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CONSIDERATIONS ON THE CALCULATION OF THE MAIN CHARACTERISTICS OF THE SHIP SEAKEEPING

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Abstract: *The motion of a ship or floating structure is important for determining of the dynamic load on the crew/ passengers, structural materials and equipment, and cargo. In this paper we propose to determine the parameters that influence heaving and pitching amplitude relevant to study the 97,000 dwt bulk carrier. With equations based on regression analysis can be estimated amplitude values for various degrees of sea agitation and for various loading situations of the ship. The results are useful for determining additional loads induced both structural elements and the components of equipment and installations on board ships.*

Keywords**:** *heaving, pitching, regression analysis*

INTRODUCTION
Presented model in fig.1. will be used in Autoship parameter calculus.

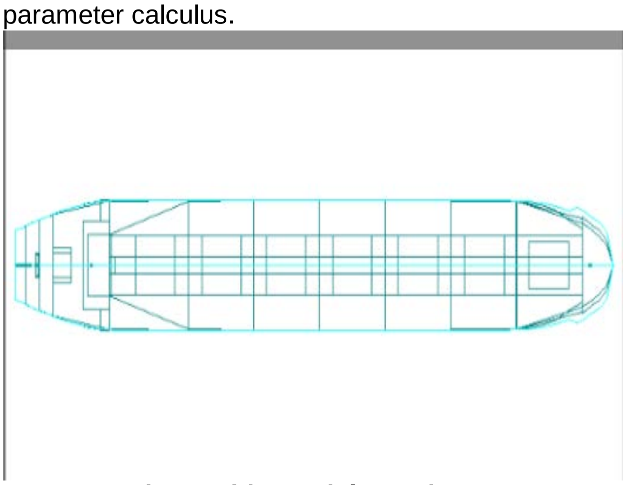

Fig. 1. Ship model top view

As a rigid body, a ship has six degrees of freedom: three translations (*heave, surge* and *sway*) and three rotations (*roll, pitching* and *yaw)*. In this paper we deal with heaving and pitching motions, becouse they are very important for discomfort of passengers and crew, and for operation of machines and installations.

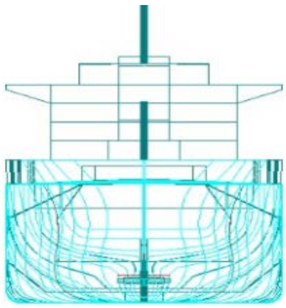

Fig. 2 Ship model bow view

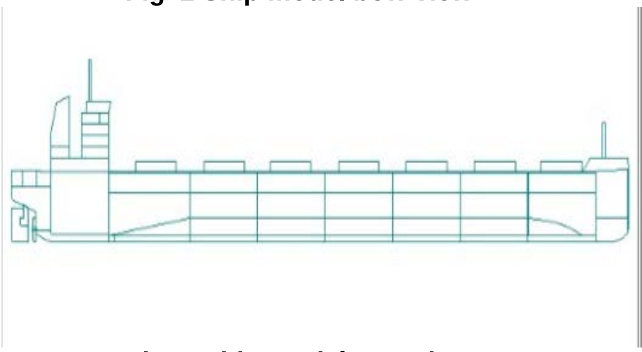

Fig. 3 Ship model port view

With the data obtained from various seakeeping tests, were made statistical analyses as function of different parametric values. One of these methods is *multiple regression analyses* [1] by which we can estimate heaving and pitching amplitude in regular seas as function of ship dimensions (*L, B, d*), waterplane area coefficient (C_W), block coefficient (C_B), buoyancy center (x_B), inertial characteristics of the ship (k_{yy}), ship speed (v) and sea state (Beaufort Number).

