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Seakeeping qualities of open-top containerships

SUMMARY

This paper presents the works carried out within the scope of the Applied Research Project entitled „Large Open-top Containerships". The research and development part of the project was realized by Ship Hydromechanics Division (OHO), Ship Design and Research Centre (CTO) for the benefit of the Szczecin Shipyard. It concerned first of all the hull form optimization taking into account resistance/ propulsion as well as manoeuvring and seakeeping qualities of the ships. Structural calculations and design of certain on-board systems were also included into the project.

This paper is focused on seakeeping qualities prediction based on model tests and numerical calculations of two ships. The tests were carried out in regular and irregular waves according to IMO recommendations concerning open-top containerships.

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INTRODUCTION

The introduction of a new ship type - open-top containership - was the stimulus for International Maritime Organisation (IMO) to prepare „Interim Guidelines for Open-top Containerships" - circular No MSC/608 [1]. According to it an open-top containership is *„every containership especially designed so that one or more of the cargo holds need not be fitted with hatch covers"*. Among many guiding rules of that circular a quite detail procedure for carrying out model tests of seakeeping qualities, the most important parameters of tests or recommendations on their selection and a criterion for assessment of ingress rate of green water into holds can be found. The main requirements of the test procedure and test parameters are the following according to [1] :

- selection of irregular wave spectrum and period for the given significant height of 8.5 m
- minimum scope of tests: five directions of waves (i.e. five model headings to waves) :
  - following seas (0^0)
  - quarter following seas ($45^0/315^0$)
  - beam seas ($90^0/270^0$)
  - quarter head seas ($135^0/225^0$)
  - head seas (180^0)
- determination of model speed for each heading
- characteristics and method of model guidance during test runs
- recommended loading condition
- determination of the holds most prone to green water ingress
- preparation of the model and measuring devices to record motions, accelerations and amount of green water entering the chosen holds.

Criterion for green water ingress rate assessment :

Hourly rate of green water ingress into any one open hold determined from model tests should not exceed the hatch opening area multiplied by 400 mm/hour (full scale).

To fulfil the programme recommended by the IMO one must have access to a special seakeeping basin, where waves from the directions of 45^0, 135^0, 225^0 and 315^0 can be generated. Neither the Division nor any other laboratory in Poland has such a facility. Therefore an alternative programme of investigation of seakeeping qualities of open-top containerships, combining model tests with numerical calculation, was devised at the Division.

The proposal of the Ship Hydromechanics Division (OHO), Ship Design and Research Centre (CTO) is the following :

- model tests for waves directions 0^0, 20^0, 90^0, 160^0, 180^0
- numerical calculation (by means of WARES program [2]) for the wave directions 0^0, 20^0, 45^0, 90^0,135^0, 160^0, 180^0
- calculation of green water ingress rate for chosen open holds for quarter following (45^0) and quarter head (135^0) seas based on the above-mentioned tests and calculations.

In 1995 the OHO-CTO, became the main contractor to carry out R&D works included in the scope of the Applied Research Project entitled „Large Open-top Containerships"on the basis of a contract with the State Committee for Scientific Research and the Szczecin Shipyard. An extensive programme of seakeeping model tests and numerical calculations for two open-top containerships was included in the R&D works in the field of hydromechanics apart from resistance/propulsion optimization.

DATA OF INVESTIGATED SHIPS

The models of two ships [3],[4] of different size were investigated. The smaller one was tested in two versions of superstructure location : aft or fore.

For seakeeping tests special models were used of a smaller scale than that applied in resistance/propulsion tests.

Ship's project No.			9296-PA	9297-PA
Model No.			M469	M459-A
Model scale factor			34.0	40.0
Length between perpendiculars	L	[m]	164.56	192.0
Breadth moulded	B	[m]	30.6	32.2
Draught: fore	T_F	[m]	9.77	12.38
aft	T_A	[m]	10.13	12.44
Displacement volume	∇	[m³]	33 071.0	46 806.2
Transverse metacentric height	GM	[m]	1.02	1.06
Longitudinal relative radius of gyration	k_{yy}/L	[-]	0.25	0.25
Transverse relative radius of gyration	k_{xx}/B	[-]	0.40	0.40
Natural period of roll	T_Φ	[s]	24.2	25.0
Service speed	V	[knots]	20.0	21.5

