Data of Model Experiments for Ship A-1

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revised by N. Umeda in May 2000
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1. Details of Ship A-1

Free-running model experiments were carried out with a 1/60 scaled model of a 15000 gross tonnes container ship of which principal particulars are shown in Table 1 and the lines are presented in Fig. 1. The offset data file, cont103.off, is also provided as a form of text file in full scale. The righting arm curves in calm water, as well as in a longitudinal wave, calculated for the ship with the metacentric height of 0.15m are shown in Fig.2. This ship critically complies with the IMO intact stability code. The model is fitted with forecastle, poop and bilge keels. Deck houses were not realised on the model because stability criteria ignore them as non-watertight structures. To store experimental equipment, additional watertight hatches and their coamings were fitted on the upper deck. The details of the layout of upper deck are given in Fig. 3. Inside the model hull, a DC motor for propulsion, a steering gear, gyroscope, batteries and on-board computer were equipped. By using the on-board computer, the auto pilot is simulated and the propeller revolution is controlled to be constant. During the experiments, the ship model is self-propelled and is completely free. The propeller thrust coefficient is given as follows:

$$K_T = \frac{T}{\rho n^2 {D_P}^4} = -0.0844 J^2 - 0.4882 J + 0.4539$$

where J: the propeller advance coefficient, ρ: water density, n: propeller revolution number.

2. Data of the capsizing model experiments

This series of model experiments were carried out at the seakeeping and manoeuvring basin of Ship Research Institute, Tokyo. The details of these experiments were reported in Hamamoto et al. (1995). The ship model ran to keep a straight course by using the auto pilot in regular following and quartering waves. Among many model runs, 4 model runs are selected for the ITTC benchmark testing. The control parameters for these selected runs are shown in Table 2. Until a generated wave train propagated enough, the model was kept near the wave maker without propeller revolution. Then the model started to drift and, at a certain moment, we commanded the propeller revolution to immediately increase up to the specified one and auto pilot to be active for the specified course. At this moment, the on-board computer started to measure and store the data. Thus, these first data can be regarded as the initial conditions for numerical simulation, which is provided in Table 3. The measured time histories are shown in Figs. 4-7 in model scale. The measured items consist of the pitch angle, the roll angle, the yaw angle, rudder angle and the propeller revolution number. The data files, specified in Table 2, involve digital values of the pitch, roll, yaw and rudder angle as well as the propeller revolution number as functions of time in model scale. The roll decay test was carried out without a forward velocity and its result is shown in Fig. 8.

3. Data of captive model tests

For estimating hydrodynamic coefficients, several captive tests were carried out. The results of the resistance test and the rudder angle tests in model scale at the towing tank of Osaka University are shown in Fig. 9 and 10, respectively. The results of circular motion tests (CMT) at the seakeeping and manoeuvring basin of National Research Institute of Fisheries Engineering are shown in Fig. 11. Here the sway force, Y, the yaw moment, N, the roll moment, K, and the rudder normal force, F_N, are plotted as functions of the rudder angle, δ, the drift angle, β, and the non-dimensional yaw rate, r'.

4. Example of benchmark testing

As an example, the benchmark test results executed by Osaka University are shown in Figs. 12-15. These are the comparison between the capsizing model test results and results with Osaka University's numerical code for the ship A-1. Here the pitch angle, θ, the roll angle, ϕ, the heading angle, $\psi(=\chi)$, the rudder angle, δ, are presented. The details of this numerical method are described in Munif et al. (2000).

References

Hamamoto, M. et al. (1995) Model Experiment of Ship Capsize in Astern Seas –Second Report-, Journal of the Society of Naval Architects of Japan, 179.

Munif, A., Hamamoto, M. and Umeda, N. (2000) Dynamic Stability of a Ship Leading to Capsize in Severe Astern Waves, Proc. of STAB2000.

Table 1 Principal Particulars of Ship A-1

Items	*Ship*	*1/60 scaled model*
length : L_{pp}	150.0 m	2.5 m
breadth : B	27.2 m	0.453 m
depth : D	13.5 m	0.225 m
draught at FP : T_f	8.5 m	0.142 m
mean draught : T	8.5 m	0.142 m
draught at AP : T_a	8.5 m	0.142 m
block coefficient : C_b	0.667	0.667
prismatic coefficient : C_p	0.678	0.678
water plane coefficient : C_w	0.787	0.787
wetted surface area : S	5065 m^2	1.407 m^2
roll radius of gyration : κ_{xx}/L_{pp}	N/A*	N/A*
pitch radius of gyration : κ_{yy}/L_{pp}	0.244	0.244
yaw radius of gyration : κ_{zz}/L_{pp}	0.244	0.244
longitudinal position of centre of gravity from the midship : x_{CG}	1.01 m aft	0.0168 m aft
vertical position of centre of gravity from the keel line : KG	11.48 m	0.1913 m
metacentric height : GM	0.15 m	0.0025 m
natural roll period : T_ϕ	43.3 s	5.59 s
rudder area : A_R	28.11 m^2	0.00781 m^2
rudder aspect ratio : Λ	1.69	1.69
vertical location of top of the rudder from the keel line	6.93 m	0.116 m
vertical location of bottom of the rudder from the keel line	0.79 m	0.0132 m
propeller diameter : D_P	5.04 m	0.084 m
propeller pitch ratio : P/D_p	0.7049	0.7049
bilge keel area	22.5 m^2 X 2	0.00625 m^2 X 2
position of fore end of bilge keel from the midship	15 m fore	0.25 m fore

position of aft end of bilge keel from the midship	22.5 m aft	0.375 maft
breadth of bilge keel	0.549 m	0.00915 m
maximum limit of rudder angle	10 degrees	10 degrees
maximum limit of rudder angular velocity	7.5 degrees/s	58.1 degrees/s
time constant of steering gear : T_E	1.24 s	0.160 s

* The virtual roll radius of gyration, $I_{xx}+J_{xx}$, can be estimated with the metacentric height and natural roll period as follows: $I_{XX} + J_{XX} = \rho g^2 LBT \times C_b \times GM \times T^2{}_{\phi} / (2\pi)^2$ where ρ and g are the water density and gravity acceleration, respectively.

Table 2 Control parameters of capsizing model runs of Ship A-1

nominal Froude number	F_n	0.2	0.2	0.3	0.4
auto pilot course from the wave direction	χ_c(degree)	0.0	45.0	30.0	30.0
wave steepness	H/λ	1/25	1/25	1/25	1/25
wave length to ship length ratio	λ/L_{pp}	1.5	1.5	1.5	1.5
proportional gain	K_P	1.2	1.2	0.8	0.5
differential gain in full scale	K_R(sec)	53.0	53.0	35.3	22.1
differential gain in model scale	K_R(sec)	6.84	6.84	4.56	2.85
data file name for time history		FN02K0.DAT	FN02K45.DAT	FN03K30.DAT	FN04K30.DAT

Here the propeller revolution is indicated by the nominal Froude number, which is the Froude number when the ship runs in calm water with the specified propeller revolution. The algorithm of the auto pilot is as follows: $\delta = -K_P(\chi - \chi_c) - K_R r$

where δ, χ and r are the rudder angle, heading angle and yaw rate, respectively.

