**Final outcome: survival/capsize => Predictions ≈ O.K. (?)**

**Evolution of the floodwater distribution in time =>**
**Development of the heeling angle with time =>**

**Improvements/other flooding models are needed.**

**(Many codes are not able to simulate the flooding and heeling of damaged ship in calm water!)**

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# *MT RoPax- Transient and gradual ship flooding – Benchmark tests -Conclusions*

- A brief study on realistic opening times of a ship-to-ship collision damage was carried out.
- A watertight sliding door mechanism with adjustable opening times for the ship model tests was constructed.
- Benchmark data on transient and gradual ship flooding was generated with model tests.

  => Tests in calm water, in regular waves and irregular beam seas, long-crested vs. short-crested seas, waves from the damage side vs. from the lee side. Comparison of ship behavior in free-drifting vs. soft-moored cases.
- A paper 'International benchmark study on numerical simulation of flooding and motions of a damaged ropax ship' by Ruponen + 8 other authors will soon appear in Applied Ocean Research. The conclusions of the paper are politely written, but the clear message is:

=> There is still lots of place for further development in the ship survivability simulation codes.
=> Particularly we need better numerical models for the water flow in the damaged ship.

- Some points, in which improvement in numerical codes for the level 'forensic analysis' is desirable and possible, have been indicated: (1) Flooding model for internal flow, (2) Effect of drift and sway on the inflow, (3) use of unsteady orifice equation instead of Bernoulli equation for steady flow.

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# Thank you for your attention!

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