Model Tests on Stabilizing Moment Created by Passive Anti-Rolling Tanks

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ABSTRACT

The paper summarizes results of series model tests on passive anti-rolling tanks of Frahm type, intended for installation on a large container ship. Tank sizes, water level and internal damping have been varied to get maximum efficiency. Two different kinds of tests have been implemented.

The first series included stand tests of the tank alone, using 3 DoF large scale stand for forced oscillations, and in the second series, the ship model with tank installed has been tested in the towing tank. Roll, heave and sway of the model/tank have been measured along with the forces and moment created by the tank. Tests have been carried out at "free" as well as "frozen" water level in the tank, with harmonic oscillations on the stand or regular as well irregular waves in the model basin correspondingly. Conclusions have been drawn on the correlation between experiments in the model basin and stand tests.

Keywords: *passive stabilizing tanks, stand model tests*

1. INTRODUCTION

Passive stabilizing tanks are widely applied to reduce rolling amplitudes in resonant and near-resonant zones. High effectiveness could be reached by proper selection of internal damping. Besides, these tanks easily could be activated and used as an anti-heeling system during loading-discharging operations.

Optimum selection of tank type and size is to be implemented at earlier design stages, but theoretical methods are approximate, model experiments are commonly used in any particular case. Eventual existence of serial model test data on ship behavior, tank effectiveness, fluid motion in tank and internal damping could bring considerable alleviation.

Industrial model tests on stabilizing tanks are mostly carried out in irregular seas with spectra corresponding to particular operation conditions, but variation of tank geometry and internal damping is restricted. More expedient from the view point of proper modeling and avoidance of scale effects is the testing of isolated large-scale tank models on special stands simulating ship motion as done i.e. by Bosh & Vugts (1966), Morenshild (1968), Zdybek (1980), Honkanen (1986), Rakitin & all (1990). To assess compatibility and prediction correctness of both methods, serial model tests on Frahm type stabilizing tanks have been carried out at BSHC. Hydraulically driven 3 DoF stand has been utilized. For comparison, tests in model basin have been carried out at different scale on corresponding ship model equipped with a stabilizing tank of similar geometry, attached to the hull by a 3 DoF force balance.

Regular wave parameters as well as internal damping characteristics have been widely varied and stabilizing moment measured.

Natural inertia and damping have been estimated by free decay tests.

Serial data on the influence of tank geometry, internal damping and frequency and intensity of excitation have been obtained and used in 22000 TDW containership design.

2. THEORETICAL BACKGROUND

Steady rolling motion of the ship - passive tank system could be considered by the simplified motion equation in absolute coordinates, assuming small amplitudes:

$$I_I\ddot{\Phi} + 2N_{\Phi}\dot{\Phi} + \Delta h0\Phi = MT \qquad (1)$$

where:

$M_T = M_{SW} + M_{ST}$ is the harmonic excitation due to waves and liquid motion in tank, correspondingly:

$M_{SW} = \Delta\ h_0\ \alpha_m \sin\sigma t$

$M_{ST} = -\ 2F_0\ \gamma CH \sin\sigma t$

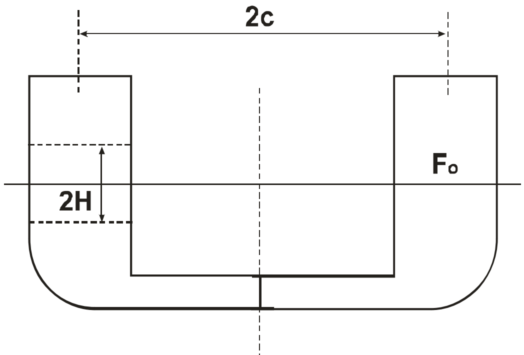

Figure 1. Tank geometry definition

Model tests with harmonicaly oscilating tanks have shown that the assumption for harmonity of tank liquid moment is correct at conditons of smal amplitude oscillations, when tank liquid is moving within half tank height limit and no roof impacts occur.