Table 3 Initial conditions of capsizing model runs of Ship A-1 in model scale

nominal Froude number	F_n	0.2	0.2	0.3	0.4
auto pilot course	χ_C(degree)	0.0	45.0	30.0	30.0
nondimensional longitudinal position from a wave trough	ξ_G/λ	0.22	0.79	0.51	0.26
ship velocity in x direction	u(m/sec)	0.99	0.90	1.49	1.98
ship velocity in y direction	v(m/sec)	0.0	0.0	0.0	0.0
nondimensional vertical position from the still water level	ζ_G/a	0.28	0.13	-0.20	0.07
ship velocity in z direction	w(m/sec)	0.053	-0.087	0.015	0.034
roll angle	ϕ(degree)	-10.01	-5.77	-0.71	-0.71
roll angular velocity	p(degree/sec)	30.3	1.30	-6.29	-1.70
pitch angle	θ(degree)	-4.17	4.48	0.30	-2.50
pitch angular velocity	q(degree/sec)	-3.00	-7.8	12.73	6.99
yaw angle from the wave direction	χ(degree)	0.65	44.74	41.56	39.32
yaw angular velocity	r(degree/sec)	-0.88	-11.00	2.40	8.60
rudder angle	δ(degree)	10.0	10.0	-10.0	-10.0

Here the value of v is assumed to be zero, because this was not measured in the experiment. The values of ξ_G, u, ζ_G, and w are estimated from the measured value of θ and q with the assumption of low encounter frequency. λ and a are wave length and amplitude, respectively. The definition of the above valued are based on the attached co-ordinate systems.

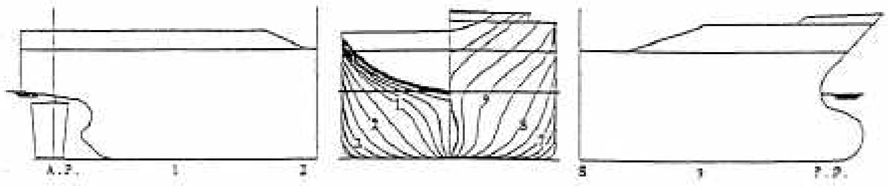


Fig. 1 Lines of Ship A-1

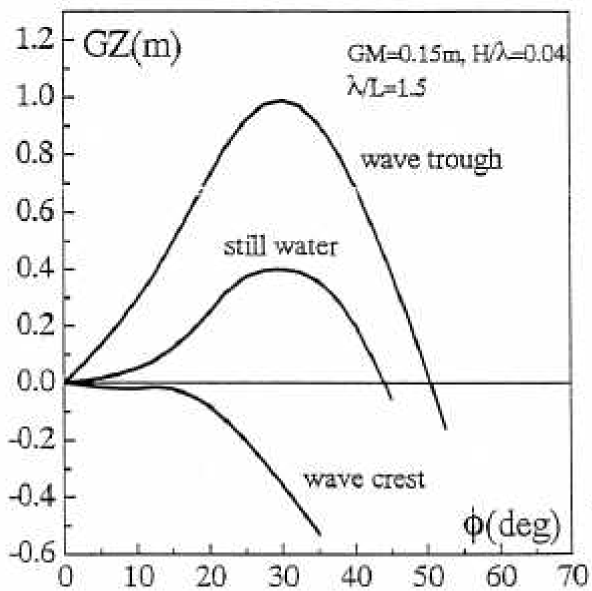


Fig. 2 Calculated righting arm curves of Ship A-1 in still water , wave trough and crest in full scale

