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# Prediction of the rare events connected with ship's behaviour in rough seas

SUMMARY

*In the paper results of the model tests are presented of shipping seas on the deck of S-175 containership in irregular waves, carried out by Ship Hydrodynamics Division (OHO) of Ship Design and Research Centre (CTO) as a part of the ITTC-initiated international research project. The project was aimed at elaborating the methodic recommendations for carrying out model tests of the rare events which shipping seas on the deck (deck wetness) is dependent on.*

*The author came to the conclusions contradictory to those established within ITTC. Attention is paid to the experimentally stated, non-linear phenomena which usually are neglected in the computerized calculation methods for ship's behaviour prediction in rough seas, based on the linear mathematical models. It is postulated to take into account the phenomena in the case of numerical simulations of the rare events in the domain of time.*

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## INTRODUCTION

The ship sailing in rough seas is accompanied by many burdensome and unwanted phenomena such as: deck wetness, propeller emergence and bottom slamming. Shipping water on the deck appears especially at the design draught and that close to it when the freeboard takes the lowest values. Propeller emergence and bottom slamming endanger first of all the ship which goes under ballast or not fully loaded when her draught is the lowest. The phenomena of too high intensity can impair ship's safety: her structural integrity, hull tightness or propulsion reliability. Therefore the designer makes efforts to design the ship and the ship master to operate her in such a way as to reduce the hazards as much as possible. The occurrence probability of a hazard is its measure. Hence recommendations are defined in terms of allowable mean frequencies of occurrence of the phenomena. Their values depend on ship's type and kind of the phenomenon in question. For instance the deck wetness probability $p_{WET}$ according to Gerritsma [4] has to fulfil the following inequalities :

- for tankers

$$p_{WET} \leq 0.10 \div 0.12 \tag{1}$$

- for general cargo ships with deck loading

$$p_{WET} \leq 0.05 \div 0.07 \tag{2}$$

On the other hand the deck wetness probability $p_{WET}$ according to Chryssostomidis [2] (at the distance of 0.1L from fore perpendicular-F.P.) and the bottom slamming probability at the distance of 0.2L from F.P. $p_{SLAM}$ have to fulfil the respective inequalities :

$$p_{WET} \leq 0.01 \tag{3}$$

$$p_{SLAM} \leq 0.01 \tag{4}$$

and, if the probabilities are determined by calculations, the energy spectrum of relative motions and their velocities is assumed to be the wide-band spectrum, i.e. the spectrum width parameter ε should be accounted for.

To comply with the above mentioned recommendations the ship designer searches for the most suitable ship's form and the ship master reduces ship's speed or changes ship's course relative to wave direction or uses both means at the same time.

Predicting the rare events is particularly necessary during ship design process if the relevant requirements are included in the ship contract specification. Such predictions for a given ship hull are usually elaborated in relation to ship's loading condition, motion parameters (speed and heading angle relative to waves) and sea state. Sometimes during optimization process they are prepared for different ship forms.

There are two ways of predicting the rarely occuring events: model tests and calculations. Predicting the rare events by using calculations still awakes much doubts in spite of the developments in the theory of the phenomena, numerical methods and computer techniques. It so happens because simple linear models are not adequate enough for their exact mathematical description. That is why not only the designers but also shipowners prefer model tests. Therefore model test methods of rare events applicable to deck wetness are first of all presented in this paper.

# MODEL TEST METHODS OF RARE EVENTS

## ITTC initiatives

International Towing Tanks Conference (ITTC) is the organization which formulates recommendations concerning the methods of model tests in the area of ship hydrodynamics. 18th ITTC recommended the following tentative, standard procedure of model tests of rarely occuring events :

*„Experiments to determine the statistics of rarely occuring events such as slamming and deck wetness in irregular waves should last for a minimum of one hour (full scale equivalent). In comparative tests (e.g. to establish the relative merits of different designs) the wave conditions should be chosen so that a substantial number of events occur."*

The statement is based on only one model test cycle [5] and it was therefore adopted as tentative. For this reason the 18th ITTC recommended as follows :

*„A study aimed at establishing a more soundly based standard for experiments on rarely occurring events should be initiated."*

Seakeeping Committee of 19th ITTC gave response to the recommendation at its first meeting by initiating the collaborative model experiment to which all ITTC members were invited to take part in. Admiralty Research Establishment in Haslar (Great Britain) accepted to serve as a coordinator of the project. Ship Hydrodynamic Division of CTO declared to participate in it.

## Model tests performed by OHO-CTO

Selecting the model was eventually left to decision of the experiment participants. However the organizers preferred the Japanese containership S-175 and British frigate. S-175 containership was used as the standard ship for model testing and calculations of ship motions in waves carried out also within ITTC cooperation. Two versions of the containership's hull forms were assumed: one with low and the other with high forecastle.The frigate was tested at ARE-Haslar; the ITTC tentative recommendations were based on results of the tests.

The existing S-175 containership model with low forecastle was used for the tests carried out by OHO-CTO. The ship's and model main parameters are presented in Tab.1 [6].