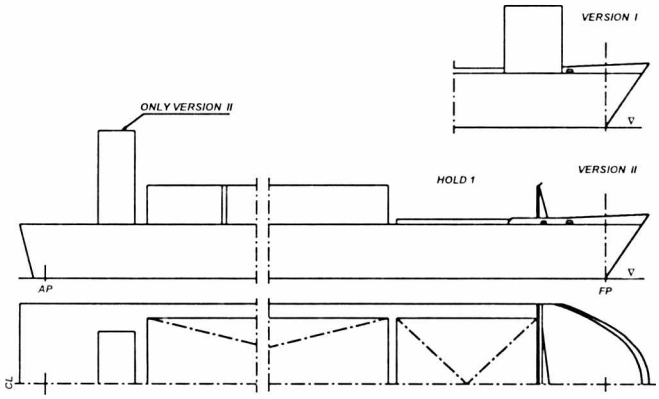

Fig.1. Model M469, hull above design waterline

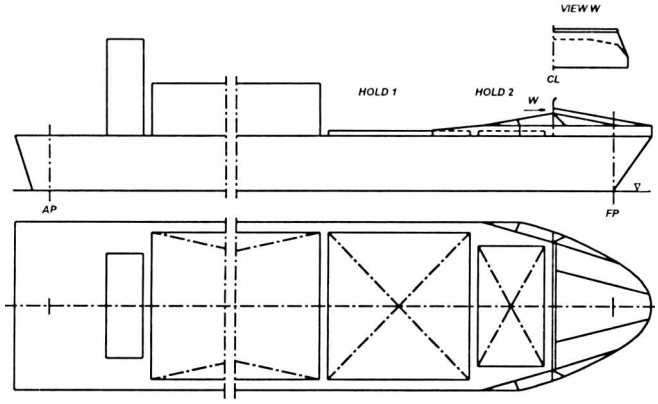

Fig.2. Model M459-A, hull above design waterline

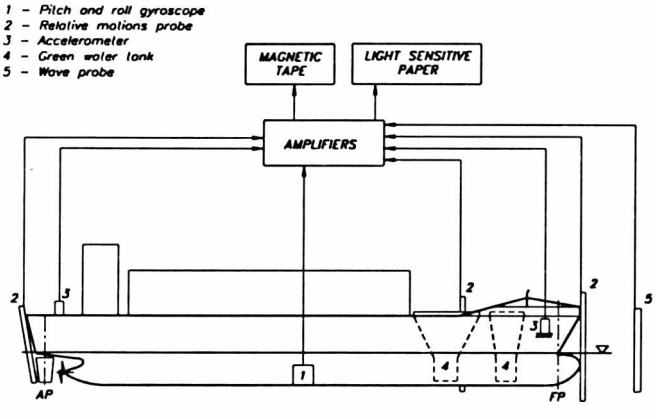

Fig.3. Scheme of the measuring system (model M459-A)

MODEL TESTS AND NUMERICAL CALCULATIONS

Seakeeping model tests were carried out according to the IMO procedure [1].

- The programme included tests in two long-crested irregular waves of the significant height of 8.5 m. The wave W1 of the shorter characteristic period of $\overline{T}_{01}$ = 11s was considered on the basis of the Division's experience to be less favourable from the point of view of seakeeping qualities. The introduction of the second wave (W2) of a longer period ($\overline{T}_{01}$ = 12.5 s) enabled to check the influence of period change on ship performance in beam seas. The tank waves corresponded to sea state 7 (Beaufort Scale No 11) in North Atlantic. Both waves were determined by means of the Pierson-Moskovitz spectral density function of wave energy.
- The scope of tests consisted of five wave directions. Because of technical limitations (12 m breadth of the towing tank) the direction of oblique seas was 20°/340° for following seas and 160°/200° for head seas. During numerical calculations quartering seas of 45°/315° and 135°/225° were also taken into account.
- The model speed in head and quarter head seas was determined as follows :
  According to [1] the ship speed in head seas was determined only with regard to resistance increase in regular waves. Resistance tests in calm water and regular waves were carried out. The determined resistance increments were used to calculate resistance in irregular waves which yielded the rough sea speed of 12 and 15 knots for ships 9296-PA and 9297-PA respectively.
  Additionally the influence of ship speed in head seas (180°) was investigated by carrying out tests in regular wave at two speeds (the one mentioned above and that decreased by two knots). In following seas the speed equal to 1/3 of service speed was assumed. In beam seas the speed was zero according to [1].
- The models, in order to be prepared for seakeeping tests, were equipped with decks, superstructures, bulwarks, bilge keels and other elements which might influence the investigated phenomena. The models were self-propelled and equipped with an autopilot and had six degrees of freedom. The influence of security ropes on model motion was negligible. During tests in oblique seas it was necessary to change model heading by 40° several times because of the limited breadth of the towing tank. Only the rectilinear fragments of test runs were used during the analysis of test results.
- Loading conditions of the tested models were accepted by the shipyard: displacement was close to the design one, small trim by the stern, metacentric height slightly above 1.0 m.
- The fore hold of the ship 9296-PA and the two fore holds of the ship 9297-PA were assumed to be the most prone to green water ingress. The remaining hatches were covered with a wall simulating piles of containers protruding from holds.
- The model was provided with equipment to measure roll, pitch, accelerations, probes to determine relative motions and the holds were equipped with a system to collect green water.