7

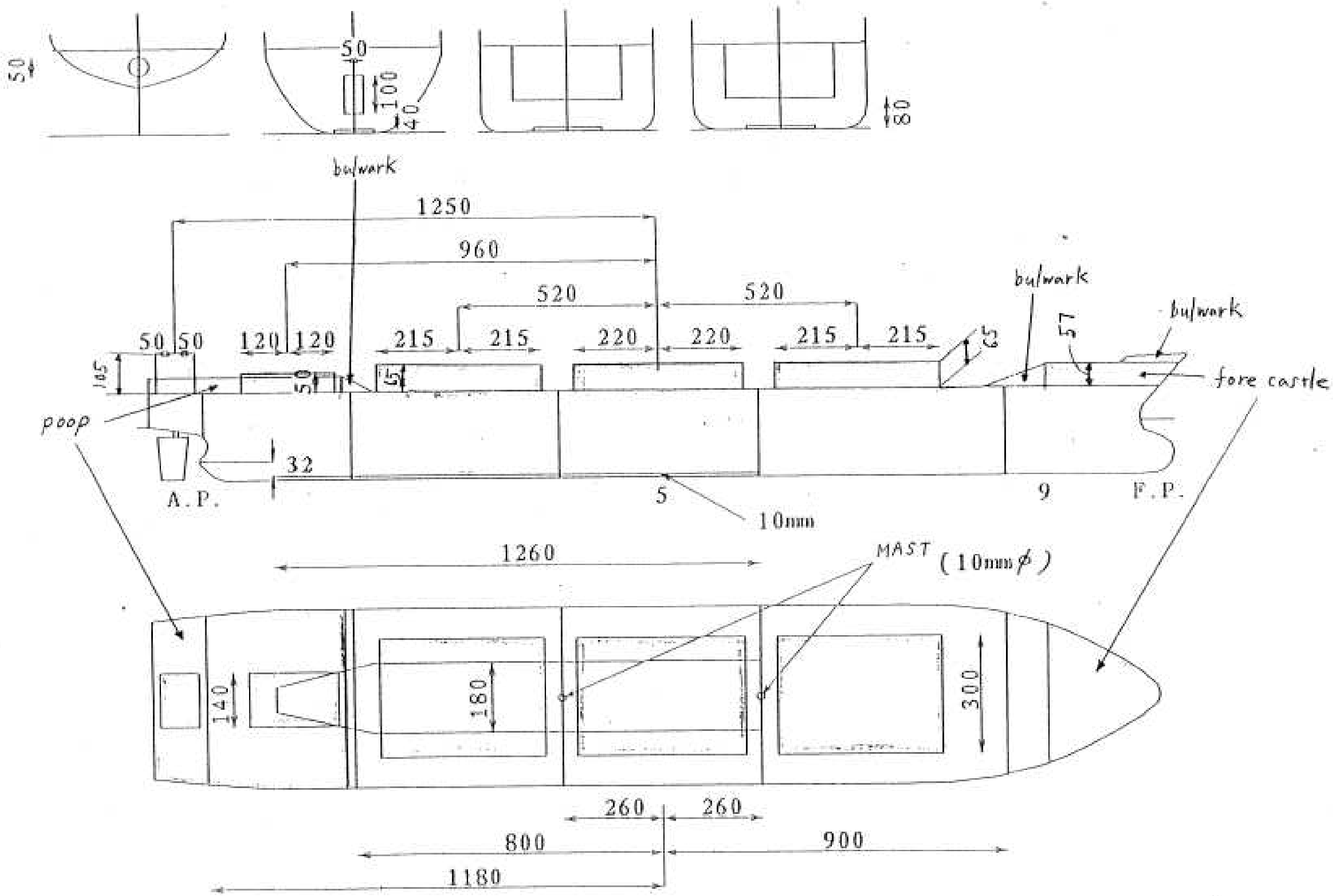


Fig. 3 layout of the superstructure of the model of ship A-1 in model scale

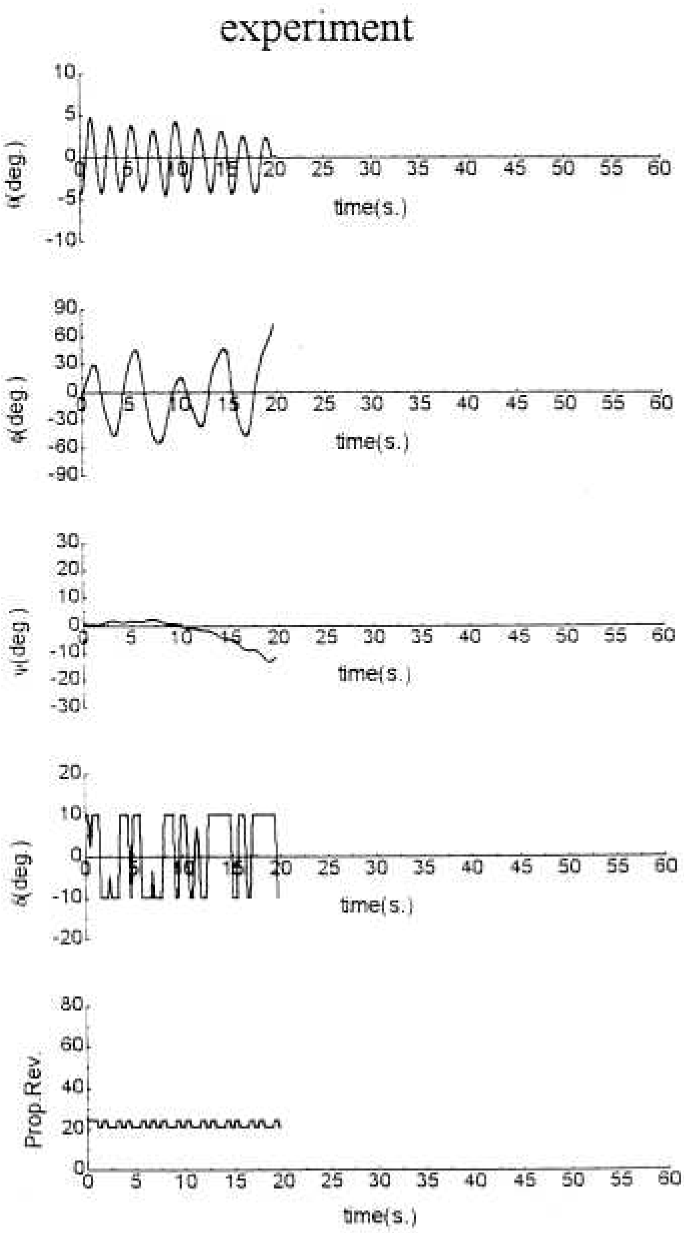


Fig. 4 Measured time history of the free-running model run of the ship A-1 in model scale (λ/L_{pp}=1.5 H/λ=1/25, F_n=0.2 χ_c=0 degrees)

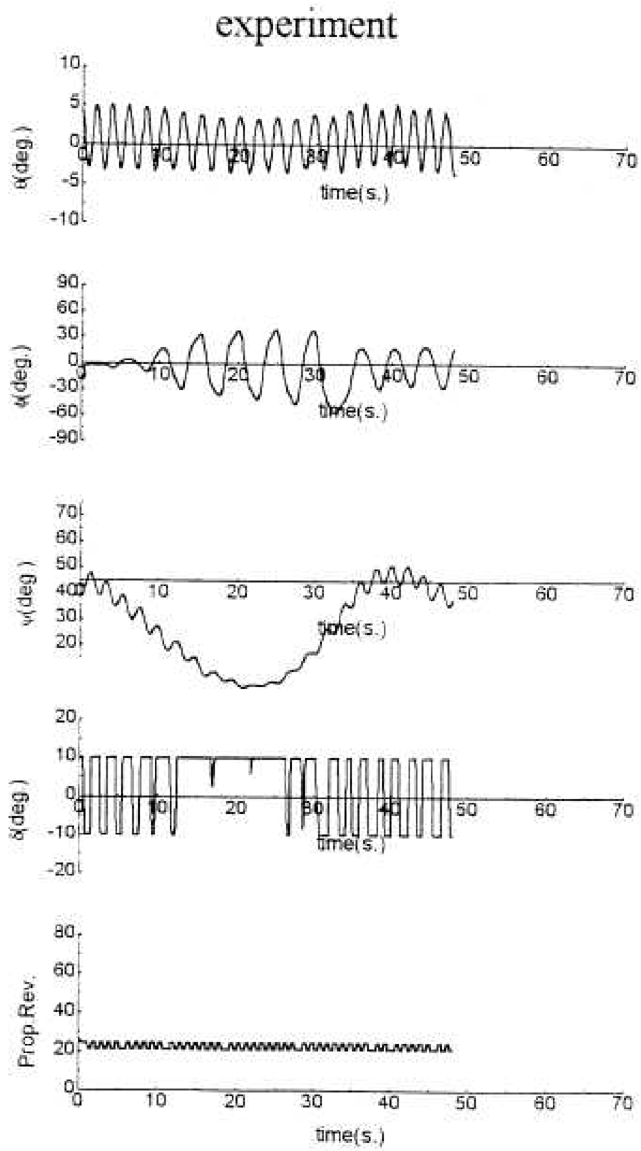


Fig. 5 Measured time history of the free-running model run of the ship A-1 in model scale (λ/L_{pp}=1.5 H/λ=1/25, F_n=0.2 χ_c=45 degrees)

10

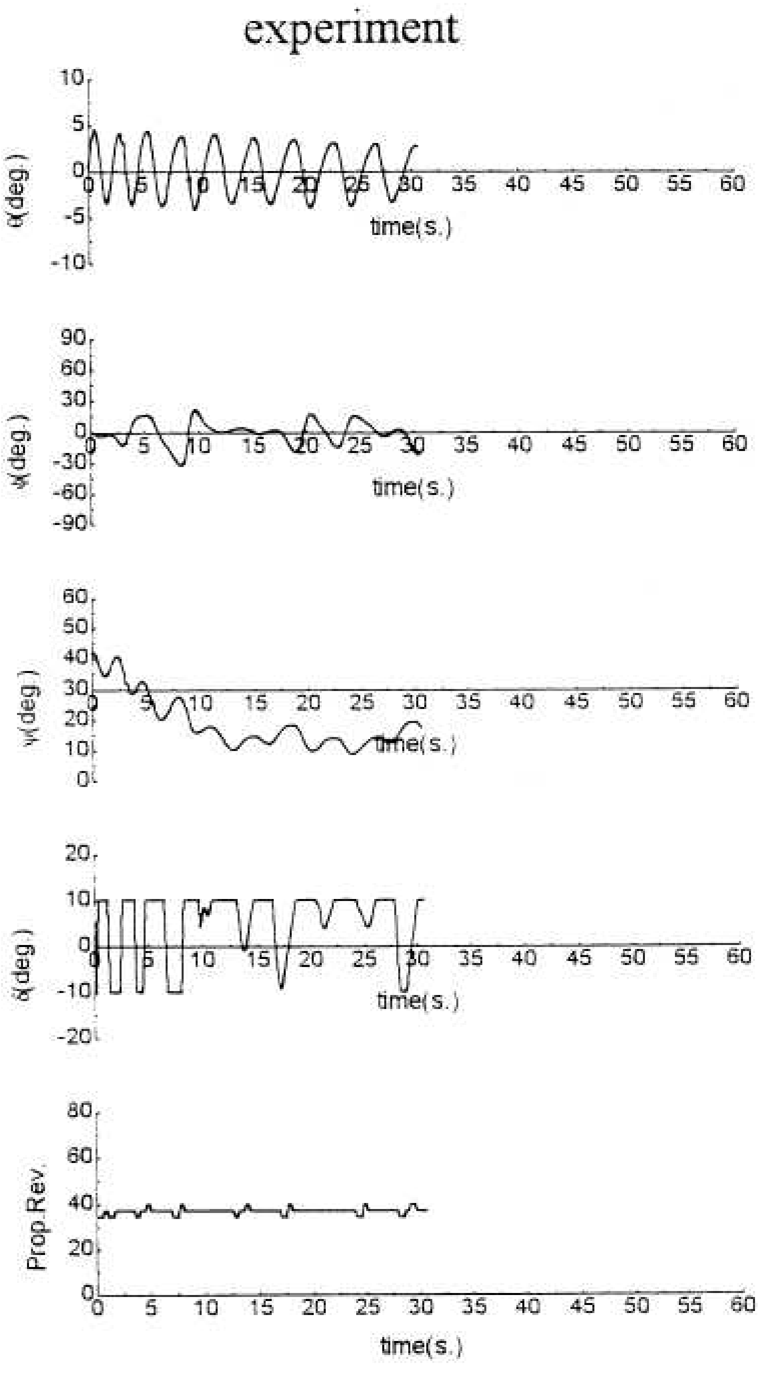


Fig. 6 Measured time history of the free-running model run of the ship A-1 in model scale (λ/L_{pp}=1.5 H/λ=1/25, F_n=0.3 χ_c=30 degrees)

