SHOPERA Benchmark Specification
Part II: The DTC Case Study

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1 Introduction

The 2012 guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships, MEPC.212(63), represent a major step forward in implementing energy efficiency regulations for ships through the introduction of the EEDI limits for various types of ships. There are, however, serious concerns regarding the sufficiency of propulsion power and steering devices to maintain maneuverability of ships in adverse conditions, hence regarding the safety of ships, if the EEDI requirements are achieved by simply reducing the installed engine power. To address the challenges of this issue by in-depth research studies, a new European research project called SHOPERA (Energy Efficient Safe SHip OPERAtion) [1], funded by the European Commission in the frame of FP7, was launched in October 2013, aiming at developing suitable methods and tools and systematic case studies which will enable the development of improved guidelines and their submission for consideration to IMO-MEPC in 2016. Numerical simulation methods (on simulating the maneuverability of a ship in waves) of varying complexity, such as simplified formulas, potential flow methods, motion simulators and viscous field methods, will be compared with each other and with model tests for selected cases. As the employed methods are of varying complexity and capability, their robustness in predicting is expected to be accordingly of mixed quality. Within this context, an open blind international benchmark study is being organized by SHOPERA using for validation selected tank tests, which were conducted within the SHOPERA project. The aim of this benchmark study is to assess the accuracy/reliability of current numerical simulation methods worldwide and the international State- of-Art in the study field. The SHOPERA benchmark study will be jointly organized by NTUA-SDL and UDE-ISMT. The present study is conducted in the frame the European Project SHOPERA.

In short, this study aims to contribute to the international state of the art in the assessment of the operation of ships in adverse sea conditions by:

- recording numerical simulation methods employed at international level for the prediction of the added resistance (including drift forces) and maneuverability of ships in waves, and
- assessing the current level of accuracy and efficiency of the relevant numerical prediction methods by comparison with model experimental data.

2 Duisburg Test Case (DTC) Container Vessel

Figure 1: DTC hull

2.1 Geometry

The Duisburg Test Case (DTC) design is a post Panamax 14000 TEU container vessel. It was developed at the Institute of Ship Technology, Ocean Engineering and Transport Systems (ISMT) of the University of Duisburg-Essen for benchmarking and validation of numerical methods and its lines and other characteristics are available to the public, see [2]. The DTC CAD offset file is available for download by the benchmark participants from the SHOPERA benchmark study link http://www.shopera.org/benchmark-study/...Call/Specifications.

The main particulars of this vessel for the design loading condition (Draft T = 14.5 m) are given in Table 1 in full scale. The tests were conducted with a model scale of 63.65. Note that the below given wetted surface S is without the area of the appendages.

The coordinate system is right-handed with the x-axis positive towards the bow and the z-axis positive downwards. The origin of the ship bound coordinate system used in the measurements is located at [Lpp/2, CentreLine, BaseLine]. Head wave is denoted by 0°, following wave by 180°, beam wave by 90° from PS. A positive rudder angle δ indicates that the rudder has been set to port side (PS).

Table 1: Main Dimensions of the DTC, [2]

L_{pp} [m]	B_{WL} [m]	T [m]	V [m^3]	S [m^2]	CB [-]
355.0	51.0	14.5	173467	22032	0.661

The DTC design features a twisted rudder with Costa bulb and a NACA 0018 base profile (see **Figure 2**). The projected area of the movable part of the rudder is 95.1 m^2.

Figure 3 shows the DTC container vessel's fixed-pitch five-bladed propeller of 8.911 m full scale diameter and a pitch ration of P/D = 0.959. The direction of rotation is right-handed, looking in positive x direction.

Figure 2: DTC twisted rudder

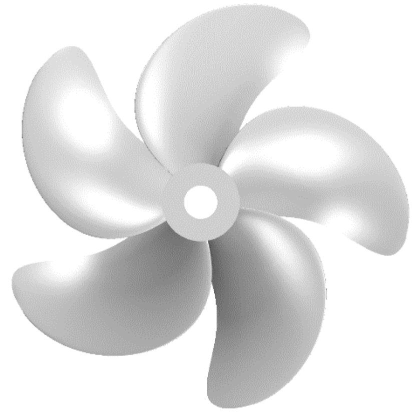

Figure 3: DTC propeller

On each side of the vessel, a segmented bilge keel is placed symmetrically around the midship section, consisting of five segments, each with 14.85 m length and 0.4 m profile height. The gap width between the segments is 3 m. CAD data is available on the SHOPERA website (www.shopera.org)

The ship's draft and mass/inertia characteristics for the loading condition used in the seakeeping and maneuvering tests of the present benchmark are shown in Table 2.