*Tab. 1. Main parameters of S-175 ship and model*

| Parameter | | Ship | Model |
|---|---|---|---|
| L | [m] | 175.0 | 3.182 |
| B | [m] | 25.4 | 0.462 |
| D | [m] | 15.4 | 0.280 |
| T | [m] | 9.5 | 0.173 |
| V | [m³] | 24 138.5 | 0.145 |
| L/B | - | 6.89 | |
| B/T | - | 2.67 | |
| $X_B/L \cdot 100$ | - | -1.417 | |
| $X_F/L \cdot 100$ | - | -3.909 | |
| $C_B$ | - | 0.5716 | |
| $C_M$ | - | 0.970 | |
| $z_G$ | [m] | 9.52 | 0.173 |
| $k_{YY}/L$ | - | 0.24 | |
| Model number | | 277 | |
| Model scale | | 55 | |

In Fig.1 the ship's moulded frame sections together with bow and stern profiles are shown.

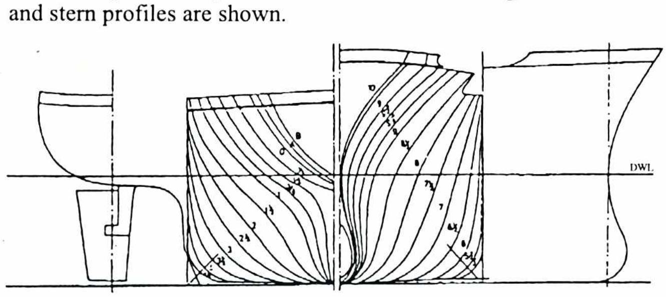


*Fig. 1. Moulded frame sections together with bow and stern profiles of S-175 containership*

The model represented also the overwater part of the ship hull, i.e. that extending to the main deck and forecastle deck line. It was fitted with bulwarks on the forecastle as well as the main deck, rudder and bilge keels. The model had no propeller as it was towed. The model was statically and dynamically balanced to get the required value of the inertia moment of mass around the central transverse axis, $k_{YY}/L = 0.24$.

The test program contained measurements of ship oscillatory motions and shipping water on the deck in one loading condition, at one ship speed corresponding to the Froude number value $F_n = 0.275$, in one sea state approximated by the irregular two-dimensional waves of the energy density spectrum according to ITTC standard and of the following parameters :

- the relative significant wave height $\zeta_{w1/3} / L = 0.045$
- the dimensionless modal period $T_0\sqrt{\frac{g}{L}} = 3.50$,

in head seas only.

The total minimum on-run time for the model should correspond to 1 hour in nature. That is 485.4 s in the model scale. The time of one model run over 30 m measurement length of the auxiliary towing tank of OHO-CTO was as follows :

$$t = \frac{l}{V} = \frac{30}{1.536} = 19.5\ s \tag{5}$$

Therefore the minimum number of runs (samples) was :

$$n_{\min} = Int\left(\frac{485.4}{19.5}\right) + 1 = 25 \tag{6}$$

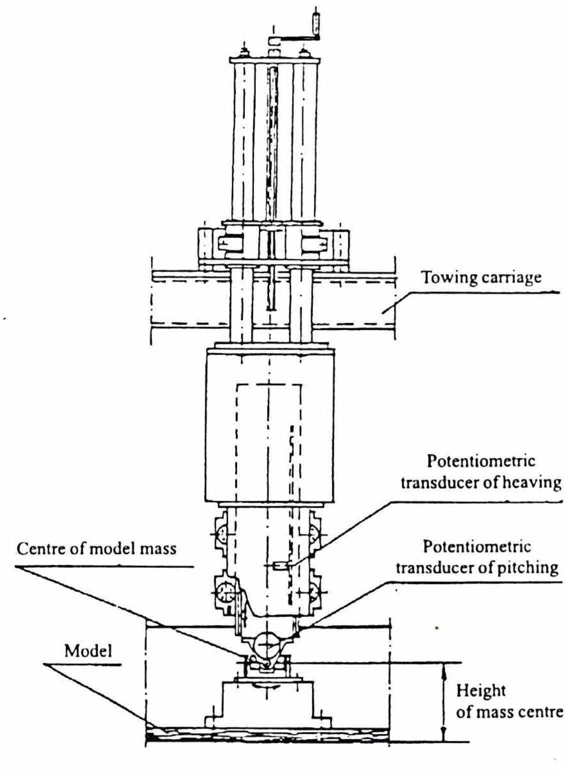


*Fig. 2. OPN-86 model guiding device suitable for simultaneous measurement of heaving, pitching and hull resistance*

The model was guided under the carriage by means of the OPN-86 device shown in Fig.2, which, fitted so as to get pitching axis passing through the model mass centre, allows for two degrees of freedom of the model during its oscillating motions: heaving and pitching, apart from uniform translational motion with the speed equal to that of the towing carriage.

The following magnitudes were measured:

- the towing carriage speed equal to that of the model and steady, by means of the permanent equipment of the carriage
- waves at the towing tank wall, by means of a resistance probe
- waves at the towing carriage in the point situated 2.358 m forward of the model mass centre and 0.810 m apart of the symmetry plane of the model, also by means a resistance probe
- heaving of the model mass centre, by means of the OPN-86 device
- pitching, by means of the OPN-86 device
- absolute vertical displacement of the model point situated on its plane of symmetry in the distance of 0.15 L abaft the F.P., by means of a potentiometric transducer (Fig.3)
- relative vertical motion at 0.15 L abaft the F.P, by means of a resistance probe (Fig.4)
- vertical accelerations of the model point situated on its plane of symmetry 0.15 L abaft the F.P., by means of HMB 1/250-5 accelerонmeter
- the dynamic force applied to the forcastle deck, by means of two HBMQ 11/1 kp force gauges on which the deck was supported.