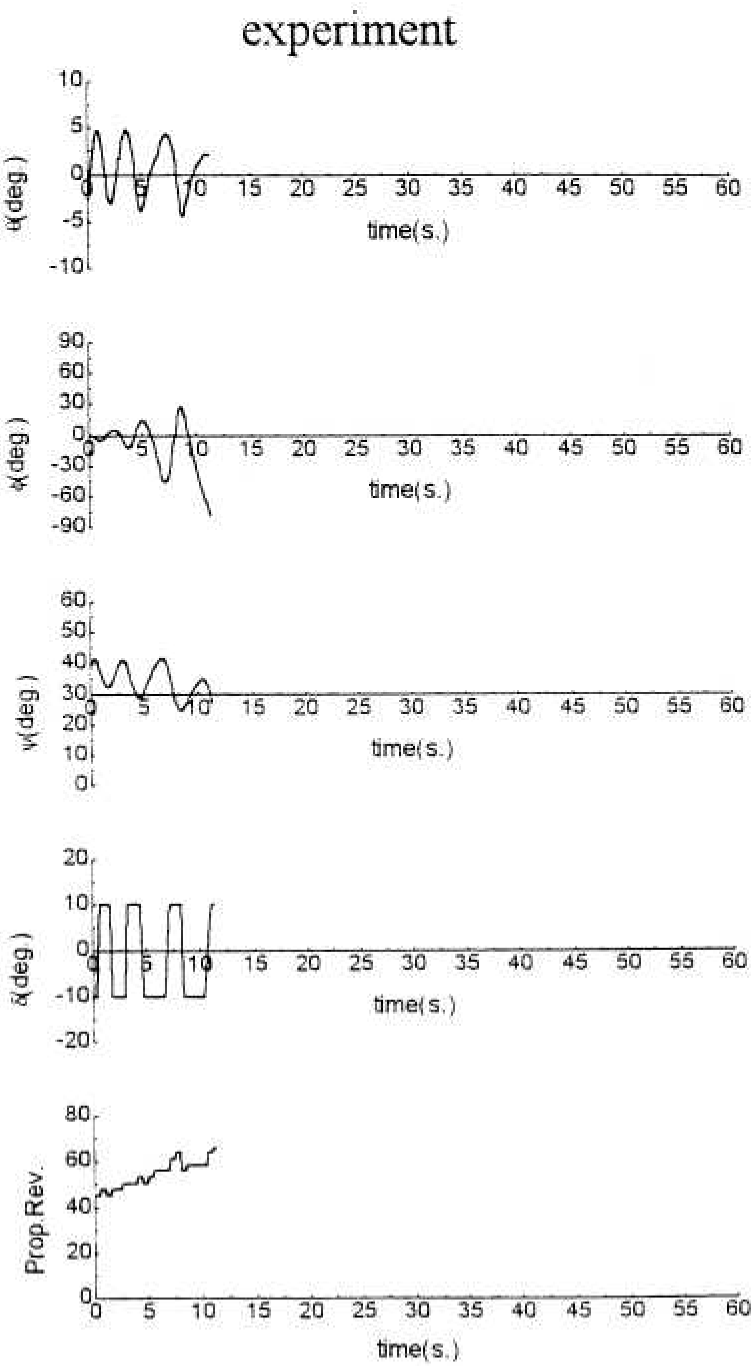


Fig. 7 Measured time history of the free-running model run of the ship A-1 in model scale (λ/L_{PP}=1.5 H/λ=1/25, F_n=0.4 χ_c=30 degrees)

12

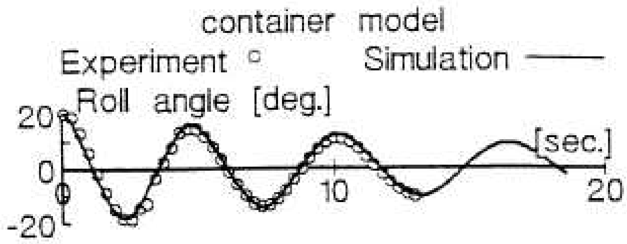


Fig. 8 Roll decay test of the ship A-1 in model scale without forward velocity

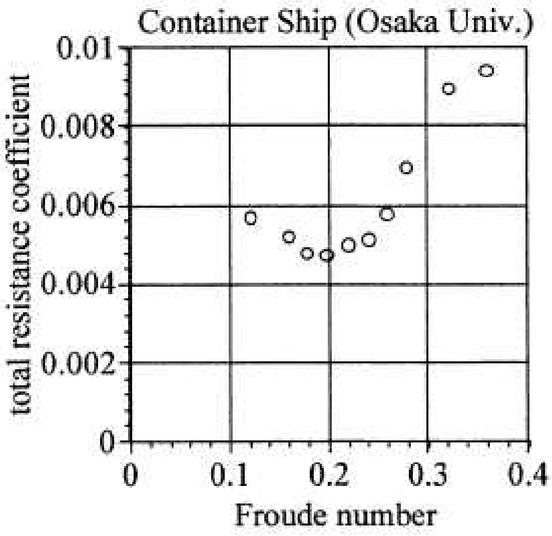


Fig. 9 Measured total resistance coefficient, C_T, as the function of the Froude number, F_n, obtained from the resistance test of the ship A-1

$$C_T = \frac{R}{\frac{1}{2}\rho U^2 S} \qquad F_n = \frac{U}{\sqrt{L_{PP} g}}$$

where R : ship resistance and U : ship forward velocity.