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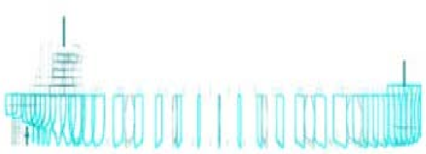

Fig. 4. Ship model frames view

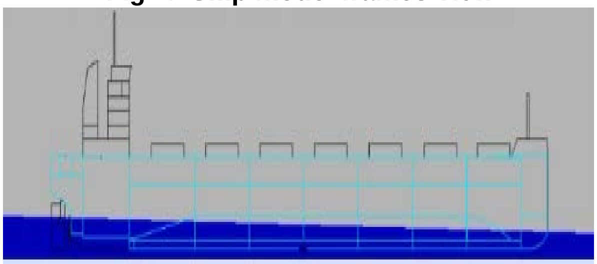

Fig. 5. Ship model floating in Autohydro-1

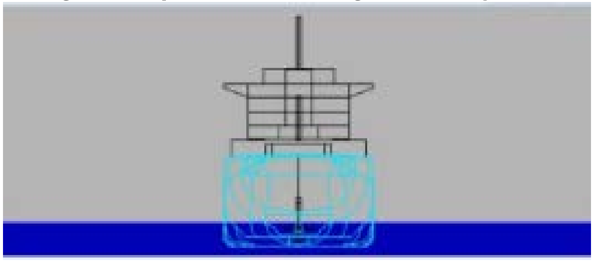

Fig. 6. Ship model floating in Autohydro-2

Equations for the estimation of heaving and pitching amplitude in regular seas, with *multiple regression analyses* are [1] below (1) and (2) :

$$z_a = A_0 + A_1 \cdot C_W + A_2 \cdot C_B + A_3 \cdot \frac{L}{B} + A_4 \cdot \left(\frac{L}{d}\right)^{-1} + A_5 \cdot 100 \cdot \frac{x_B}{L} + A_6 \cdot \frac{k_{yy}}{L} + A_7 \cdot \frac{v}{\sqrt{L}}$$

$$\theta_a = B_0 + B_1 \cdot C_W + B_2 \cdot C_B + B_3 \cdot \frac{L}{B} + B_4 \cdot \frac{L}{d} + B_5 \cdot 100 \cdot \frac{x_B}{L} + B_6 \cdot \frac{k_{yy}}{L} + B_7 \cdot \frac{v}{\sqrt{L}} + B_8 \cdot \left(\frac{v}{\sqrt{L}}\right)^2$$

where the coefficients $A_0 \div A_7$ and $B_0 \div B_8$ are given in Table 1÷ 6 as functions of length of the ship and Beaufort Number; $C_W =$ waterplane area coefficient; $C_B =$ block coefficient; $L\ [m] =$ length of the ship; $B\ [m] =$ beam of the ship; $d\ [m] =$ draft of the ship; $x_B\ [m] =$ abscissa of buoyancy center; $k_{yy}\ [m] =$ radius of gyration about y-axis; $v\ [knots] =$ ship speed.

$$a = A_0 + A_1 \cdot C_W + A_2 \cdot C_B + A_3 \cdot \frac{L}{B} + A_4 \cdot \left(\frac{L}{d}\right)^{-1} + A_5 \cdot 100 \cdot \frac{x_B}{L} + A_6 \cdot \frac{k_{yy}}{L} \quad (3)$$

$$b = B_0 + B_1 \cdot C_W + B_2 \cdot C_B + B_3 \cdot \frac{L}{B} + B_4 \cdot \frac{L}{d} + B_5 \cdot 100 \cdot \frac{x_B}{L} + B_6 \cdot \frac{k_{yy}}{L} \quad (4)$$

relationships 1 and 2 are as follows:

$$z_a = a + A_7 \cdot \frac{v}{\sqrt{L}} \quad (5)$$

$$\theta_a = b + B_7 \cdot \frac{v}{\sqrt{L}} + B_8 \cdot \left(\frac{v}{\sqrt{L}}\right)^2 \quad (6)$$

Relation (5) shows that the heaving amplitude is a 1st grade function in $\frac{v}{\sqrt{L}}$, while relation (6) shows that the pitching amplitude is a 2nd grade function in $\frac{v}{\sqrt{L}}$, where *a* and *b* can be found in Table 3, for each of the three load cases considered.