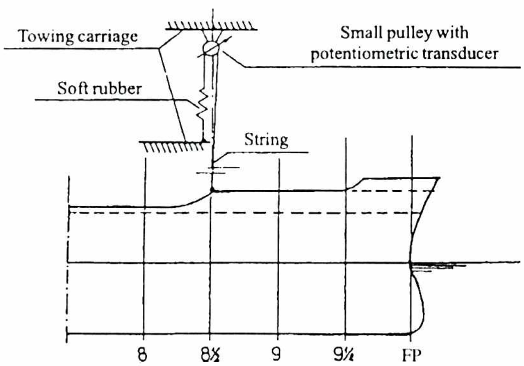


*Fig.3. Measurement scheme of the absolute bow motion*

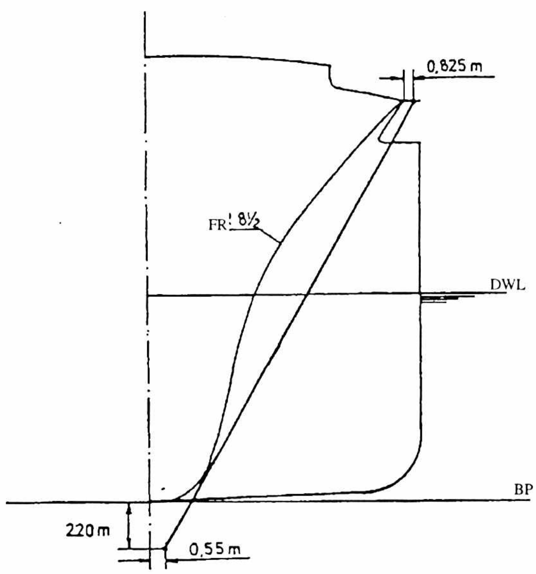


*Fig.4. Wave probe for measuring the relative motion of water*

The measurement method of the dynamic water action on the deck is explained in Fig.5. As the movable, stiffened forcastle deck is of some mass, an inertia force component appears in the force gauges due to changable vertical accelerations of the deck, which disturbs the measured dynamic water action. The problem was settled by including, in counter-phase mode, the signal from the vertical accelerometer fitted under the mass centre of the movable forcastle deck, into the circuit of the total electric signal from the force gauges.

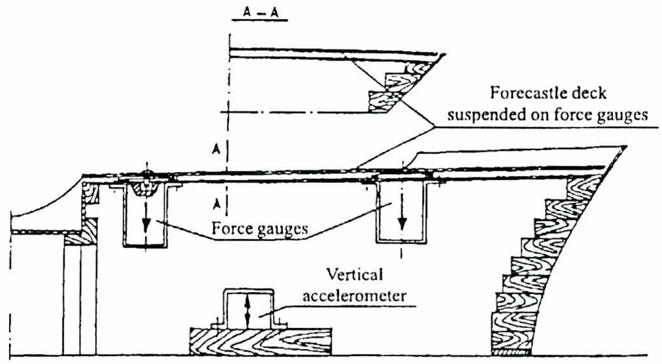


*Fig.5. Sketch of the equipment for measuring the dynamic action of water shipped on the forecastle deck*

Amplification of the accelerometer signal was so selected to obtain the value of measuring system signal close to zero at dry forecastle deck during model pitching. Its value gave an information about measurement error of the dynamic water action; it was not greater than 490 mN (for model).

The measured magnitudes were recorded on the paper tape :

- heaving, pitching, absolute vertical displacements, relative vertical displacements and dynamic water action force - by using a six-channel recorder
- waves in the movable reference system - by a two-channel recorder, and
- waves in the fixed reference system - by a two-channel recorder.

Simultaneously the magnitudes (except of the force and waves in the fixed reference system) were recorded by using a magnetic recorder. Block scheme of the measurment system is shown in Fig.6.

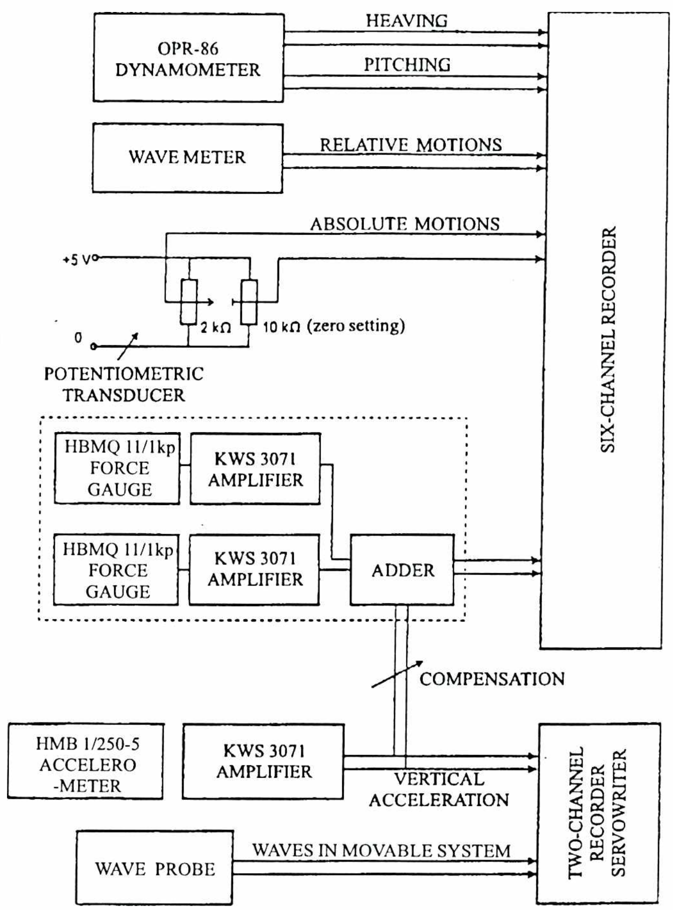


*Fig.6. Block scheme of the measurement system fitted at the towing carriage (inputs of the graphic recorders were included in parallel to the magnetic recorder)*