13

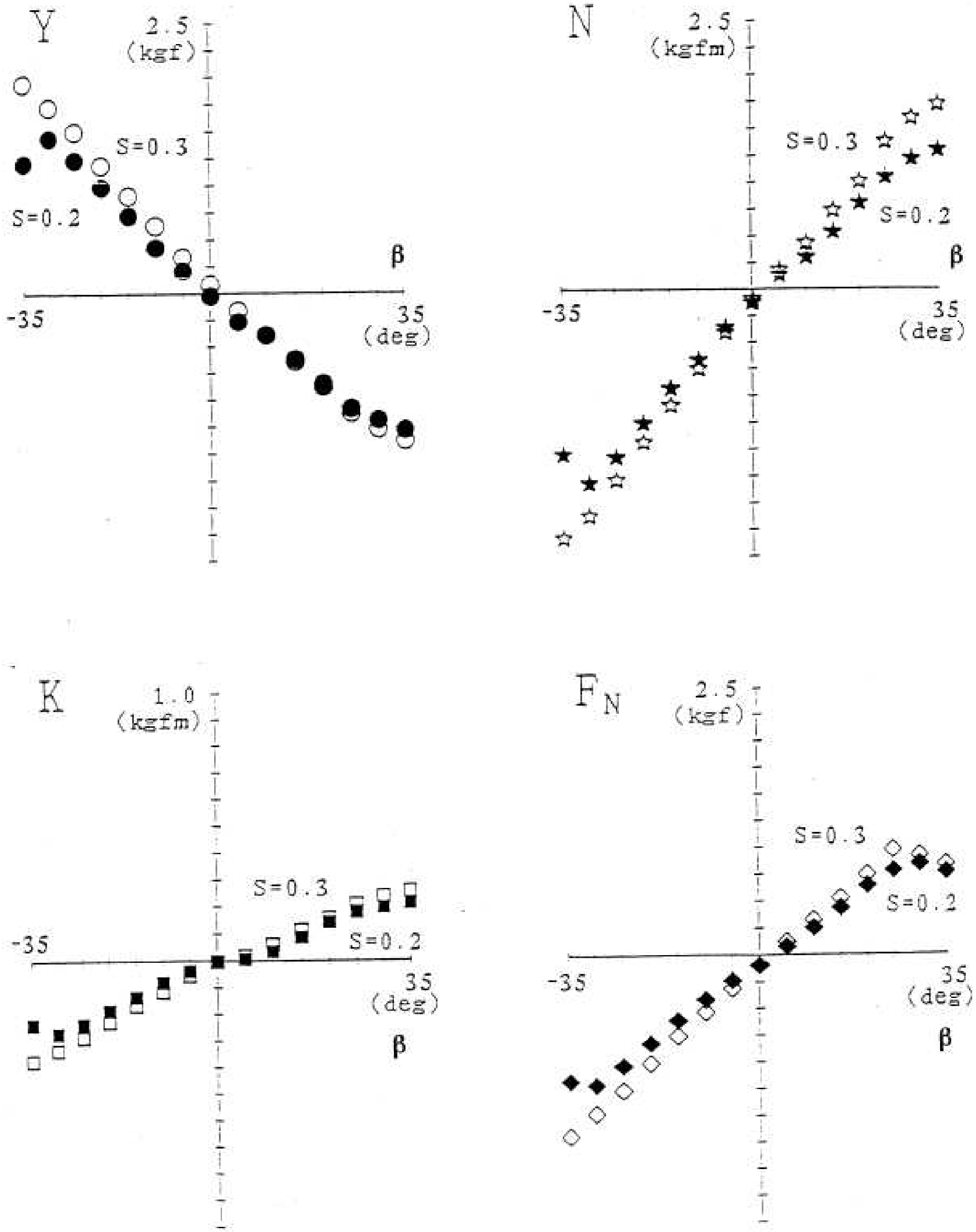


Fig. 10 Results of the rudder angle tests of the ship A-1 at Fn=0.242 in model scale where s : the propeller slip ratio $(s = 1 - U_A/(nP))$, U_A : propeller advance velocity, ρ : water density.

14

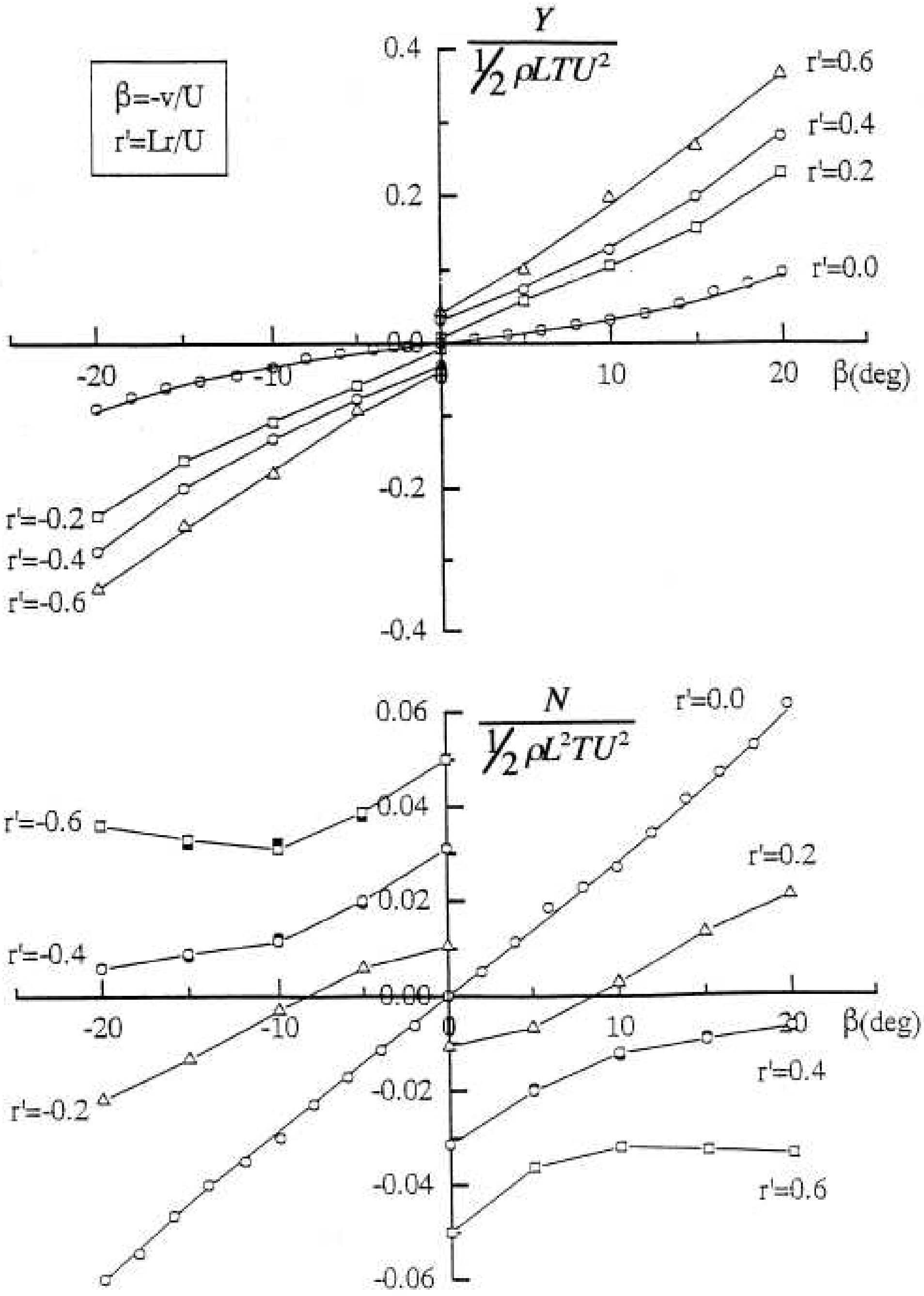
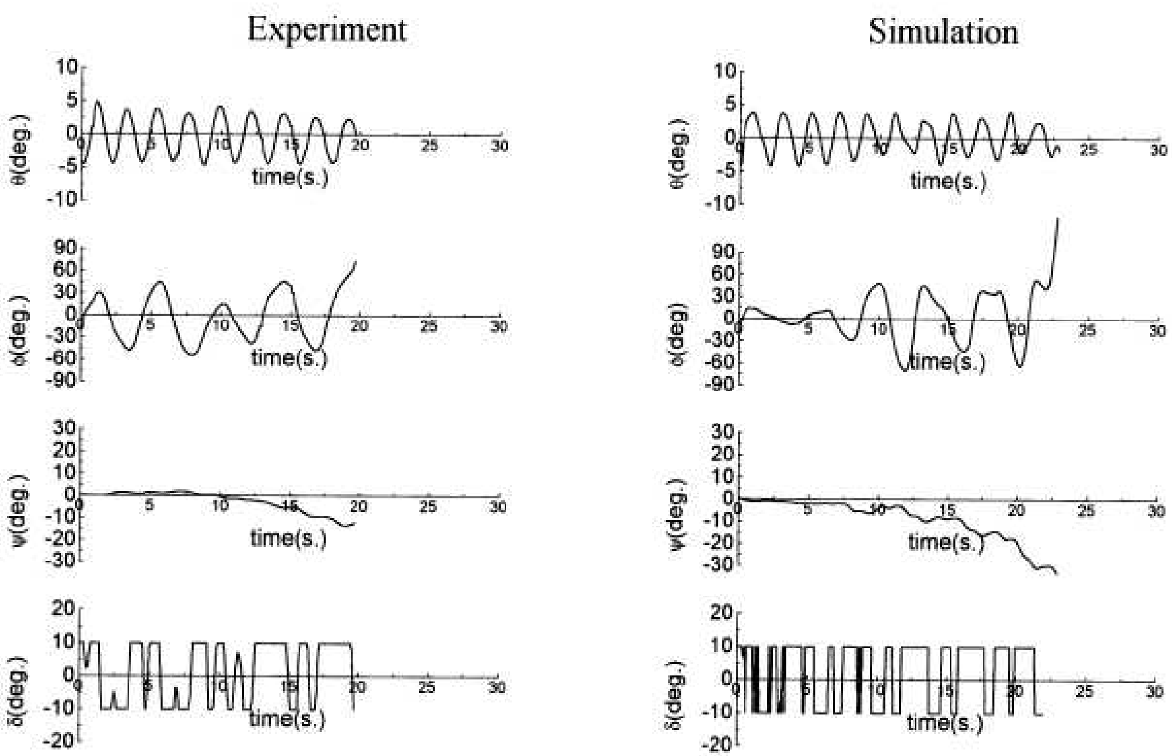