Table 2: DTC Loading Conditions

T_f [m]	T_a [m]	m [kg]	LCG [m]*	VCG [m]*	GM [m]	rx [m]	ry [m]	rz[m]
14.5	14.5	177804	174.059	19.851	5.1	20.3	87.3	87.4

*Coordinate system with origin at [AP, CL, BL]

2.2 Calm Water Resistance

The conducted calm water resistance tests (bear hull with bilge keel and rudder) by MARINTEK within the scope of the SHOPERA Project are given in the following.

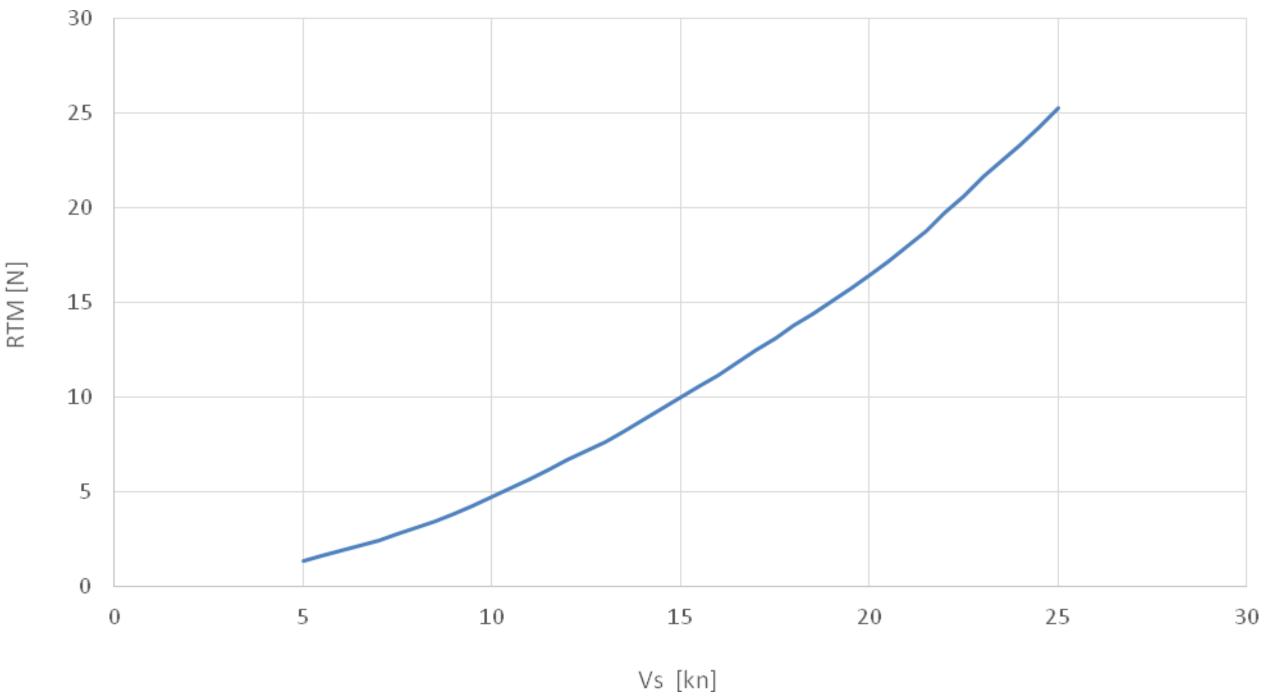

Figure 4: DTC calm water resistance

Table 3: DTC calm water resistance forces and coefficients

V_S [knots]	V_M [m/s]	Fn [-]	RN_M [10^{-6} N]	RT_M [N]	CT_M [10^3]	CF_M [10^3]	CR [10^3]
5	0.322	0.043	1.735	1.334	4.644	4.173	0.088
5.5	0.355	0.048	1.908	1.585	4.561	4.093	0.091
6	0.387	0.052	2.082	1.854	4.482	4.022	0.088
6.5	0.419	0.056	2.255	2.14	4.409	3.958	0.083
7	0.451	0.06	2.429	2.446	4.344	3.9	0.08
7.5	0.484	0.065	2.602	2.773	4.292	3.847	0.084
8	0.516	0.069	2.775	3.116	4.238	3.799	0.082
8.5	0.548	0.073	2.949	3.47	4.18	3.754	0.071
9	0.58	0.078	3.122	3.851	4.139	3.713	0.074
9.5	0.613	0.082	3.296	4.268	4.116	3.674	0.092
10	0.645	0.086	3.469	4.71	4.1	3.638	0.114
10.5	0.677	0.091	3.643	5.174	4.085	3.605	0.136
11	0.709	0.095	3.816	5.654	4.068	3.573	0.152
11.5	0.742	0.099	3.99	6.146	4.045	3.543	0.162
12	0.774	0.104	4.163	6.645	4.017	3.515	0.163
12.5	0.806	0.108	4.337	7.146	3.981	3.488	0.156
13	0.838	0.112	4.51	7.657	3.944	3.462	0.146