A double plate, single acting, hydraulic wave maker is installed in the auxiliary towing tank of the OHO-CTO. Two possible modes of controlling the wave maker operation are available: by setting manually twenty harmonic components (the amplitude and phase angle of each harmonic component can be set) or by using a computer-generated electric signal recorded on the magnetic tape [7,8].

The investigations contained 25 samples (model runs) in irregular head waves corresponding to one and the same sea state. To satisfy the investigation target the energy wave spectrum was required to be the same, but waving realizations different. It was not possible to fulfil the requirement exactly, but in an approximate way only: the generated irregular wave system was of an energy spectrum close to that theoretical, however different energy spectra approximating the theoretical spectrum will correspond to different waving realizations. It is desirable that the energy wave spectrum obtained by averaging the spectra from 25 samples would approximate the theoretical spectrum better than the spectra from particular samples.

Wave generating by using the electric signal control would require therefore a set of 25 different control signals to be generated, each providing a different waving realization of theoretically the same, but practically approximate energy spectrum. The solution would be time consuming as the control signal is practically obtained by means of the trial-and-error method on the basis of measurements and analysis of the wave generated by means of the signal. That is why the manual control was selected. The required energy distribution in the spectrum was approximated in consecutive approximation steps by changing the set harmonic component amplitudes at the constant phase shifts of the harmonics. The realized energy spectrum considered as the sufficient approximation of the theoretical spectrum, was obtained in 7th step. Then, 24 sets of phase angle values were generated from $(0 \div 360^{\circ}]$ interval, each of 20 components (i.e. 20 harmonic components of the wave system).

Generating the waves of the assumed characteristics was possible by changing only the phase angles manually.

The recorded waves by using the probe in the movable reference system (on the towing carriage) and in the fixed system (at the tank wall), were processed by means of the computerized spectrum analysis and statistical methods procedures included into the software presented in [7] as well as by means of the manual statistical analysis. Energy spectral diagrams: of the theoretical spectrum, realized in the first run (after seven steps) and of that averaged from 25 runs are presented in Fig.7.

The achieved results cannot be admitted as satisfactory. Especially the average spectrum deviates too much from the theoretical: the maximum value of the spectrum is shifted towards shorter waves. It means that the modal period of the wave system averaged from 25 runs is lower than that of the theoretical waving.

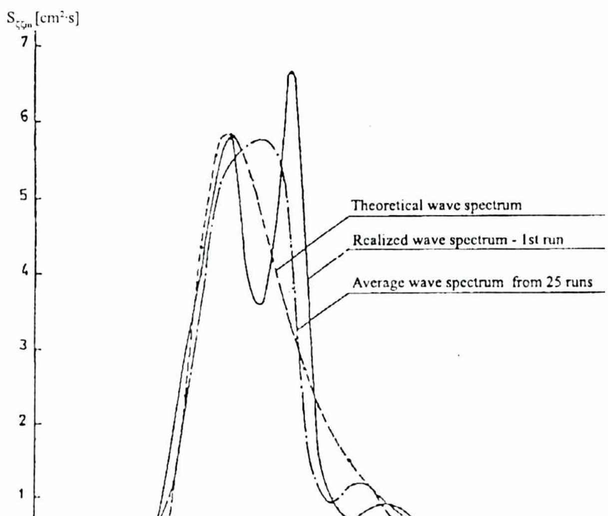


*Fig. 7. The energy wave spectra: theoretical and realized, compared in the model scale*

## Test results

Each time before starting the tests, zero levels of all measured magnitudes were determined on all recording channels, at first at the motionless model in calm water, then, in calm water also, but at the model being in uniform translational motion with the required speed ($F_n$=0.275).

The zero levels, averaged from three measurements (corresponding to three test groups) were as follows :

| Measured magnitudes | Model | Ship | Exprenation |
|---|---|---|---|
| waves in the movable system | - 2.5 mm | -0.138 m | water ramming |
| heaving | +10 mm | + 0.55 m | draught increment |
| pitching | - 2' 52" | - 2' 52" | bow trim |
| absolute motion | + 11 mm | + 0.603 m | downward displacement |
| relative motion | - 13.5 mm | - 0.740 m | water level elevation |

After activating the wave maker some time (abt. 45÷50 s) was let to pass to allow short wave components to come to the oposite end of the tank and only then the towing carriage guiding the model commenced going. Recording the measurement results was started when a required constant speed of the towing carriage was obtained. Measurements were performed only if the pump which removes water out of the space between the wave maker plates and the tank head was stopped (the water is sent within a short time back to the tank, causing the water level in the tank to be changed and in result also the zero levels of all linear magnitudes).