Then, equation (1) can be written, after normalizing, as:

$$\ddot{\Phi} + 2\nu_{\Phi}\dot{\Phi} + n_{\Phi}{}^2\Phi =$$
$$= \alpha_m n_{\Phi}{}^2 \sin\sigma t - \frac{2F_0\gamma CH}{\Delta h_0} n_{\Phi}{}^2 \sin\sigma t \qquad (2)$$

where the expression $2F_0\ \gamma\ C\ H\ /\Delta h_0 = \varphi_s$ gives the static tank characteristic, so finally we get:

$$\ddot{\Phi} + 2\nu_{\Phi}\dot{\Phi} + n_{\Phi}{}^2\Phi = (\alpha_m - \varphi_S).n_{\Phi}{}^2 \sin\sigma t \qquad (3)$$

It can be seen, that stabilizing tanks ideally act out of phase against external wave action. The static tank characteristic depends on tank geometry as well as on ship's mass and inertia, and those are parameters to vary in an eventual series model investigation on the stabilizing moment. The fnal goal is presumably bringing the natural frequency of tank liquid oscillations as close to ship's natural frequency as possible and to bring liquid motion out of phase with ship motion by proper selection of internal damping.

3. FORCED OSCILLATION STAND

3.1 The Stand

The BSHC stand for forced oscillation tank testing (Fig. 2) ensures motions in 3DoF, namely linear motions along OY and OZ axes and rotation around OX axis, which corresponds to sway, heave and roll motions consequently. It is hydraulically and independently driven within the limits of ± 0.250 m sway, ± 0.350 m heave and ± 30° roll, in frequency range of 0.05 – 1.25 Hz. Introduction of phase lag between the three modes of motion up to 180° is possible.

The moment around OX and linear forces along OY and OZ axes are measured by a multi-component dynamometer, allowing maximum values of ± 1500 N in sway and heave forces, and ± 500 Nm in roll moment. It’s construction ensures minimum cross-coupling effects.

3.2 Tank Models

The Frahm type tanks were constructed by aluminum plates and plastic, in scales of 1:26.5 and 1:53 correspondingly (Fig. 3).

The connecting channel height is taken 25% of the side tanks width. A movable shutter with varying coefficient of permeability was situated it the center-plane, to control internal damping.

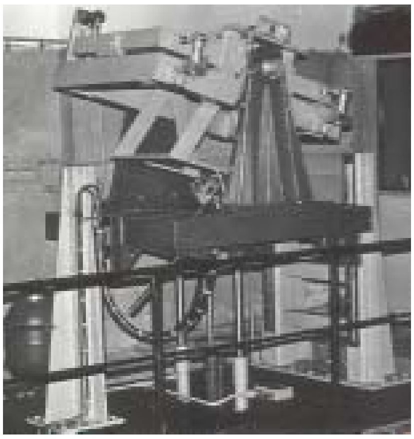

Figure 2. 3DoF stand overview

To ensure similitude, static and dynamic ballancing of tanks has been implemented before tests. In static, the CG positions at different water levels in tank were estimated. In dynamics, mass moment of inertia was adjusted by solid weights having mass and inertia of actual water content, in order to be able to model “frozen water” option, and natural periods of water oscillation in tank were estimated. The internal damping variations with water level in tank as related to tuning coefficient were assessed.

Figure 3. Tank model overview

3.3 Series Stand Tests

The stand tests were performed at following conditions:

- Forced roll motion amplitude,
- $\Phi_a = [5° - 20°]$
- Forced sway motion amplitude,
- $Y_a = [0 - 240 \text{ mm}]$
- Phase lag between linear and angular motions, $E_{Y\Phi} = 0°$ or $90°$
- Oscillation frequency, $F_a = [0.05 - 1.00 \text{ Hz}]$.