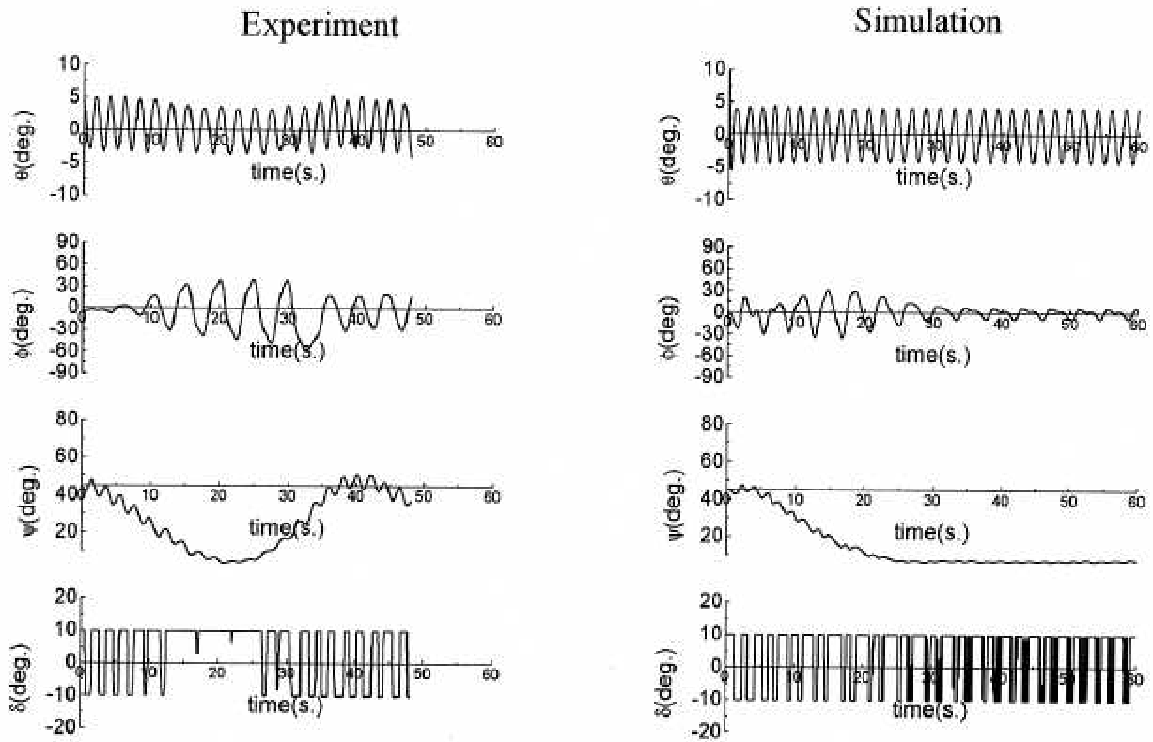
Fig. 11 Results of the circular motion tests of the ship A-1 at Fn=0.242 where L : ship length between perpendiculars and v : ship lateral velocity

15



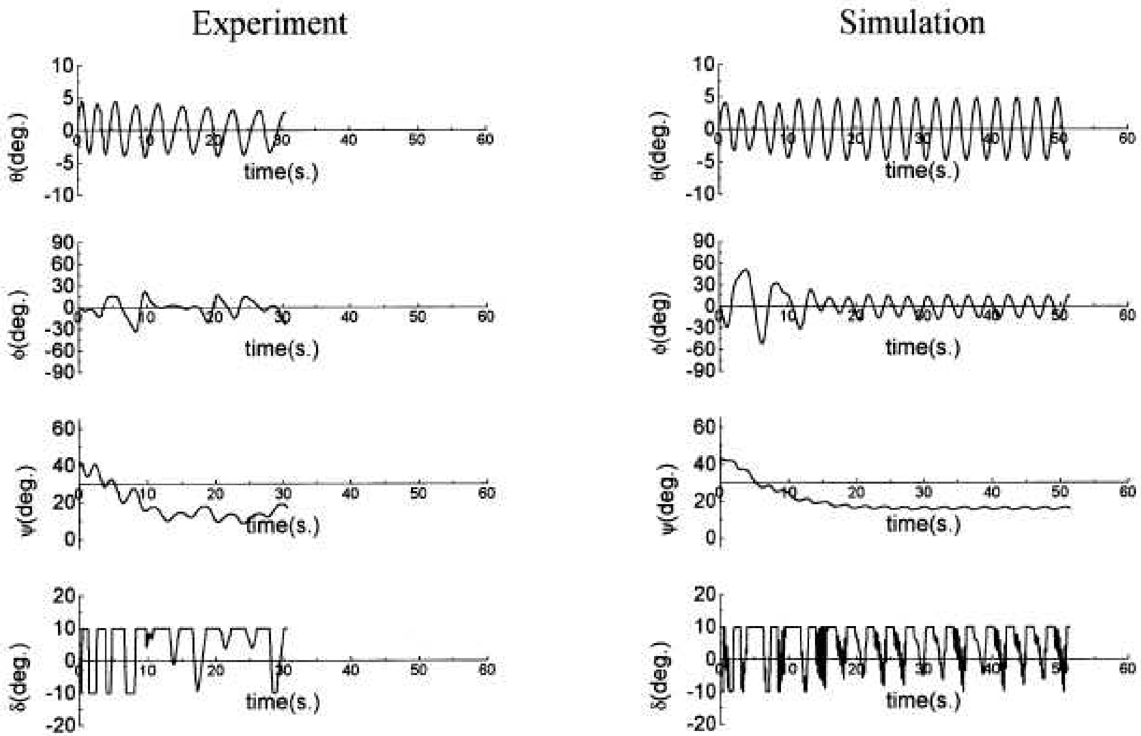
GM=0.15m, $\lambda/L=1.5$, $H/\lambda=1/25$, Fn=0.2 and $\chi=0^o$

Fig. 12 Comparison between the experiment and the numerical code of Osaka University (Munif, et al. 2000) for the ship A-1 in model scale