Some tests were recorded by using the video recorder with the camera covering the fore part of the model. First of all the tests were aimed at recording a way of shipping water on the deck.

The water shipped on the forecastle deck flew down overboard. A small amount of it entered the model inside and was removed out of it after each run.

The test courses recorded by using the magnetic recorders, i.e. the waves in the fixed reference system and that in the movable reference system, heaving, pitching, absolute displacements, relative displacements and vertical accelerations of the absolute motion were processed by means of a computerized result analysis sub-system of S3 software system used for seaworthiness model tests [8]. The continuous time courses were discretized by using S-300 sub-system (of typical sampling interval: 70 ms, sample number: 256, realization time: abt. 18 s). The discretized time courses were submitted to the computerized spectral and statistical analyses (S-360 sub-program) with the following typical input data: static level: 0, static and dynamic levels difference: 0, lower frequency: 0.01 $^1/_s$, upper frequency: 1.6 $^1/_s$, class number for determining the cumulative distribution function: 8 + Int(8/3) + Int(8/3) = 12.

An extended statistical analysis was performed for waves in the fixed and movable reference systems, absolute and relative motions, i.e. additionally the probability density cummulative distributions of the magnitudes were determined.

Simultaneously the short „manual" analysis was performed of the test results recorded on the paper tape: of waves in the fixed and movable reference system, absolute motions, relative motions and dynamic water action on the forcastle deck. The analysis was applied to four first out of the above mentioned realizations in the following range :

- reading out the amplitudes measured against the zero level in calm water at zero speed, of the positive and negative values of the stochastic process, for each of 25 samples separately
- calculation of the mean values of the amplitudes
- preparation of the probability density histograms, mean values and significant values of the amplitudes considering all the measurements (25 samples) as one realization.

Waves records in the movable reference system were additionally processed in the above mentioned scope to obtain the wave heights. Both the amplitudes of the analyzed processes and wave heights were considered in the sense of Rayleigh distribution, i.e. with omitting the so called secondary extremes (negative maxima and positive minima).

The dynamic force of the water shipped on the forecastle deck is of impulse (impact) character. Its record is exemplified in Fig.8.

Processing the records consisted in the following :

- calculation of impact number in one test (water impact on the deck is considered equivalent to deck wetness)
- finding the maximum force values in consecutive impacts, in each test separately, together with calculation of the mean maximum values
- preparation of the maximum force probability density histogram of the mean and significant value, considering all the measurements (25 samples) as one realization.

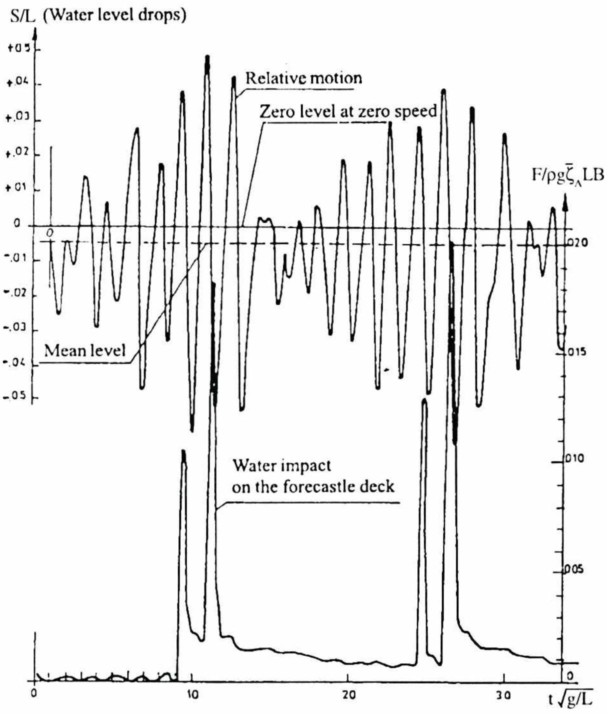


*Fig.8. Example of records of the relative motion at 8½ frame station and of water impacts on the forecastle deck. (a fragment of the test No 12)*

Additionally one magnetic record of waves in the fixed reference system (test No 12) was displayed on the paper tape and analyzed manually.

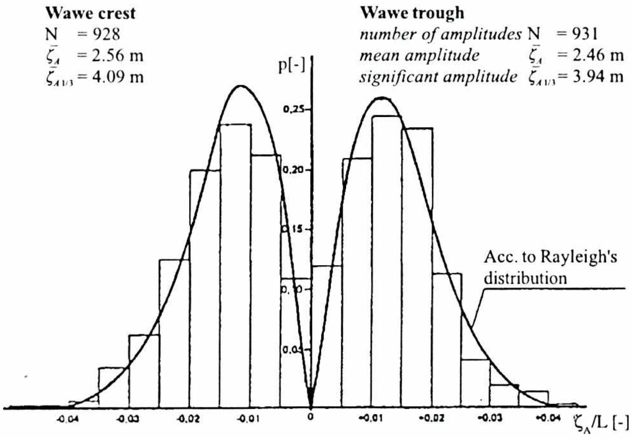


*Fig.9. Histograms of wave relative amplitudes measured in the fixed reference system (post-correction manual analysis)*

Histograms of the wave relative amplitudes in the immovable reference system are shown in Fig.9 for wave crests and troughs separately. Histograms of the relative amplitudes of bow absolute motions and of water relative motions are presented in Fig.10 and 11, respectively. In Fig.12 the histogram is shown of the maximum values of the dynamic force of water shipped on the forecastle deck.