Table 1

Beaufort Number	A_0	A_1	A_2	A_3	A_4	A_5	A_6	A_7
5	2.34	-5.88	0.82	0.152	17.4	0.094	7.5	0.39
6	2.97	-13.22	2.8	0.243	55.39	0.214	19.27	0.89
7	3.06	-21.65	5.56	0.329	107.2	0.357	32.73	2.24
8	3.05	-31.27	9.6	0.302	171.6	0.507	49.3	4.18

Table 2

Beaufort Number	B_0	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
5	2.21	-4.21	2.21	0.09	-0.0055	-0.035	-1.4	0.95	-0.46
6	3.86	-8.88	4.75	0.172	-0.0175	-0.062	1.6	2.13	-0.94
7	5.01	-14.38	7.91	0.252	-0.0356	-0.085	4.9	4.13	-1.51
8	5.98	-20.52	11.57	0.305	-0.0592	-0.105	12.9	5.14	-2.01

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Table 3

Beaufort Number	case 1		case 2		case 3	
	a	b	a	b	a	b
5	1.649079	0.250105	1.187617	0.024243	0.72172	-0.16262
6	3.181047	0.748633	1.744736	0.206545	0.290972	-0.30823
7	5.08345	0.470576	2.321076	-0.50335	-0.48292	-1.50501
8	7.698549	0.761416	3.238125	-0.74133	-1.29136	-2.36567

Ship data:

Caz 1: $C_W = 0.921$; $C_B = 0.839$; $\frac{L}{B} = 6.284$; $\frac{L}{d} = 16.67$; $\frac{x_B}{L} = 1.73$; $\frac{k_{yy}}{L} = 0.25$

Caz 2: $C_W = 0.91$; $C_B = 0.71$; $\frac{L}{B} = 6.284$; $\frac{L}{d} = 23.103$; $\frac{x_B}{L} = 0.35$; $\frac{k_{yy}}{L} = 0.25$

Caz 3: $C_W = 0.878$; $C_B = 0.552$; $\frac{L}{B} = 6.284$; $\frac{L}{d} = 35.649$; $\frac{x_B}{L} = -2.41$; $\frac{k_{yy}}{L} = 0.25$

Graphics: $z_a = f\left(\frac{v}{\sqrt{L}}\right)$ si $\theta_a = f\left(\frac{v}{\sqrt{L}}\right)$, forcele 4 Beaufort scale and tree load cases.

Hull Data (with appendages)

Baseline Draft: 14.097 at Origin
Trim: 0.01 deg.
Heel: zero

DIMENSIONS
Length Overall: 238.800 m LWL: 238.800 m
Beam: 38.000 m BWL: 38.000 m
Volume: 107512.200 m^3 Displacement: 110200.600 MT

COEFFICIENTS
Prismatic: 0.843 Block: 0.839 Midship: 0.995 Waterplane: 0.921

RATIOS
Length/Beam: 6.284 Displacement/length: 225.528 Beam/Depth: 2.691
MT/ cm Immersion: 85.651

AREAS
Waterplane: 8356.173 m^2 Wetted Surface: 13756.710 m^2
Under Water Lateral Plane: 3348.244 m^2
Above Water Lateral Plane: 2287.907 m^2

CENTROIDS (Meters)
Buoyancy: LCB = 4.071 fwd TCB =0.000 port VCB = 7.347
Flotation: LCF = 3.770 aft

Under Water LP: 1.928 aft of Origin, 7.013 below waterline.
Above Water LP: 11.979 aft of Origin, 6.278 above waterline.