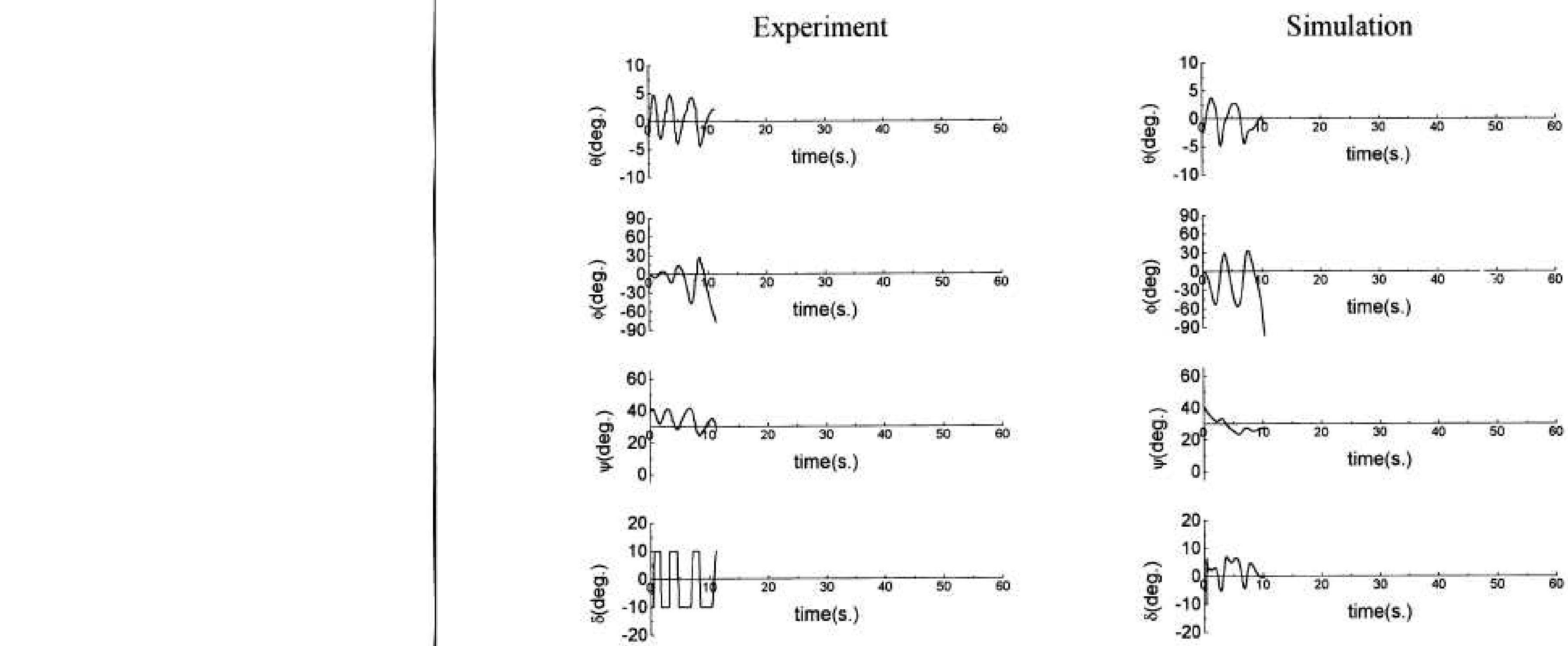
GM=0.15m, $\lambda/L=1.5$, $H/\lambda=1/25$, Fn=0.2 and $\chi=45^{\circ}$

Fig. 13 Comparison between the experiment and the numerical code of Osaka University (Munif, et al. 2000) for the ship A-1 in model scale



GM=0.15m, $\lambda/L=1.5$, $H/\lambda=1/25$, Fn=0.3 and $\chi=30^{o}$

Fig. 14 Comparison between the experiment and the numerical code of Osaka University (Munif, et al. 2000) for the ship A-1 in model scale



GM=0.15m, λ/L=1.5, H/λ=1/25, Fn=0.4 and χ=30°

Fig. 15 Comparison between the experiment and the numerical code of Osaka University (Munif, et al. 2000) for the ship A-1 in model scale

