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Instructions for the benchmark study on cruise ship flooding

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CONTENTS

1 INTRODUCTION

1.1 Background

Within the EU Horizon 2020 project FLARE, an extensive benchmark study on numerical simulation of flooding and motions of a damaged ship was conducted. New dedicated model tests for cruise ship flooding in calm water and in irregular beam seas were performed at MARIN. In addition to the FLARE partners, also external participants with recent publications on flooding simulation tools were invited to contribute. The results of the benchmark study have been published in Ruponen et al. (2022).

The FLARE consortium has agreed to share the benchmark material to enable validation of new and improved simulation tools and further benchmarking in the future. This short document describes the available material.

1.2 Use of material

The provided material can be freely used for validation of flooding simulation codes, provided that:

- FLARE consortium and MARIN are acknowledged for sharing the data
- The following publication, presenting the benchmark study cases, is cited:

  Ruponen, P., van Basten Batenburg, R., van't Veer, R., Braidotti, L., Bu, S., Dankowski, H., Lee, G.J., Mauro, F., Ruth, E., Tompuri, M. 2022. International benchmark study on numerical simulation of flooding and motions of a damaged cruise ship, *Applied Ocean Research*, Article 103403. https://doi.org/10.1016/j.apor.2022.103403

1.3 Summary of material

Geometry and definitions:

- Flare3_NEW_hull.igs (bare hull form)
- P30703-0600_Deck overview-D2-v2.dxf (geometry and dimensions of floodable compartments and openings)
- 30703Fi01_M10155_PropArr-01.dxf (geometry of propellers and shafts)
- 30703Fi02_M10155_BilgeKeel-01.dxf (detailed geometry of bilge keels)
- P30703-0600_Waterlevel gauges-v2.dxf (locations of water level gauges)
- Drawings on each deck:
  - P30703-0600 Deck 0&1&2&3_5.pdf
  - P30703-0600 Deck 4_6.pdf
  - P30703-0600 Deck 5&6_7.pdf

Measurement data:

- 30703_09SMB_66_004_002_01_roll_decay.csv (roll angle history from the roll decay test of an intact ship)
- 30703_06SMB_01_001_001_02.csv (undisturbed wave history, note that breach was opened after 1410.1 s)
- case1_measured.csv (measurement data for case 1 transient flooding in calm water)
- case2_measured.csv (measurement data for case 2 progressive flooding in waves)
- case3a_measured.csv (measurement data for case 3 progressive flooding in calm water GM=2.41m)
- case3b_measured.csv (measurement data for case 3 progressive flooding in calm water GM=2.29m)

Note that the model was constructed in scale 1:60 and the model drawings have dimensions in model scale. However, all measurement data are given in full-scale.

1.4 Contact information

The FLARE benchmark study was coordinated by NAPA, and general questions should be addressed to Dr. Pekka Ruponen (pekka.ruponen@napa.fi)

Model tests were conducted at MARIN, further information can be asked from Mr. Rinnert van Basten Batenburg (r.v.bastenbatenburg@marin.nl) and Dr. Riaan van't Veer (r.vantveer@marin.nl)

2 BENCHMARK MATERIAL

2.1 Hull geometry

The studied ship design is an unbuilt large cruise ship, kindly supplied by Chantiers d'Atlantique.

	Full scale	Model scale
Length over all	About 300 m	About 5.0 m
Length between perpendiculars	270.00 m	4.5 m
Breadth	35.20 m	0.587 m
Draught (in tests)	8.20 m	0.137 m
Trim (in tests)	0.00 m	0.000 m
Height of bulkhead deck form base line	11.00 m	0.183 m
Gross tonnage	95 900	-
Metacentric height (in tests)	2.36 m	0.0393 m
Radius of inertia for roll	13.904 m	0.2317 m

The bare hull form is provided as IGES file:

- Flare3_NEW_hull.igs

The bare hull lines drawing is shown in Figure 1.