During experiments, internal damping was varied by changes in channel sizes as well as shutter permeability. The tests were repeated for frozen and free water-in-tank conditions. The testing procedure is outlined in details by Rakitin et al (1990).

In Figs. 4 – 7, sample results obtained for the stabilizing moment are presented against the non-dimensional frequency of oscillation

$$F_{aN} = 2\pi F_a \sqrt{B_T/g} \, .$$

The general aim of above described stand experimental investigations was the obtaining of analytical approximation expressions about the stabilizing moment and its phase, as a function of the parameters varied during the tests. Several multi-parameter linear regression models were derived, all ensuring good prediction accuracy. On this basis, a practical prediction method has been developed at BSHC by Rakitin (1988) for design evaluation of stabilizing tank parameters, which include:

- Estimation of un-stabilized ship motions;
- Data regression based estimation of the stabilizing moment necessary for reduction of roll amplitudes down to allowable values at given load condition;
- Estimation of passive stabilizing tank size and internal damping according to required stabilizing moment and recommended geometry relations;
- Estimation of free surface influence on the initial stability;

- Estimation of roll motions of the stabilized ship.

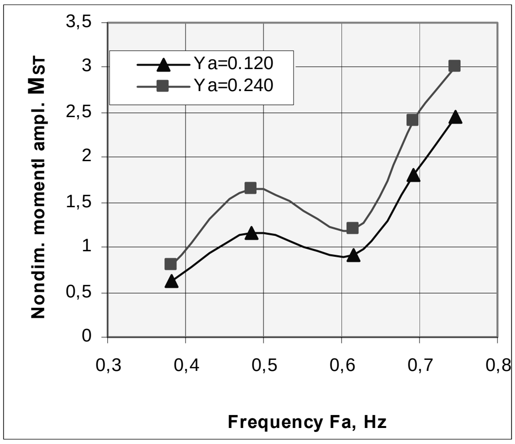

Figure 4. Stabilizing moment M_{ST}
$E_{Y\Phi} = 0$ deg

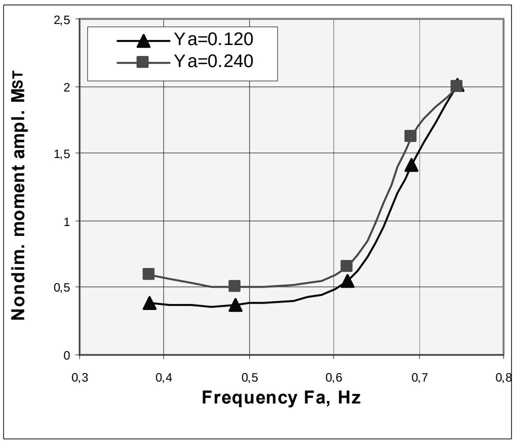

Figure 5. Stabilizing moment M_{ST}
$E_{Y\Phi} = 90$ deg

This approach was used in the design of a stabilizing tank for a 22000 TDW containership. Control stand tests of designed tank at so obtained tuning factor were also performed. Tank effectiveness of $\bar{K} = 1.56$ was estimated for this sample case.

4. MODEL TESTS IN WAVES

4.1 The Model

The model tests in waves were carried out with a 1:53 scaled model of a containership, having main particulars, as follows:

Lpp = 4,03 m   Δ = 274,4 kg

Lpp/B = 7,0   B/T = 2,86   Cb = 0,617

The model was equipped with passive stabilizing tank corresponding to above described one.

For motion measurements, 3DoF non-inertial gyro platform was utilized. Force interaction between stabilizing tank and model was measured by a special 3DoF dynamometric platform. All static, mass and inertia characteristics of the tank and the model were properly adjusted.