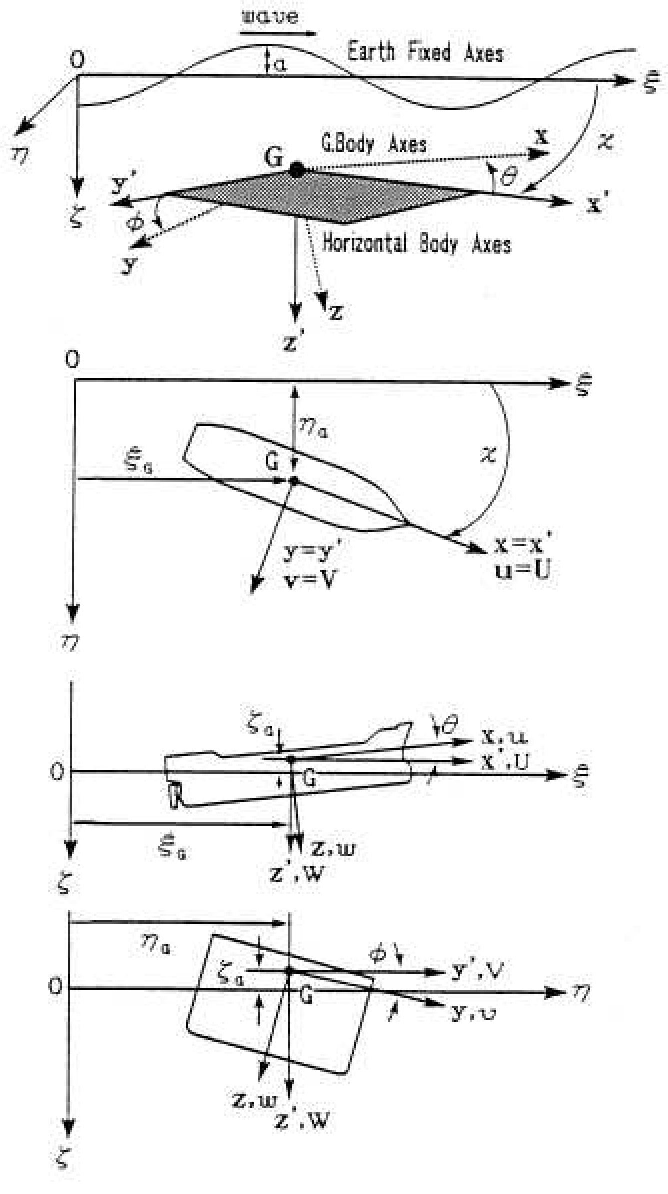


Fig. 16 Co-ordinate systems

Offset data of the container ship
prepared by Osaka University, Japan.


```
21 /number of transverse sections
(AP section)
  10,-75.0     /number of sample points at this station, position of this section in x
 0.000,  8.000  /Sample points (y & z)
 4.810,  9.000
 7.700, 10.000
 9.540, 11.000
10.900, 12.000
11.940, 13.000
12.820, 14.000
13.600, 15.000
13.600, 15.900
13.600, 16.300
(1/4 section)
  11,-71.25
 0.000,  7.200
 2.700,  8.000
 6.140,  9.000
 8.540, 10.000
10.200, 11.000
11.430, 12.000
12.340, 13.000
13.170, 14.000
13.600, 15.000
13.600, 15.900
13.600 16.300
(2/4  section)
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```
  19,-67.5
 0.100,  0.000
 0.550,  0.500
 0.820,  1.000
 1.080,  2.000
 1.180,  3.000
 1.250,  4.000
 1.400,  5.000
 1.810,  6.000
 2.960,  7.000
 4.980,  8.000
 7.400,  9.000
 9.340, 10.000
10.750, 11.000
11.900, 12.000
12.750, 13.000
13.420, 14.000
13.600, 15.000
13.600, 15.900
13.600, 16.300
(3/4 section)
  19,-63.75
 0.500,  0.000
 1.206,  0.500
 1.552,  1.000
 2.006,  2.000
 2.320,  3.000
 2.700,  4.000
 3.170,  5.000
 3.900,  6.000
 5.200,  7.000
 6.750,  8.000
 8.520,  9.000
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```
10.100, 10.000
11.310, 11.000
12.300, 12.000
13.050, 13.000
13.600, 14.000
13.600, 15.000
13.600, 15.900
13.600, 16.300
(1 section)
  18,-60.0
 0.920,  0.000
 1.950,  0.500
 2.470,  1.000
 3.140,  2.000
 3.658,  3.000
 4.200,  4.000
 4.800,  5.000
 5.720,  6.000
 6.960,  7.000
 8.210,  8.000
 9.550,  9.000
10.800, 10.000
11.800, 11.000
12.700, 12.000
13.310, 13.000
13.600, 14.000
13.600, 15.000
13.600, 15.900
13.600, 16.300
(1+1/2 section)
  19,-52.5
 2.000,  0.000
 3.635,  0.500
```

```
 4.356,  1.000
 5.391,  2.000
 6.215,  3.000
 6.994,  4.000
 7.792,  5.000
 8.619,  6.000
 9.474,  7.000
10.323,  8.000
11.200,  9.000
12.000, 10.000
12.700, 11.000
13.250, 12.000
13.600, 13.000
13.600, 14.000
13.600, 15.000
13.600, 15.900
13.600, 16.300
(2 section)
  16,-45.0
 3.482,  0.000
 5.641,  0.500
 6.501,  1.000
 7.722,  2.000
 8.642,  3.000
 9.435,  4.000
10.142,  5.000
10.778,  6.000
11.400,  7.000
11.950,  8.000
12.450,  9.000
12.880, 10.000
13.270, 11.000
13.580, 12.000
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```
13.600, 13.000
13.600, 13.500
(2+1/2 section)
 16,-37.5
 5.519,  0.000
 7.713,  0.500
 8.640,  1.000
 9.874,  2.000
10.740,  3.000
11.406,  4.000
11.940,  5.000
12.360,  6.000
12.697,  7.000
12.980,  8.000
13.211,  9.000
13.570, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(3 section)
  16,-30.0
 7.761,  0.000
 9.656,  0.500
10.528,  1.000
11.636,  2.000
12.296,  3.000
12.780,  4.000
13.037,  5.000
13.237,  6.000
13.384,  7.000
13.483,  8.000
13.555,  9.000
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```
13.600, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(3+1/2 section)
  16,-22.5
 9.805,  0.000
11.317,  0.500
11.998,  1.000
12.801,  2.000
13.195,  3.000
13.403,  4.000
13.520,  5.000
13.578,  6.000
13.600,  7.000
13.600,  8.000
13.600,  9.000
13.600, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(4 section)
  16,-15.0
11.194,  0.000
12.450,  0.500
12.955,  1.000
13.443,  2.000
13.578,  3.000
13.600,  4.000
13.600,  5.000
13.600,  6.000
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13.600,  7.000
13.600,  8.000
13.600,  9.000
13.600, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(5 section; midship)
  16,0.0
11.800,  0.000
13.045,  0.500
13.412,  1.000
13.600,  2.000
13.600,  3.000
13.600,  4.000
13.600,  5.000
13.600,  6.000
13.600,  7.000
13.600,  8.000
13.600,  9.000
13.600, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(6 section)
  16,15.0
10.150,  0.000
11.783,  0.500
12.439,  1.000
13.180,  2.000
13.470,  3.000
```

```
13.572,  4.000
13.600,  5.000
13.600,  6.000
13.600,  7.000
13.600,  8.000
13.600,  9.000
13.600, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(6+1/2 section)
  16,22.5
 8.338,  0.000
10.554,  0.500
11.368,  1.000
12.396,  2.000
12.957,  3.000
13.268,  4.000
13.442,  5.000
13.534,  6.000
13.580,  7.000
13.600,  8.000
13.600,  9.000
13.600, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(7 section)
  16,30.0
 6.286,  0.000
 8.921,  0.500
```

```
 9.891,  1.000
11.169,  2.000
11.948,  3.000
12.477,  4.000
12.856,  5.000
13.120,  6.000
13.296,  7.000
13.425,  8.000
13.510,  9.000
13.579, 10.000
13.600, 11.000
13.600, 12.000
13.600, 13.000
13.600, 13.500
(7+1/2 section)
  16,37.5
 4.170,  0.000
 7.019,  0.500
 8.082,  1.000
 9.487,  2.000
10.386,  3.000
11.050,  4.000
11.573,  5.000
12.007,  6.000
12.359,  7.000
12.656,  8.000
12.713,  9.000
13.152, 10.000
13.373, 11.000
13.510, 12.000
13.595, 13.000
13.600, 13.500
(8 section)
```

```
  16,45.0
 2.398,  0.000
 5.088,  0.500
 6.117,  1.000
 7.389,  2.000
 8.239,  3.000
 8.889,  4.000
 9.425,  5.000
 9.918,  6.000
10.390,  7.000
10.870,  8.000
11.359,  9.000
11.862, 10.000
12.380, 11.000
12.920, 12.000
13.370, 13.000
13.470, 13.503
(8+1/2 section)
  17,52.5
 1.235,  0.000
 3.377,  0.500
 4.239,  1.000
 5.211,  2.000
 5.740,  3.000
 6.122,  4.000
 6.455,  5.000
 6.933,  6.000
 7.429,  7.000
 8.020,  8.000
 8.726,  9.000
 9.541, 10.000
10.500, 11.000
11.500, 12.000
```

```
12.250, 13.000
12.600, 13.522
12.900, 14.000
(9 section)
  20,60.0
 0.576,  0.000
 2.000,  0.500
 2.620,  1.000
 3.246,  2.000
 3.461,  3.000
 3.554,  4.000
 3.648,  5.000
 3.816,  6.000
 4.123,  7.000
 4.627,  8.000
 5.378,  9.000
 6.377, 10.000
 7.630, 11.000
 8.950, 12.000
10.150, 13.000
11.250, 14.000
12.100, 15.000
12.800, 16.000
13.200, 17.000
13.300, 17.108
(9+1/2 section)
  20,67.5
 0.231,  0.000
 0.990,  0.500
 1.350,  1.000
 1.720,  2.000
 1.823,  3.000
 1.790,  4.000
```

```
 1.680,  5.000
 1.520,  6.000
 1.470,  7.000
 1.660,  8.000
 2.147,  9.000
 3.030, 10.000
 4.200, 11.000
 5.570, 12.000
 6.940, 13.000
 8.150, 14.000
 9.250, 15.000
10.300, 16.000
11.250, 17.000
11.400, 17.150
(FP section)
  21,75.0
 0.100,  0.000
 0.340,  0.500
 0.580,  1.000
 0.900,  2.000
 1.040,  3.000
 0.970,  4.000
 0.790,  5.000
 0.490,  6.000
 0.220,  7.000
 0.080,  8.000
 0.080,  9.000
 0.100, 10.000
 0.580, 11.000
 1.500, 12.000
 2.710, 13.000
 3.900, 14.000
 5.230, 15.000
```

```
6.600, 16.000
7.900, 17.000
8.200, 17.219
9.200, 18.000
```