Details of the appendages are presented in the drawings:

- 30703Fi01_M10155_PropArr-01.dxf
- 30703Fi02_M10155_BilgeKeel-01.dxf

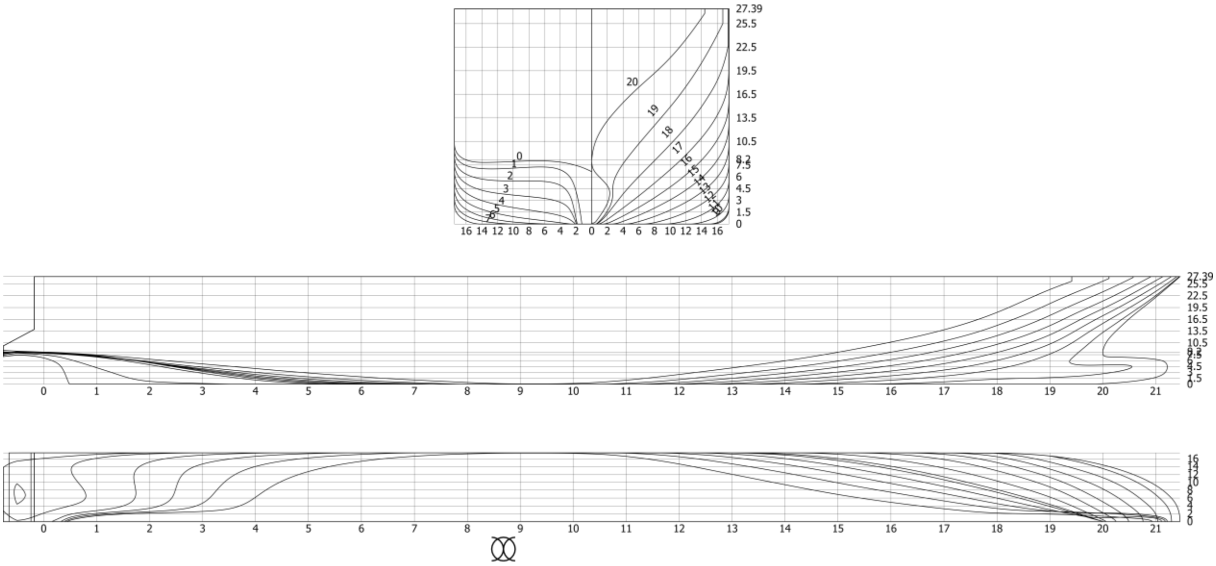

Figure 1 Lines drawing of the bare hull without appendages.

2.2 Floodable compartments and internal openings

An overview of the floodable compartments is shown in Figure 2.

The geometry and dimensions of the floodable compartments and the openings connecting the compartments are presented in the drawing;

- P30703-0600_Deck overview-D2-v2.dxf

It is important to account for the thickness of the decks and bulkheads directly in the dimensions of the compartments, and to apply a permeability of 1.0 for all compartments.

The hashed compartments in the drawing were filled with foam, and thus they were not involved in the flooding.