13.5	0.871	0.117	4.684	8.189	3.911	3.438	0.139
14	0.903	0.121	4.857	8.753	3.887	3.415	0.14
14.5	0.935	0.125	5.031	9.359	3.875	3.393	0.151
15	0.967	0.13	5.204	9.979	3.86	3.372	0.159
15.5	0.999	0.134	5.378	10.563	3.827	3.351	0.148
16	1.032	0.138	5.551	11.152	3.792	3.332	0.133
16.5	1.064	0.143	5.724	11.8	3.773	3.313	0.134
17	1.096	0.147	5.898	12.467	3.755	3.295	0.135
17.5	1.128	0.151	6.071	13.108	3.726	3.278	0.124
18	1.161	0.155	6.245	13.745	3.693	3.261	0.109
18.5	1.193	0.16	6.418	14.395	3.661	3.245	0.095
19	1.225	0.164	6.592	15.06	3.631	3.23	0.081
19.5	1.257	0.168	6.765	15.737	3.602	3.215	0.069
20	1.29	0.173	6.939	16.428	3.575	3.2	0.057
20.5	1.322	0.177	7.112	17.155	3.553	3.186	0.05
21	1.354	0.181	7.286	17.951	3.543	3.172	0.055
21.5	1.386	0.186	7.459	18.794	3.539	3.159	0.065
22	1.419	0.19	7.633	19.68	3.539	3.146	0.079
22.5	1.451	0.194	7.806	20.619	3.545	3.133	0.098
23	1.483	0.199	7.98	21.572	3.55	3.121	0.116
23.5	1.515	0.203	8.153	22.457	3.54	3.109	0.118
24	1.548	0.207	8.326	23.321	3.524	3.098	0.115
24.5	1.58	0.212	8.5	24.257	3.518	3.087	0.12
25	1.612	0.216	8.673	25.251	3.517	3.076	0.131

2.3 Propeller Open Water Characteristic

The open water tests for the used were performed earlier by Potsdam Model Basin (SVA).

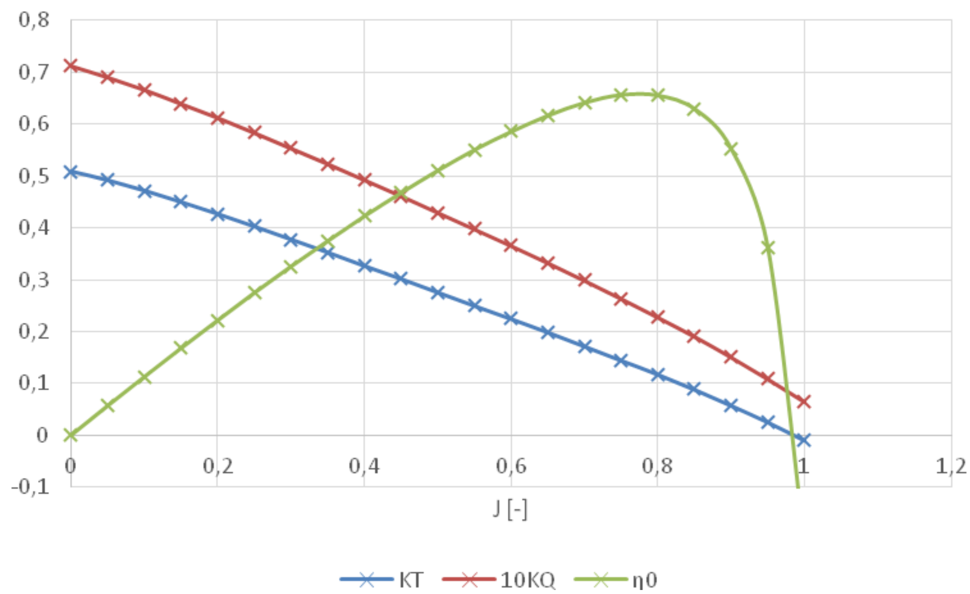

Figure 5: Open water characteristic of DTC propeller

Table 4: Open water characteristic of DTC propeller, see [2]