Model tests in irregular waves carried out according to [1] and additional tests in regular waves were supplemented with a numerical, short-term prediction of seakeeping qualities. The calculations were performed with the use of theWARES program. The input data (wave characteristics and directions, speed, loading conditions etc.) corresponded to the values used during the model tests. The program calculated amplitudes and periods of the quantities measured during model tests as well as several others, apart from green water ingress rate, assessment of which was based on calculated probability values of green water ingress onto deck at some fixed points.

Results of the model and numerical tests were used to calculate the ingress rate of green water into holds for quartering seas (135° and 45°), included in the IMO guidelines, but not modelled during experiments. The following assumptions were made :

- linear dependence of the ingress rate and probability of green water ingress onto the deck
- the ratio of measured and calculated relative motions constant at any point of the hull.

RESULTS OF EXPERIMENTS

Selected results of model and numerical tests of the ships [3], [4] are presented in the following tables and figures: Tab.1 - for SHIP 9296-PA, and Tab.2 and Fig.4 to 7 - for SHIP 9297-PA.

Ingress of green water into open holds

PREDICTION BASED ON RESULTS OF TESTS IN IRREGULAR WAVES AND COMPUTATIONS

During the tests in irregular waves the green water ingress into hold No 1 was only observed. The maximum hourly rates of ingress h_{gw} defined as the green water volume per 1 hour V_{gw} divided by the hatch opening area (670 m^2 for SHIP 9296-PA and 290 m^2 for SHIP 9297-PA) are presented in Tab.1 and Tab.2 for the first and second ship respectively.

Tab.1. SHIP 9296-PA

Test No	Wave direction [°]	Speed [knots]	V_{gw} [m^3/h]	h_{gw} [m/h]
8107	180	12.0	103.6	0.155
8108	160	12.0	166.8	0.249
8110	180	12.0	40.2	0.060
8109	160	12.0	34.1	0.051
computation	135	12.0	42.2	0.063
8113	270	0	0	0
8114	270	0	0	0
computation	45	7.0	0	0
8112	20	7.0	0	0
8111	0	7.0	0	0

Tab.2. SHIP 9297-PA

Test No	Wave direction [°]	Speed [knots]	V_{gw} [m/h]	h_{gw} [m/h]
8057	180	15.0	60	0.21
8058	160	15.0	60	0.21
computation	135	15.0	33	0.11
8063	270	0	0	0
computation	45	7.0	0	0
8062	20	7.0	0	0
8061	0	7.0	0	0

The computations are based on measurement results of relative motions and green water ingress and numerical computation results of relative motions obtained from WARES software. Linear dependence between deck wetness probability and green water ingress was assumed. The ratio of measured to computed values of relative motions was assumed constant. The result for SHIP 9296-PA at wave direction 135° was computed for the second version of deck arrangement (deckhouse aft, wave breaker fore).

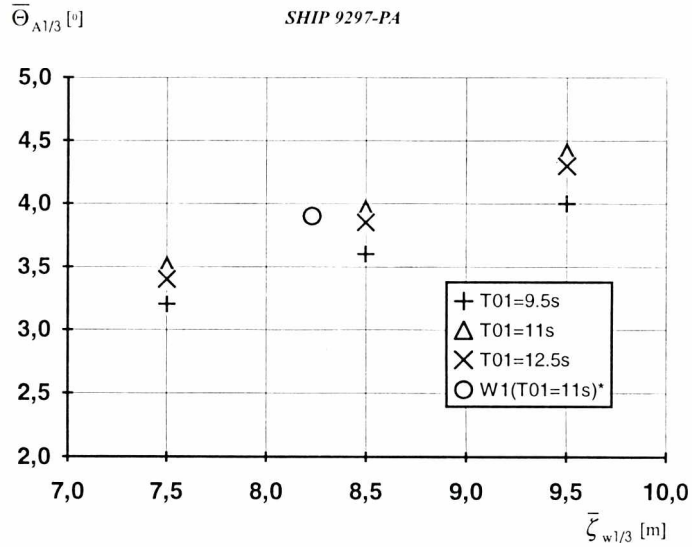

Fig.4. Pitching prediction based on results of test in regular head waves (test No 8065, ship speed 15 knots)