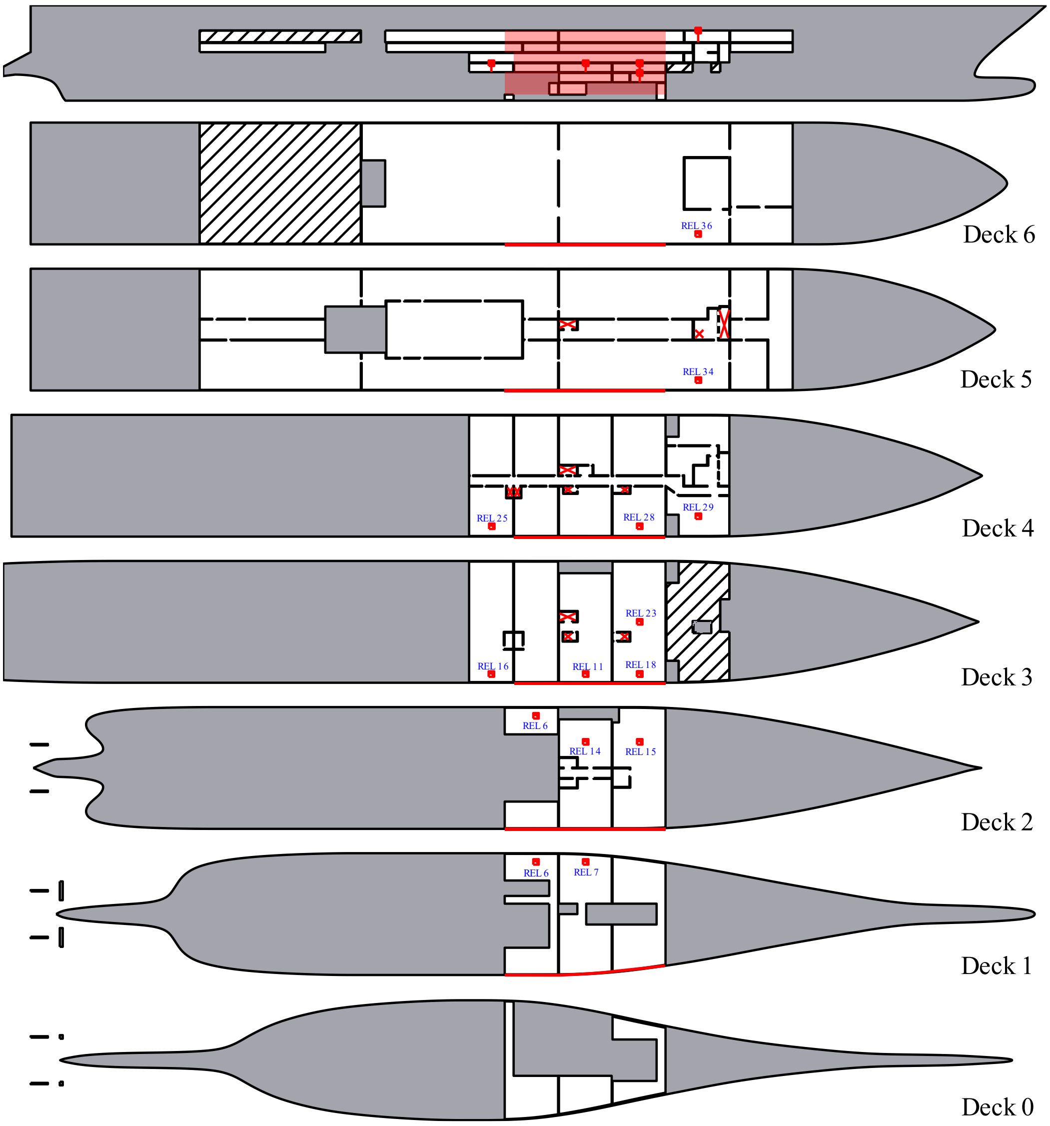

Figure 2 Floodable compartments and breach.

For the simulation codes based on Bernoulli's theorem, the discharge coefficients of different openings were evaluated experimentally at MARIN, and the results are listed below.

Opening	**C_d**	**Explanation**
Narrow openings (width < 30 mm)	0.73	Based on test at MARIN with opening size 17 mm × 34 mm
Wide openings (width ≥ 30 mm)	0.70	Based on test at MARIN with opening size 47 mm × 34 mm
Breach openings	0.65	Based on test result for 80 mm × 80 mm opening

2.3 Breach

Three compartment damage scenarios were studied. The breach was opened rapidly, and in simulations, instant opening can be assumed. The breach openings are shown in Figure 3. In the benchmark cases 1 and 2, the whole breach was open, whereas in the case 3 only the breaches to the 2 lowest decks were open.

Figure 3 Breach openings in the SB side of the model)photo courtesy of MARIN).

2.4 Measurements

The locations of the water level gauges are presented in the file:

- P30703-0600_Waterlevel gauges.dwg (in model scale)

Note that the gauges do not extend to the full deck height, due to sealings. Therefore, it is important also to consider the upper end of the gauge.

2.5 Roll decay test

A roll decay test was conducted for intact ship before the flooding tests. The model included the appendages. The results for the roll angle as a function of time are given in the file:

- 30703_09SMB_66_004_002_01_roll_decay.csv

2.6 Case 1: transient flooding in calm water

Full measurement data, converted to full scale, is included in the file case1_measured.csv. The relevant columns are:

- Time [s], note that flooding starts at time 156.76 s
- Rel 01 … Rel 36 [m]: water level heights in the flooded compartments. For sensor numbers, refer to the drawing P30703-0600_Waterlevel gauges-v2.dxf
- Roll_COG [deg] roll angle
- Pitch_COG [deg] pitch angle

2.7 Case 2: transient and progressive flooding in waves

Softly moored ship flooding in beam seas with damage facing the waves. The undisturbed wave history is available in the file 30703_06SMB_01_001_001_02.csv and the breach was opened after 1410.1 s, see Figure 4.

Soft spring moorings

The vessel was kept at location by a soft spring mooring system. The mooring lines were connected at the bow and stern of the vessel, Figure 5. The angle of the mooring lines was 45 degrees with the centreline.