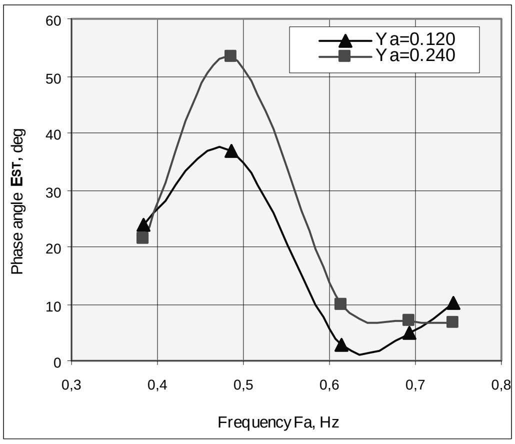

Figure 6. Phase angles of the moment M_{ST}
$E_{Y\Phi} = 0$ deg

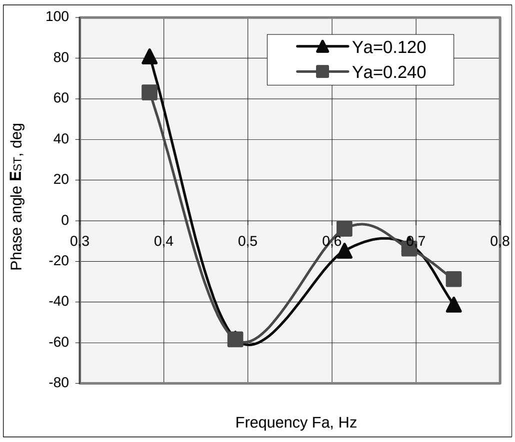

Figure 7. Phase angles of the moment M_{ST}
$E_{Y\Phi} = 90$ deg

4.2 Test Conditions

Tests in waves were realized at following conditions:

- Regular waves of λ = 2.0 - 10.0 m (corres-ponding wave frequency 0.880 – 0.395 Hz) and relative height of (H_w / λ) = 1/40;
- Irregular seas of ITTC spectrum corresponding to Bf7 intensity (H_s = 7.00 m and T_z = 12.0 sec in full scale);

The model was aligned parallel to wave front (μ = 90°) at zero speed, entirely free to move and drift along the basin.

All tests were repeated for frozen and free water-in-tank conditions.

4.3 Test Results – Regular Waves

In the process of model tests, following values have been measured:

- Wave elevation;
- Roll, heave and sway motions;
- Vertical and horizontal forces as well as rolling moment exerted by water in tank.

The first-order amplitude and phase of stabilizing moment have been then evaluated following Zdybek (1980):

$$M_{ST} = \sqrt{(M_{SW} \cdot cosE_{SW} - MF)^2 + (M_{SW} \cdot sinE_{SW})^2} \quad (4)$$

$$E_{ST} = arctg\left[M_{SW}\, sinE_{SW}/(M_{SW} cosE_{SW} - MF)\right] \quad (5)$$

Sample results of regular wave tests of containership model equipped with Frahm type stabilizing tank are presented in Figs. 8 – 10, and the stabilizing moment and its phase characteristic obtained according (4) and (5) are shown in Figs. 11 and 12.

As mentioned above, the force measuring system has 3 degrees of freedom, in order to ensure independent measurements of forces and moment components.