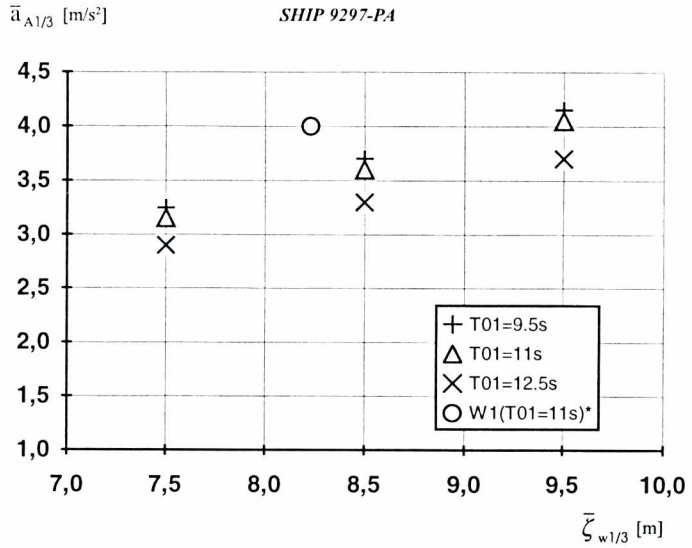

Fig.5. Vertical acceleration at forepeak - prediction based on results of test in regular head waves (test No 8065, ship speed 15 knots)

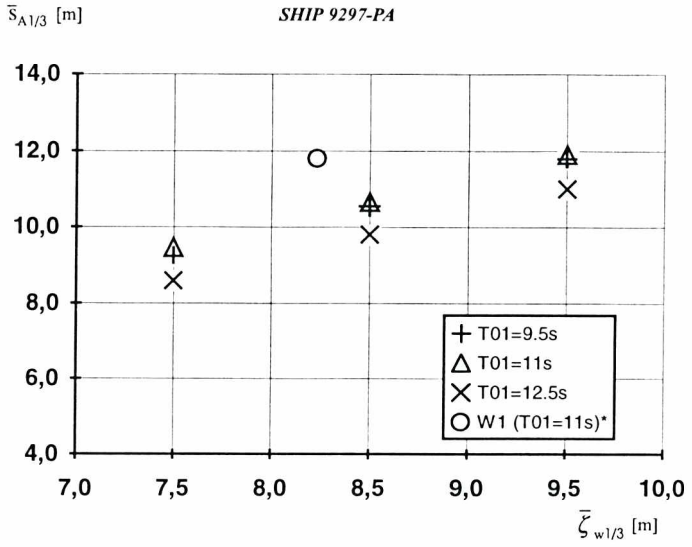

Fig.6. Relative bow motions prediction based on results of test in regular head waves (test No 8065, ship speed 15 knots)

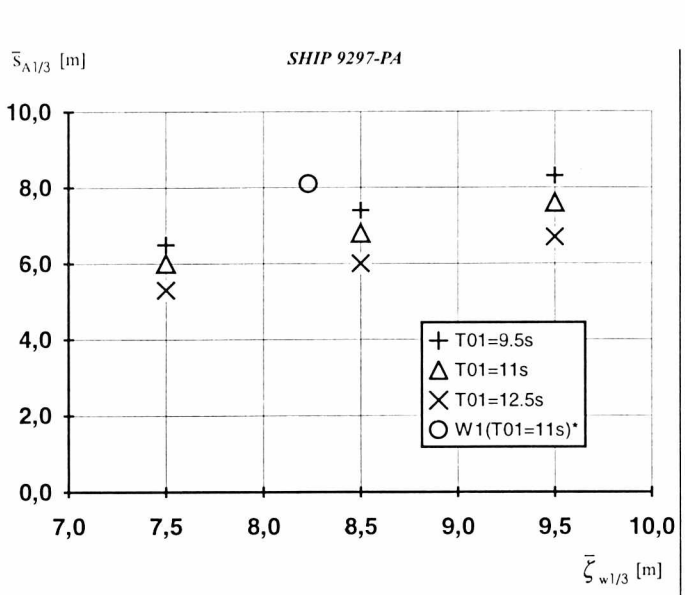

Fig.7. Relative motions at the station No. 16.5 - prediction based on results of test in regular head waves (test No 8065, ship speed 15 knots)