Note: Coefficients calculated based on waterline length at given draft

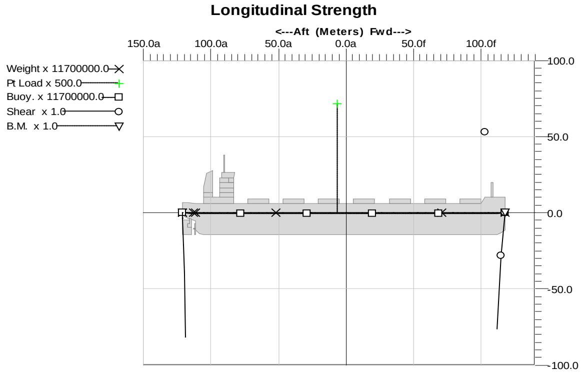

Fig. 7. Ship model results in Autohydro

* Point weight in Metric Tons

Max. Shear	18161.48 MT
Max. Bending Moment	-1033757 MT-m

Righting Arms vs. Heel

Righting Arms vs Heel Angle

Heel Angle (deg)	Righting Arm (m)
0.00	0.000
5.00s	0.643
10.00s	1.298
15.00s	1.977
20.00s	2.657
25.00s	3.173
30.00s	3.549
35.00s	3.833
40.00s	4.032
45.00s	4.132
47.47s	4.144
50.00s	4.132
55.00s	4.046
60.00s	3.892

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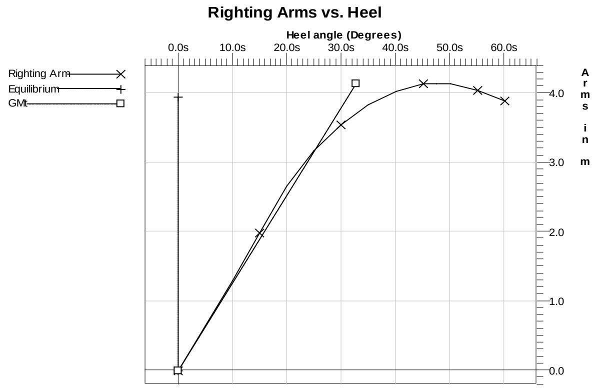


Fig. 8 Ship model righting arm results in Autohydro

Hull Data (with appendages)

Baseline Draft: 10.172 at Origin
Trim: aft 0.82 deg.
Heel: zero

DIMENSIONS
Length Overall: 238.800 m LWL: 238.700 m
Beam: 38.000 m BWL: 38.000 m
Volume: 75257.480 m3 Displacement: 77139.330 MT

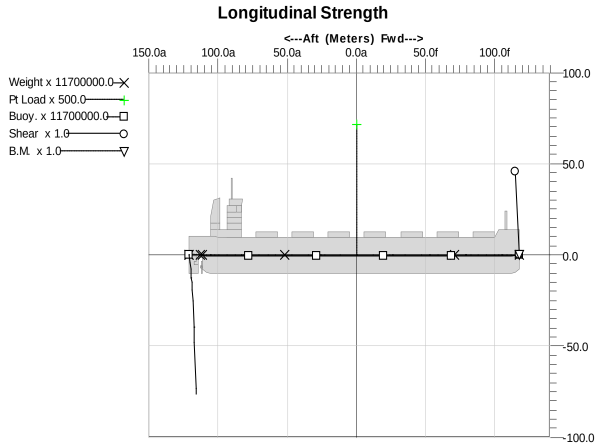
COEFFICIENTS
Prismatic: 0.783 Block: 0.710 Midship: 0.907 Waterplane: 0.910

RATIOS
Length/Beam: 6.284 Displacement/length: 158.066 Beam/Depth: 3.250
MT/ cm Immersion: 84.628

AREAS
Waterplane: 8256.372 m2 Wetted Surface: 11778.250 m2
Under Water Lateral Plane: 2418.640 m2
Above Water Lateral Plane: 3217.510 m2

CENTROIDS (Meters)
Buoyancy: LCB = 0.831 fwd TCB =0.000 port VCB = 5.330
Flotation: LCF = 2.259 aft
Under Water LP: 8.684 aft of Origin, 5.111 below waterline.
Above Water LP: 4.304 aft of Origin, 7.732 above waterline.