J [-]	K_T [-]	$10K_Q$ [-]	η_0 [-]	C_{Th} [-]
0	0.509	0.713	0	
0.05	0.492	0.691	0.057	500.7
0.1	0.472	0.667	0.113	120.1
0.15	0.45	0.64	0.168	50.91
0.2	0.427	0.613	0.222	27.17
0.25	0.403	0.584	0.275	16.41
0.3	0.378	0.554	0.326	10.69
0.35	0.353	0.524	0.375	7.333
0.4	0.327	0.493	0.423	5.21
0.45	0.302	0.462	0.468	3.794
0.5	0.276	0.43	0.511	2.812
0.55	0.25	0.398	0.551	2.107
0.6	0.225	0.366	0.586	1.588
0.65	0.199	0.333	0.617	1.196
0.7	0.172	0.299	0.642	0.894
0.75	0.145	0.264	0.657	0.657
0.8	0.118	0.228	0.656	0.467
0.85	0.089	0.191	0.63	0.312
0.9	0.058	0.151	0.553	0.183
0.95	0.026	0.109	0.361	0.074

2.4 SHOPERA Benchmark Test Cases

The selected SHOPERA benchmark test cases of the DTC hull in head and oblique waves, as well as maneuvering tests, are specified in the following. All test were conducted as deep water test. The actual depth of each test is given in the test description.

2.4.1 Added resistance in head waves

The DTC model was captive in a soft-mooring arrangement and towed by the carriage at a constant speed. The transverse beam was mounted on deck at $\frac{L_{pp}}{2}$ and the connection point for the lines was at [2.789m, ±0.995m, -0.448m] model scale, relative to [AP, CL, BL]. The arrangement is shown in a schematic way in Fig. 6.

The added resistance tests have been performed without the presence of the propeller, but with bilge keels, rudder box and rudder (fixed at 0° rudder angle) mounted to the DTC hull

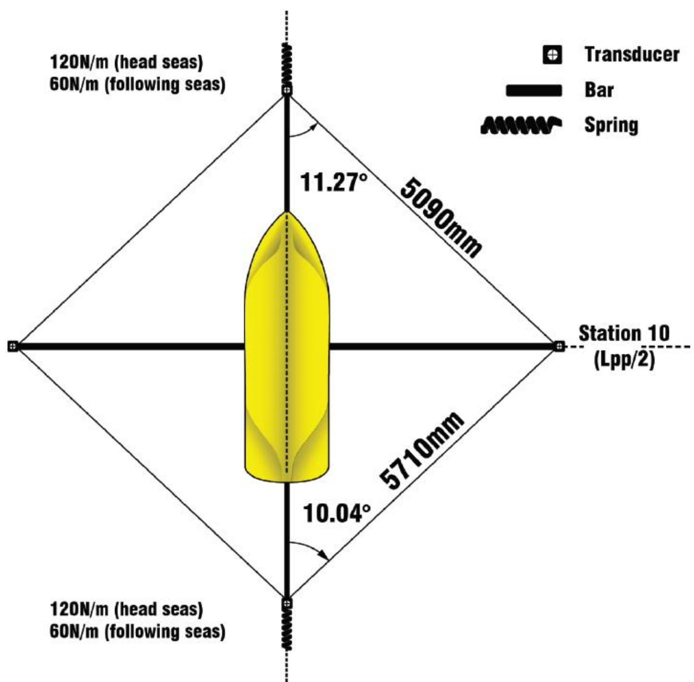

Figure 6: Soft-mooring arrangement for added resistance tests with the DTC model

The benchmark test cases for the added resistance in harmonic/regular waves are specified in Table 5 and Table 6. A test case in irregular waves is defined in Table 7. Zero degrees angle means head waves.

The regular wave tests were performed at a water depth of 10.0m and the irregular ones at 5.6m depth.