* *Results obtained during test No 8057 in irregular waves (spectral analysis).*

SUMMARY OF RESULTS

The following conclusions can be presented on the basis of the results and observations made during the tests as far as the behaviour of the tested ship in long crested irregular waves is concerned :

SHIP 9296-PA

- The ingress of green water into the first hold was observed in both head waves (180° and 160°) in the case of both deck arrangement versions. The hourly rates of ingress h_{gw} were considerably smaller for the first version of deck arrangement (deckhouse fore). The recorded maximum rate did not exceed the IMO limit value of 400 mm per hour [1]. Whole amount of the green water came from the forebody ahead of the first hold.
- Pitching was noticeable at every wave direction, but did not exceed the recommended limit. Rolling in both beam waves was small (greater in the longer wave W2). Results of roll measurement at the other wave directions were neglected because of disturbances caused by rudder operation.
- The significant amplitudes of vertical acceleration were large in head waves.

Summarizing the tests of the ship in regular waves the following can be concluded in respect to the indicated ranges of wave heights, periods and ship speeds :

- The computed predictions for the measured W1 wave spectrum confirmed generally the results obtained during tests in irregular waves. The amplitudes computed for the smooth ITTC wave spectrum were significantly smaller in any case. Therefore it can be concluded that the tank wave W1 was a worse type of seaway.
- The influence of the wave periods upon the amplitudes of pitch and acceleration was very small, but that upon the relative motions was slightly greater.
- The motions and acceleration grow slowly as the ship speed increases. Pitching is entirely not influenced by ship speed.

SHIP 9297-PA

- Ingress of green water into the first hold was observed in both head waves (180° and 160°). The recorded maximum hourly rate of ingress h_{gw} did not exceed the IMO limit value of 400 mm/h [1].Whole amount of the green water came from the forebody ahead of the first hold.
- Pitching was moderate at every wave direction. Rolling in both beam waves was small (greater in the longer wave W2). Results of roll measurement at the other wave directions were neglected because of disturbances caused by rudder operation.
- The significant amplitude of vertical accelerations did not exceed usually recommended limits.

Summarizing the tests of the ship in regular waves, the following can be concluded in respect to the indicated ranges of wave heights, periods and ship speeds :

- The influence of the wave periods of 9.5 and 11s upon amplitudes of the particular ship responses was not big, but for the period of 12.5 s the amplitudes were smaller (excluding pitching).
- The motions and acceleration grow slowly as the ship speed increases. Pitching is entirely not influenced by ship speed.

RECAPITULATION OF THE INVESTIGATIONS

- The presented model tests and numerical calculations of seakeeping qualities of open-top containerships were carried out second time at the OHO-CTO according to the IMO guidelines [1]. Nearly all requirements of the IMO procedure were adhered to. Additional model and numerical tests were performed in the case of departure from the procedure caused by technical reasons.
- The obtained results (especially those for 9297-PA ship in regular wave) supported the view that the wave of 11s period is less favourable.
- The observations made during test runs confirmed that the holds assumed to be the most prone to green water ingress had been chosen correctly.
- The use of smaller models enabled to measure the resistance increase in regular wave and made model handling during tests easier.
- It is possible to carry out seakeeping tests at the wave directions of 0÷30° and 150÷180° in a typical towing tank.
- It is possible and useful to combine model tests and numerical calculations.
- The combined procedure elaborated by the OHO-CTO is applicable to investigations of the phenomenon of green water ingress into holds of an open-top containership.

NOMENCLATURE

a_A	-	amplitude of linear vertical acceleration
h_{gw}	-	hourly rate of ingress of green water in open hold
S_A	-	amplitude of relative motions at the point considered
T_{01}	-	characteristic wave period
V_{gw}	-	volume of green water per one hour
W1,W2	-	long-crested irregular waving
Θ_A	-	pitch amplitude
ζ_w	-	wave height

INDICES

" - " over a symbol - average value
"1/3" used as a lower index - significant value

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