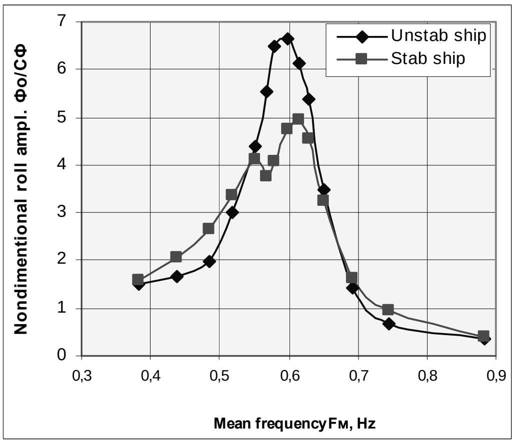

Figure 8. Roll response functions

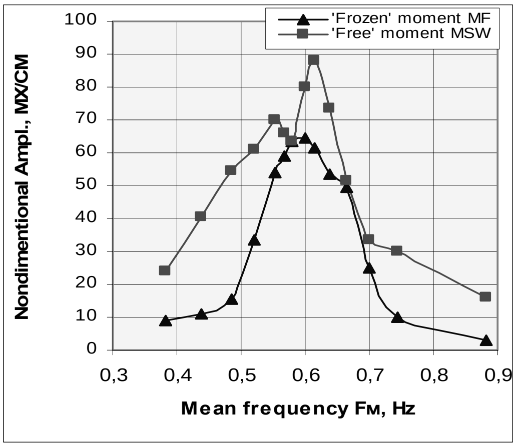

Figure 9. Roll moments

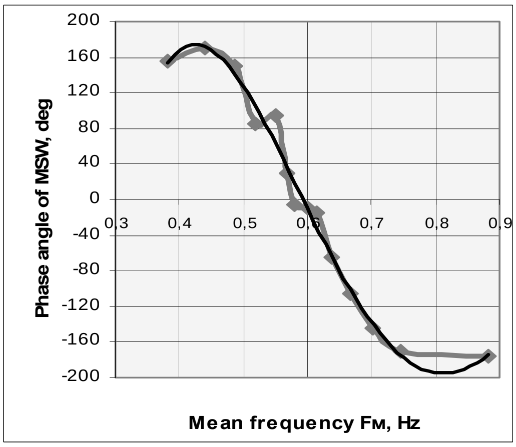

Figure 10. Phase angle of the moment M_{SW}

As horizontal as well as vertical forces do not influence directly the tank stabilizing effect, their registration had been performed with further intention for eventual sloshing studies.

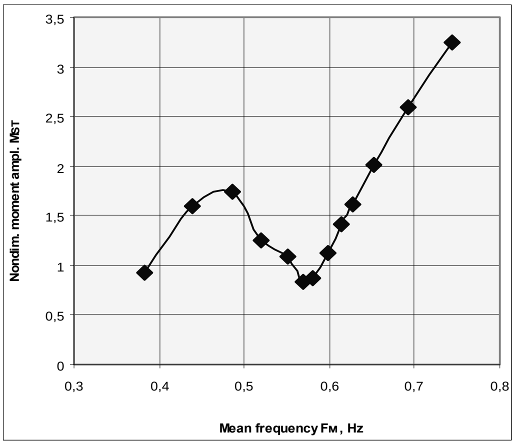

Figure 11. Stabilizing moment M_{ST}

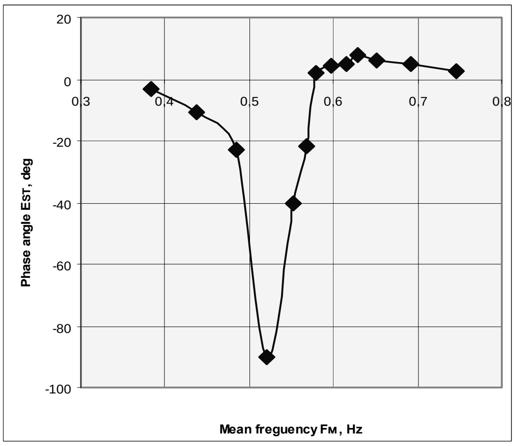

Figure 12. Phase angle E_{ST}

4.4 Test Results – Irregular Seas

Those tests have been carried out to specify the real tank effectiveness at particularly installed configuration (tuning coefficient).

As a result from spectral analysis of data, spectral and statistical parameters of measured values have been obtained. Sample results are presented in Figs. 13-14.

For effectiveness estimations at preliminary design stage, the rate of roll amplitudes reduction was obtained as a ratio of mean amplitudes in case of un-stabilized and stabilized ship:

$$\bar{K} = \frac{\Phi m_{unstab}}{\Phi m_{stab}} = \sqrt{\frac{D\Phi_{unstab}}{D\Phi_{stab}}}$$

For particularly tested configuration, an effectiveness coefficient of $\bar{K}$ =1.71 has been obtained.