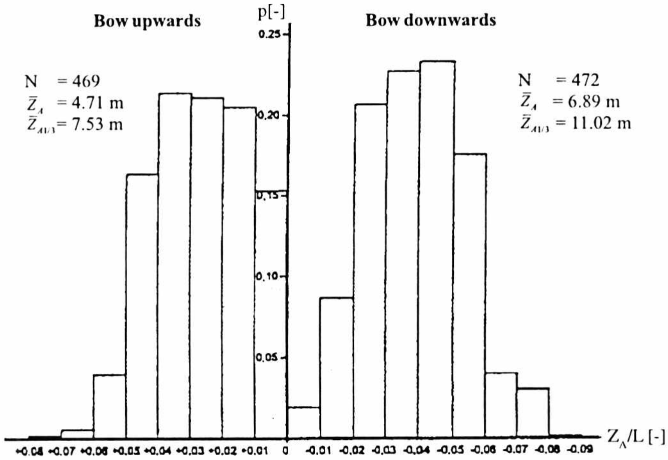


*Fig.10. Histograms of the relative amplitudes of bow absolute motions at 0.15 L abaft the F.P. (post-correction manual analysis)*

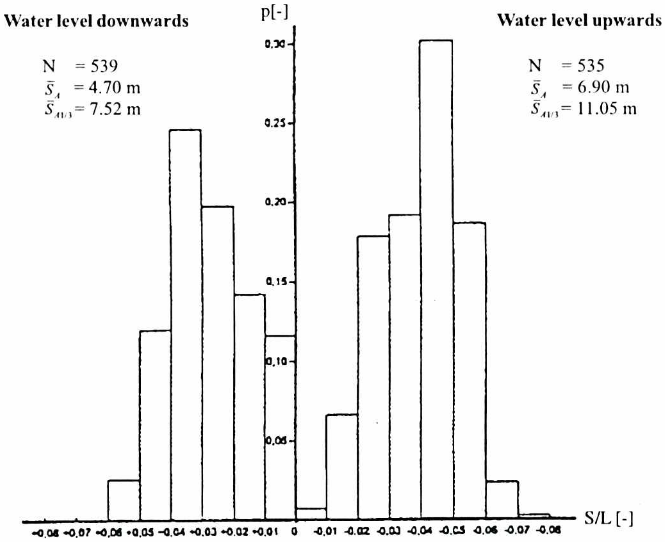


*Fig.11. Histograms of the relative amplitudes of water relative motions at 0.15 L abaft the F.P. (post-correction manual analysis)*

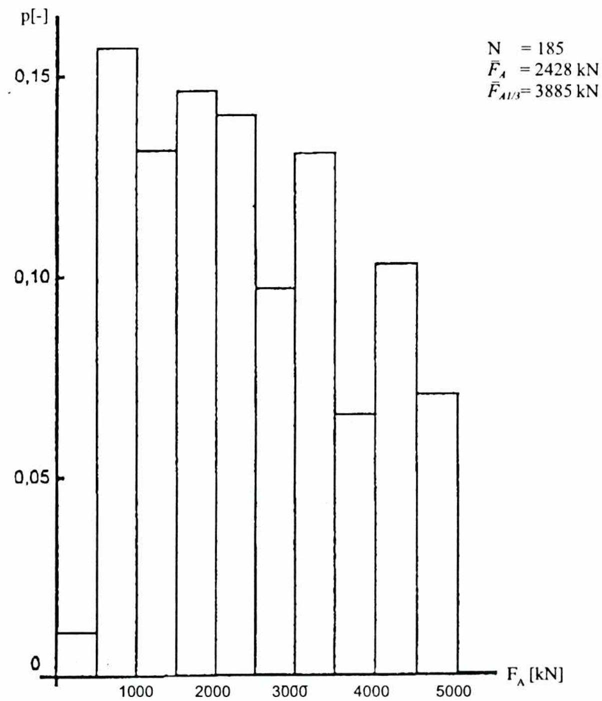


*Fig.12. Maximum values histogram of the dynamic force of water shipped on the forecastle deck (manual analysis).*

## Conclusions applicable to test metod

A sufficiently accurate modelling of the assumed sea state in the model test tank is the prerequisite for successful seagoing model testing.

The performed tests revealed the already earlier mentioned difficulties connected with the sufficiently accurate modelling [9] in the auxiliary towing tank of OHO-CTO, of the sea state with the energy spectral density function assumed in compliance with ITTC standard. The difficulties appear especially firmly in the situation in which due to methodic reasons it is necessary to generate a greater number of different realizations of the same sea state (i.e. theoretically of the same but practically an approximate wave energy spectral density function). Even if finally a realization, by manual setting and applying trial-and-error method, is obtained which satisfies the accuracy criteria related to the energy spectrum of the generated waves, then the change of phase shifts which theoretically should not change the energy spectrum, sometimes will yield unacceptable realizations in practice. The application of the trial-and-error method to any different waving process realization which corresponds to the same sea state requires more time and increases costs of testing.

It was not possible to explain the described difficulties. They are suspected to be connected to some extent with the computer program for spectral analysis of irregular waves. Therefore initiation of a special research project exclusively devoted to problems of irregular wave generation would be purposeful.