Table 5: DTC test conditions for added resistance tests with 6 knots in regular waves

Run number	H [m]	T [s]	Encounter angle [°]	v[knots]
3031	10.0	9.0	0	6
3041	7.5	8.0	0	6
3051	5.0	7.0	0	6

3700	9.0	13.94	0	6
3711	6.0	13.94	0	6
3720	7.5	13.94	0	6

Table 6: DTC test conditions for added resistance in regular waves, v=16 knots

Run number	H [m]	T [s]	Encounter angle [°]	v [knots]
4030	10.0	9.0	0	16
4040	7.5	8.0	0	16
4050	5.0	7.0	0	16
4241	9.0	14.31	0	16
4251	6.0	14.31	0	16
4260	7.5	14.31	0	16

Table 7: DTC test conditions for added resistance tests in irregular waves

Run number	H_s [m]	T_p [s]*	Encounter angle [°]	v [knots]
3670	5.0	9.5	0	6

Tp= peak period. The measured spectrum is available on the website www.shopera.org

2.4.2 Drift forces

The DTC model was moored in a diamond shaped spring arrangement that confined the motions in surge, sway and yaw and left the ship free to heave, roll and pitch (see Fig. 7). A longitudinal beam is mounted on the model and the connection points for the lines are [5.88m, 0.0m, -0.312m] and [-0.7m, 0.0m, -0.312m] model scale, relative to [AP, CL, BL].

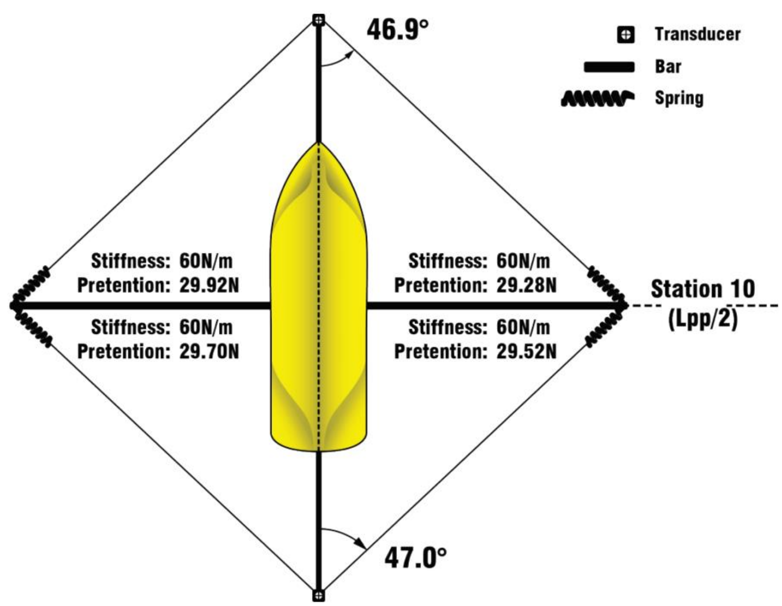

Figure 7: Soft-mooring arrangement for drift force tests with the DTC model

Two sets of benchmark calculations are specified: drift forces and yaw moment at zero speed, with the test cases shown in Table 8, and for 6knots advance speed with the associated test cases specified in

Table 9.

The tests were performed at a water depth of 5.0m.

Table 8: DTC test conditions for drift force and yaw moment tests at zero speed

Run number	H [m]	T [s]	Encounter angle [°]	v [knots]
2020	12.0	10.0	0	0
2030	10.0	9.0	0	0
2040	7.5	8.0	0	0
2050	5.0	7.0	0	0
2130	12.0	10.0	30	0
2140	10.0	9.0	30	0
2150	7.5	8.0	30	0
2160	5.0	7.0	30	0
2241	12.0	10.0	60	0
2250	10.0	9.0	60	0
2260	7.5	8.0	60	0
2270	5.0	7.0	60	0
2355	6.0	10.0	90	0
2380	5.0	7.0	90	0
2390	1.5	5.0	90	0
2430	2.5	9.0	90	0
2470	10.0	9.0	120	0
2480	7.5	8.0	120	0
2490	5.0	7.0	120	0
2570	12.0	10.0	150	0
2580	10.0	9.0	150	0
2590	7.5	8.0	150	0
2600	5.0	7.0	150	0
2690	10.0	9.0	180	0
2700	7.5	8.0	180	0
2710	5.0	7.0	180	0

Table 9: DTC test conditions for drift force and yaw moment tests, speed 6 knots

Run number	H [m]	T [s]	Encounter angle [°]	v [knots]
3140	10.0	9.0	30	6
3150	7.5	8.0	30	6
3160	5.0	7.0	30	6
3250	10.0	9.0	60	6
3260	7.5	8.0	60	6
3270	5.0	7.0	60	6
3310	7.5	9.0	60	6
3320	5.0	9.0	60	6
3351	6.0	10.0	120	6
3360	7.5	9.0	120	6
3370	7.5	8.0	120	6
3380	5.0	7.0	120	6
3420	5.0	9.0	120	6
3430	2.5	9.0	120	6
3460	6.0	10.0	150	6
3470	7.5	9.0	150	6
3480	7.5	8.0	150	6
3490	5.0	7.0	150	6

2.4.3 Zig-Zag manoeuver

Tests for three 20°/20° Zig-Zag maneuvers were carried out, namely one standard in calm water and two in regular waves of different period by the same wave height, see Table 10. All values are given in full scale aside from the propeller revolution.