- Line stiffness: 241 kN/m
- Pretension: 6516 kN

Beam seas waves

Undisturbed wave history was measured, and it is shown in Figure 4. The breach was opened after 1410.1 s. The data is given in the file:

- 30703_06SMB_01_001_001_02.csv

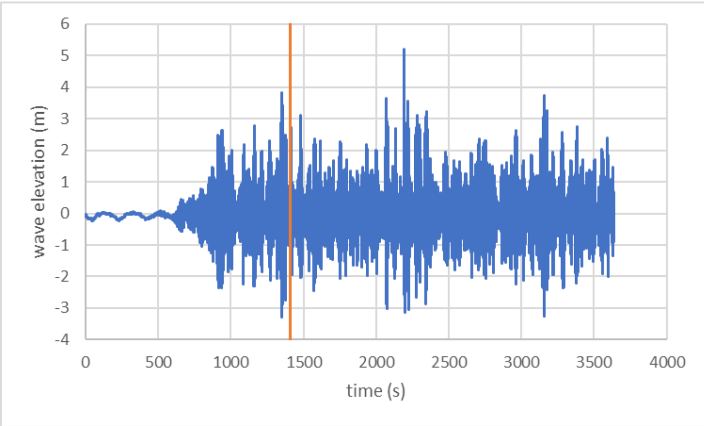

Figure 4 Undisturbed wave history for benchmark case 2 (vertical line indicates the time when the breach was opened).

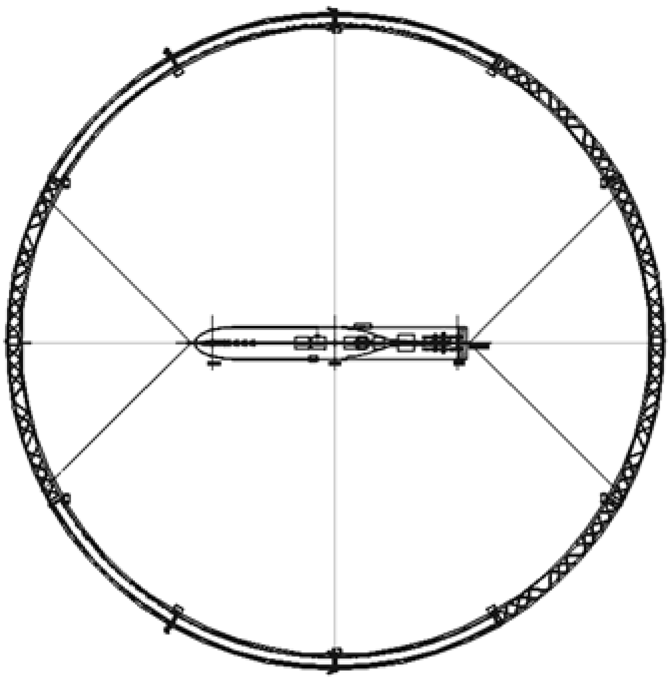

Figure 5 Soft mooring arrangement (drawing courtesy of MARIN).

Measurements are provided in the file case3_measured.csv, converted into full scale. The relevant columns are:

- Time [s], note that flooding starts at time 0 s.
- Rel 01 … Rel 36 [m]: water level heights in the flooded compartments. For sensor numbers, refer to the drawing P30703-0600_Waterlevel gauges-v2.dxf
- Roll_COG [deg] roll angle
- Pitch_COG [deg] pitch angle

2.8 Case 3: progressive flooding in calm water

Smaller vertical breach extent, resulting in up-flooding in the compartments.

These model tests were conducted separately, using initial GM values close to the one in the benchmark cases 1 and 2. In the benchmark study, numerical simulations for all three cases were done with the same initial condition. However, experimental results are provided for slightly smaller and slightly larger GM values, as explained in the journal article, Ruponen et al. (2022).

Measurement results in full scale are provided in files case3a_measured.csv (GM=2.41m) and case3b_measured.csv (GM=2.29m). The relevant columns (same order in both files) are:

- Time [s], note that flooding starts at time 156.76 s
- Rel 01 … Rel 36 [m]: water level heights in the flooded compartments. For sensor numbers, refer to the drawing P30703-0600_Waterlevel gauges-v2.dxf
- Roll_COG [deg] roll angle
- Pitch_COG [deg] pitch angle

Figure 6 Breach in benchmark case 3 (photo courtesy of MARIN).

3 REFERENCES

Ruponen, P., van Basten Batenburg, R., van't Veer, R., Braidotti, L., Bu, S., Dankowski, H., Lee, G.J., Mauro, F., Ruth, E., Tompuri, M. 2022. International benchmark study on numerical simulation of flooding and motions of a damaged cruise ship, *Applied Ocean Research*, Article 103403. https://doi.org/10.1016/j.apor.2022.103403