The basic point for model testing the deck wetness is definition of the phenomenon. An exceedance of the particular level (height of freeboard or so-called protecting freeboard, i.e. total height of the freeboard and bulwark) by the outside water level during its relative motion need not necessarily be connected with deck wetness. It can happen that the wave, due to appropriate shaping the ship side, will not come upon the deck, but be entrained by the flared ship side. Therefore it seems that measuring the relative water motion at ship's side is not sufficient, but determining the deck wetness by employing the vertical force exerted by water shipped on the deck is more appropriate (as it was applied in the OHO-CTO experiment) or by ascertaining the presence of water on the deck by means of special transducers (e.g. probes) located in selected points on its surface. (The solution applied by OHO-CTO seems to be more simple.)

It is unqestionable that the model testing of the rarely occurring events such as deck wetness or slamming requires applying a special methodic approach. First of all a sufficiently long time of realization or appropriate sample size of short realizations is required, and obtaining the waving process during the tests which complies with the full randomness postulate is also vital. In practice a single, sufficiently long realization is not obtainable due to the limited length of the towing tank used for testing. Therefore it is usually substituted by a set of short realizations which correspond to a single model run along the measurement length of the tank. The question of the minimum total time interval (minimum summed time) of short realizations remains still open.

It can be concluded only that the ITTC recommendations for carrying out the model testing of ship motions in irregular waves, which postulate the minimum realization time that corresponds to 50 encounter periods and the standard realization time that covers 100 encounter periods [10], are not sufficient for the case of rare events model testing. It seems that the minimum or standard realization time should be determined also by a number of encounter periods and not by a measurement time interval and the number should be additionally dependent on a sea state.

The results of the performed tests sufficiently justify the above stated reasoning. The number of deck wet states (in terms of the force exerted on the deck) in a single realization was from 3 to 10, at the mean number of encouter periods in the realization: 21. It clearly shows that evaluation of the phenomenon on the basis of a single realization could be highly unreliable.

The above described tests were a part of the project carried out within 19th ITTC. Apart from OHO-CTO, 12 other towing tanks, ITTC members worldwide, took part in it. The results collected and worked out by Admiralty Research Establishment were published in [3]. The recommendation dealing with the model testing method of rarely occuring events, which was formulated in the above mentioned source as a result of the research project in question, principally does not differ from the statements of 18th ITTC cited at the beginning of this paper. The result is hardly acceptable.

It seems that the minimum time of realization can be assessed in the following way. If the minimum number of 50 amplitudes is required for assessing the irregular oscillating motions, the same occurence number of deck wetness will be satisfactory for the quantitative assessment of the phenomenon. The minimum number of encounter periods in the model test of deck wetness can be obtained by assuming the limit (allowable) deck wetness frequency $p_{WET}$ which value oscillates, dependent of ship type, between 0.05 (for containerships) and 0.12 (for tankers) :

$$n_{\min} = Int\left(\frac{50}{p_{WET}}\right) \approx (417 \div 1000)$$

Hence the recommendation for the minimum realization time of deck wetness model tests of the ship in irregular waves could be formulated as follows :

*The minimum summed time of realization should be such as to allow the total deck wetness number of at least 50 to occur at the total encounter period number less than or equal to $Int(50/p_{WET})$, or to obtain the total encounter period number of at least $Int(50/p_{WET})$ at the total deck wetness number less than 50; where $p_{WET}$ - allowable deck wetness frequency.*

## COMPUTATIONAL PREDICTION OF RARE EVENTS - COMPARISON WITH MODEL TEST RESULTS

Computations can serve as an alternative for model tests of rare events. OHO-CTO has in its disposal the computer programs which make predicting by calculations the deck wetness, propeller emergence and slamming together with associated pressures possible. The computational prediction is advantageous due to its short time of execution in comparison with that based on model test results and in consequence, much lower costs. The model tests, inclusive of model building time and analysis of results, consume at least 5 do 6 weeks, in contrast to 2÷3 days which are sufficient to elaborate the computational prediction together with the most time consuming phase of input data preparation.

The prediction of deck wetness at $8^1/_2$ frame station of S-175 containership sailing in the identical conditions as initially assumed for the model tests was elaborated by means of WARES computer software [11] in order to assess applicability of the computational methods to predicting the rare events. Results of the computations and measurements are compared in Tab.2.

The comparison directly revealed that the computer software based on the linear theory is not able to correctly predict deck wetness of the typical containership in spite of that the comparison of the absolute motions and even the averaged relative motions of water at shipside seems to be acceptable. The conclusion is valid, without any doubt, also for the computational predictions of propeller emergence and slamming. The computational prediction of deck wetness and propeller emergence for S-175 containership is under-estimated, but that of slamming - over-estimated, i.e. the real deck wetness hazard or propeller emergence hazard is much higher than predicted, and the bottom slamming hazard - much less.