The tests were performed at a water depth of 5.0m.

Table 10: DTC test conditions for 20°/20° Zig-Zag maneuvers in calm water and in waves*

Run number	H [m]	T [s]	Encounter angle [°]	v [knots]	Rudder*	n [rps]**
1750	-	-	-	6	-	4.341
7121	2.0	10.6	0	6	CREST	4.799
7140	2.0	13.94	0	6	CREST	5.163

* Rudder rate is 2.25°/s (full scale),
Initial conditions (begin of ship manoeuver): initial rudder angle = 0°, increase to δ=-20° (SB), wave crest at midship
**n=propeller speed [rps] in model scale

2.4.4 Turning circle

Tests for turning circle were performed in calm water and in regular waves, see Table 11.

The tests were performed at a water depth of 5.0m.

Table 11: DTC test conditions for turning circle maneuvers (**δ=-35°)** in calm water and in waves

Run number	H [m]	T [s]	Encounter angle [°]	v [knots]	Rudder	n [rps]
1700	-	-	-	6	SB	4.336
7080	2.0	12.5	0	6	SB	5.159
7085	4.0	12.5	0	6	SB	6.476
7002	2.0	10.6	0	6	SB	4.774
7010	2.0	10.6	90	6	SB	4.884
7020	2.0	10.6	180	6	SB	4.063

*Rudder rate is 2.25°/s (full scale),
Initial condition (begin of ship manoeuver): initial rudder angle = -3° (SB), increase to δ=-35° (SB), wave crest at midship ??

3 Data for Submission

The participants of the benchmark workshop are asked to describe the method/software used and the computational procedure and setup. A grid and time discretization study is required. Convergence behavior shall be documented. A document template will be issued by the benchmark organizers.

Data to be delivered should include

1. Dimensional (model scale) motions (6 degrees of freedom)*
2. Dimensional (model scale) hydodynamic forces (3) and moments (3)*
3. The time series of all conducted simulations for at least ten encounter periods (regular waves).
4. Submission files shall include the added resistance, heave and pitch for regular head waves. The results of the computations in oblique regular waves shall include the longitudinal and transverse forces, the yaw moment and all associated motions.
5. The maneuvering simulation time series shall include the trajectories*, rudder and heading angle.

*Definitions and templates will be prepared and distributed by the benchmark organizers in due time.

4 Time Plan

- Release of specifications for the DTC benchmark: December 15, 2015
- Release of specifications for the KVLCC2 benchmark: December 21, 2015
- Release of template for benchmark results: January 25, 2016
- Submission of results: March 7, 2016
- Feedback on results and possible update/resubmission: March 21, 2016
- Analysis of results: April 8, 2016
- Presentation of results: April 15, 2016
- Release of benchmark report: May 30, 2016

5 Benchmark Contacts

Participation to the benchmark study can be requested through the SHOPERA web site or directly by email to the study coordinators:

Prof. Apostolos Papanikolaou
National Technical University of Athens – Ship Design Laboratory (NTUA-SDL)
Phone: +30 210 772 1416, Fax: +30 210 772 1408
e-mail: papa@deslab.ntua.gr
cc. Dr. Shukui Liu: liushukui@deslab.ntua.gr

Prof. Ould el Moctar
University of Duisburg Essen – Institute for Ship technology, Ocean Engineering and Transport Systems (UDE-ISMT)
Phone: +49 203 379 2539, Fax: +49 203 379 2779
e-mail: ould.el-moctar@uni-due.de
cc. Mr. Robert Potthoff: robert.potthoff@uni-due.de

References

[1] SHOPERA (2013-2016) http://www.shopera.org

[2] O. el Moctar, V. Shigunov und T. Zorn, „Duisburg Test Case: Post - Panamax Container Ship for Benchmarking," J. Ship Technology Research, Vol.59, No.3, pp. 50-65, 2012.