Note: Coefficients calculated based on waterline length at given draft



* Point weight in Metric Tons

Fig. 9. Ship model righting arm in Autohydro

Max. Shear	-18517.47 MT	at	0.000	
Max. Bending Moment	-946189 MT-m	at	0.000	(Sag

Righting Arms vs Heel Angle

Heel Angle (deg)	Righting Arm (m)
0.00	0.000
5.00s	0.452
10.00s	0.908
15.00s	1.425
20.00s	2.081
25.00s	2.879
30.00s	3.720
35.00s	4.300
40.00s	4.624
45.00s	4.786
50.00s	4.835
50.19s	4.835
55.00s	4.801
60.00s	4.698

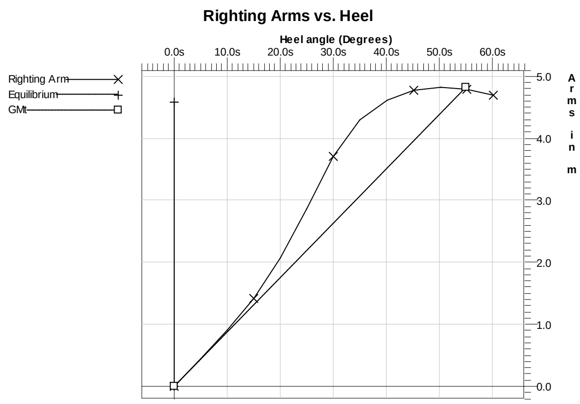


Fig. 10. Ship model righting arm results graph

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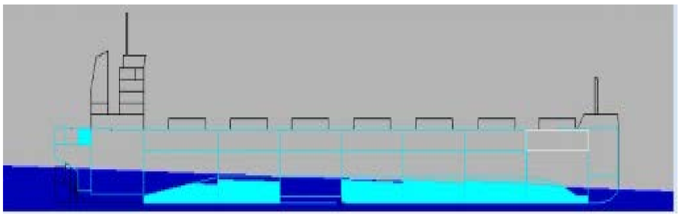

Fig. 11. Ship model floating case in Autohydro

Hull Data (with appendages)

Baseline Draft: 6.592 at Origin
Trim: aft 1.43 deg.
Heel: zero

<u>DIMENSIONS</u>
Length Overall: 238.800 m LWL: 238.643 m
Beam: 38.000 m BWL: 38.000 m
Volume: 46234.510 m^3 Displacement: 47390.630 MT

<u>COEFFICIENTS</u>
Prismatic: 0.678 Block: 0.552 Midship: 0.814 Waterplane: 0.878

<u>RATIOS</u>
Length/Beam: 6.284 Displacement/length: 97.178 Beam/Depth: 4.116
MT/ cm Immersion: 81.651

<u>AREAS</u>
Waterplane: 7965.938 m^2 Wetted Surface: 9975.805 m^2
Under Water Lateral Plane: 1576.405 m^2
Above Water Lateral Plane: 4059.747 m^2

<u>CENTROIDS (Meters)</u>
Buoyancy: LCB = 5.674 aft TCB =0.000 stbd VCB = 3.545
Flotation: LCF = 1.042 fwd
Under Water LP: 20.500 aft of Origin, 3.513 below waterline.
Above Water LP: 0.806 aft of Origin, 9.317 above waterline.