*Tab.2. Comparison of results of the deck wetness model tests and computations performed for S-175 containership*

S-175 containership in the loading conditions acc. to Tab.1.
Speed: V = 22.17 knots
Course angle: $\beta$ = 180° - head waves
Waves: $\zeta_{w1/3}$ = 7.88 m
$T_1$ = 11.40 s

| Item number | Parameter | Unit | Measured value | Calculated value WARES software |
|---|---|---|---|---|
| 1. | $S_{Aup}$ | m | 6.90 | 5.06 |
| 2. | $S_{Adown}$ | m | 4.70 | 5.06 |
| 3. | $S_{A1/3up}$ | m | 11.05 | 8.10 |
| 4. | $S_{A1/3down}$ | m | 7.52 | 8.10 |
| 5. | $T_{ORm}$ | s | 7.24 | 7.56 |
| 6. | $p_{WET}$ | - | 0.344 | 0.097 |
| 7. | $N_{WET/1h}$ | - | 171 | 46 |
| 8. | $N_{WET/1000c}$ | - | 34 | 10 |

**Notice:** The lower index : up - water level upwards
down - water level downwards
1h - one hour
1000c - one thousand cycles

Causes of those large prediction errors are the following :

■ It was observed during the measurements of zero levels of heaving, pitching, absolute and relative bow motions when ship was in the translational motion in calm water with the speed relevant to Froude number $F_n$ = 0.275 that :

- ship's draught increased by abt. 0.55 m
- ship's trim by head of abt. 2' 52" appeared
- water was rammed around the bow (at $8^1/_2$ frame station the ramming was abt. 0.14 m).

All the effects caused that the freeboard at $8^1/_2$ frame station decreased by abt. 0.74 m.

The phenomenon is well known. It is connected with the underwater form and speed during translational motion in calm water of this type of ship. WARES computer software algorithm does not account for increasing the draught and trim by head at ship's translational motion in calm water. It takes into account, in an approximate way only by using semi-empirical formula, the water ramming at shipside due to the wave generated by the ship in translational motion. Its magnitude measured on the model (abt. 0.14 m in the ship's scale) very well coincides with that calculated (abt. 0.15 m in the ship's scale).

■ Measurements of the absolute bow motion and relative water motion at shipside at $8^1/_2$ frame station, carried out for the ship sailing in head waves with the speed relevant to Froude number $F_n$ = 0.275, revealed that the dynamic trim by head was more pronounced. The average amplitude of the absolute bow motion downwards was $\bar{Z}_A$= =6.89 m , and that of the absolute bow motion upwards $\bar{Z}_A$= 4.71 m.

It gives the average dynamic trim by head at $8^1/_2$ frame station equal to $t_r$ = 1.09 m; simultaneously the average amplitude of relative water motion downwards was $\bar{S}_A$ = 4.70 m, and that of relative water motion upwards $\bar{S}_A$= 6.90 m; it gives the average dynamic trim by head at $8^1/_2$ frame station equal to $t_r$ = 1.10 m which is in a good agreement with the absolute trim value. Therefore it was pitching motions responsible for the further increase of the average trim by head by abt. 0.49 to 0.50 m relative to that measured in calm water.

The phenomenon is connected with a large asymmetry between ship's fore and aft form: bow part is slender, stern part is full. That is why the bow goes easier into water than the stern. Pitching amplitudes are greater forward than aft. An additional dynamic trim by head appears. The phenomenon should be taken into account in the computational assessment of deck wetness or slamming.

■ In model tests the deck wetness is considered as the force action of the water shipped on the deck. In the WARES computer software the deck wetness is considered as any exceedance of the „dynamic" freeboard level, i.e. the freeboard reduced by the water ram due to the ship-generated wave in calm water, by the relative water motion at shipside. Not always the magnitudes must be one and the same: not any exceedance of the „dynamic" freeboard level must result in deck wetness.

The stated deficiences of WARES software which result of its linear structure can be easily removed by elaborating a computer program for simulation of ship motion in irregular head waves, in time domain, based on a non-linear mathematical model. In such model the ship's dynamic (psedo-static) trim by head for a containership of S-175 type should be sucessfully reflected. Such program aided by calculation results obtained from BOS-L computer software [1] which makes determining the changes of ship's draught and trim during her translational motion in calm water possible, should provide a design tool for predicting the rare events, more competitive in view of model testing than theWARES software is. OHO-CTO continues efforts to elaborate such computer software.

**NOMENCLATURE**

B - breadth of ship
$C_B$ - block coefficient
$C_M$ - midship section coefficient
D - depth of ship
F - vertical force acting on the forecastle deck due to deck wetness
$F_A$ - dynamic force amplitude due to water ingress onto the deck
$F_n$ - Froude number
g - gravity acceleration
$z_G$ - centre of gravity above moulded base
$k_{YY}$ - radius of gyration about the transverse axis
l - length along path
L - ship length between perpendiculars
n - number of tests
N - number of amplitudes in a sample
$N_{WET}$ - average number of green water ingress onto the deck
p - frequency of occurence
$p_{SLAM}$ - slamming probability
$p_{WET}$ - wetness probability
S - relative motion of the water level on ship side at the point considered
$S_A$ - amplitude of the relative water motion
$S_{\zeta\zeta m}$ - wave energy spectral density function
t - time
$\bar{t}_r$ - average dynamic trim by head
T - draught of ship
$T_0$ - modal period of a random process
$T_{ORm}$ - average period related to the zero points of water motion on the ship side
$T_1$ - characteristic period of a random process
V - speed of ship
$X_B$ - coordinate of the longitudinal centre of buoyancy (from midship)
$X_F$ - coordinate of the longitudinal centre of flotation (from midship)
$Z_A$ - amplitude of the absolute bow motion
$\beta$ - heading angle
$\zeta_A$ - wave amplitude
$\zeta_W$ - wave height
$\rho$ - water density
$\omega_m$ - wave frequency
$\nabla$ - displacement

INDICES

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

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