Note: Coefficients calculated based on waterline length at given draft

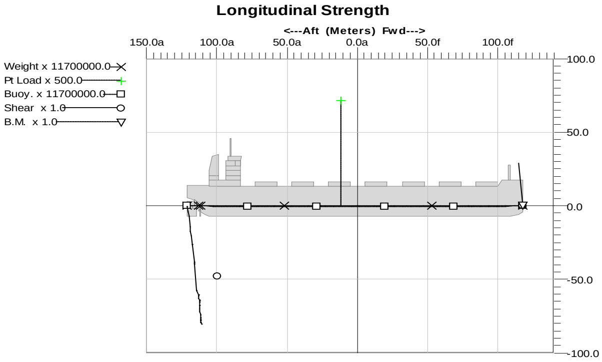

Fig. 12. Ship model BM results in Autohydro

Location (m)	Shear (MT)	Bending (MT-m)
117.443f	0.00	0
117.443f		
117.400f	0.00	0
114.563f	29.24	-41
111.625f	124.11	-262
108.687f	281.73	-857
105.750f	491.08	-1993
104.760f	571.73	-2523
104.760f		
102.812f	694.55	-3764
99.875f	896.95	-6108
94.000f	1352.03	-12715
92.845f	1446.89	-14336
88.125f	1844.10	-22118
82.250f	2361.11	-34484
78.600f	2696.19	-43726
78.600f		
70.500f	3489.03	-68750
65.500f	4015.04	-87525
58.750f	4751.52	-117125
52.440f	5465.88	-149376
52.440f		
52.400f	5467.00	-149595
52.400f		
47.000f	6109.55	-180864
35.250f	7598.10	-261326
26.280f	8818.83	-334940
26.280f		
23.500f	9258.33	-360078
11.750f	11193.69	-480162
0.120f	13233.93	-622139
0.120f		
0.000	13264.50	-623730
11.750a	16325.03	-797490
12.000a	-19597.18	-801580
23.500a	-16471.29	-594117
26.040a	-15764.40	-553188

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26.040a		
35.250a	-13804.85	-416986
47.000a	-11182.81	-270119
52.200a	-9993.52	-215082
52.200a		
58.750a	-8445.65	-154697
63.891a	-7216.79	-114463
70.500a	-5642.77	-71997
76.375a	-4271.14	-42928
82.250a	-2977.10	-21711
83.590a	-2704.82	-17913
83.590a		
88.125a	-1796.53	-7753
94.000a	-790.32	-301
99.875a	-47.55	1997
102.812a	214.37	1720
105.750a	404.15	783
106.000a	417.27	679
106.000a		
108.687a	194.86	-166
111.440a	-80.02	-347
111.440a		
111.600a	-79.02	-335
111.625a	-78.86	-333
111.844a	-77.50	-317
111.854a	-77.44	-316
111.879a	-77.23	-314
111.978a	-75.99	-307
111.982a	-75.93	-307
112.109a	-73.88	-298
112.126a	-73.60	-296
112.236a	-71.71	-289
112.300a	-70.61	-285
112.364a	-69.51	-280
112.474a	-67.65	-273
112.491a	-67.38	-272
112.618a	-65.40	-264
112.622a	-65.35	-264
112.721a	-64.19	-258
112.746a	-64.01	-257
112.756a	-63.95	-256
113.000a	-62.76	-242
113.317a	-61.42	-223
113.476a	-60.85	-214
113.555a	-60.59	-210
113.595a	-60.46	-208

* Point weight in Metric Tons

Righting Arms vs Heel Angle

Heel Angle (deg)	Righting Arm (m)
0.00	0.000
5.00s	1.554
10.00s	3.120
15.00s	4.688
20.00s	6.152
25.00s	7.365
30.00s	8.299
35.00s	9.030
40.00s	9.594
45.00s	9.961
50.00s	10.110
51.24s	10.116
55.00s	10.066
60.00s	9.861

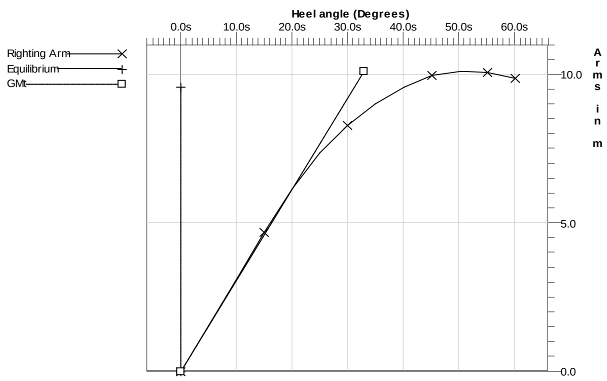

Fig. 13. Ship model righting arm in Autohydro

CONCLUSIONS

The motion of a ship or floating structure is important for determining of the dynamic load on the crew/ passengers, structural materials and equipment, and cargo. The parameters that influence heaving and pitching amplitude relevant are presented in the study the 97,000 dwt bulk carrier based on Autoship software. Based on regression analysis we estimated amplitude values for various degrees of sea agitation and for various loading situations of the ship. The results are useful for determining additional loads induced both structural elements and the components of equipment and installations on board ships.

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