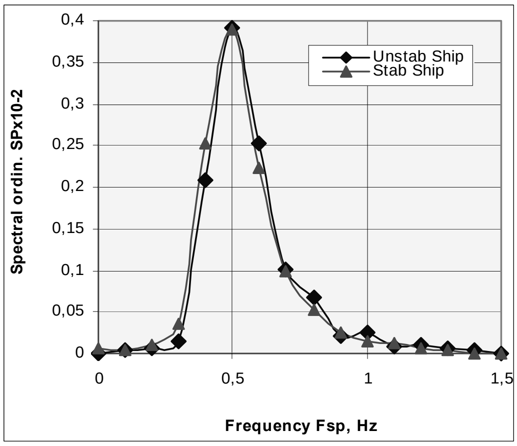

Figure 13. Generated wave spectra

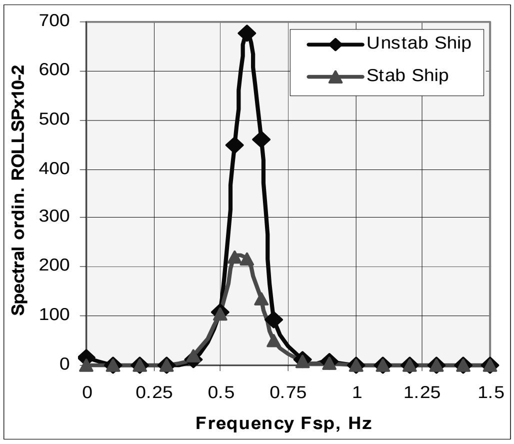

Figure 14. Roll motion spectra

5. COMPARATIVE ANALYSIS

In the process of verification of the stabilizing tank practical design method described above, it was observed, that the rate of roll amplitude decrease as predicted by the stand test data regression in most cases differ

from the corresponding value obtained by model testing in the basin, at exact modeling of tank geometry and damping parameters. When comparing results from both types of tests, as illustrated in Figs. 15 – 17, it can be observed, that even compatible as a form and tendency, the values of stabilizing moment slightly differ.

This can be attributed to scale effects, motion interaction effects and non-linearity.

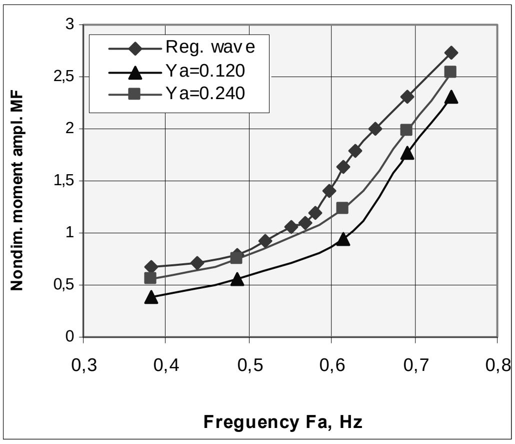

Figure 15. Roll moment at “frozen” condition

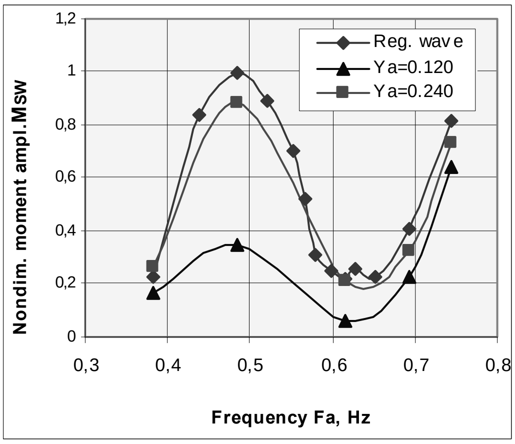

Figure 16. Roll moment at “free” condition

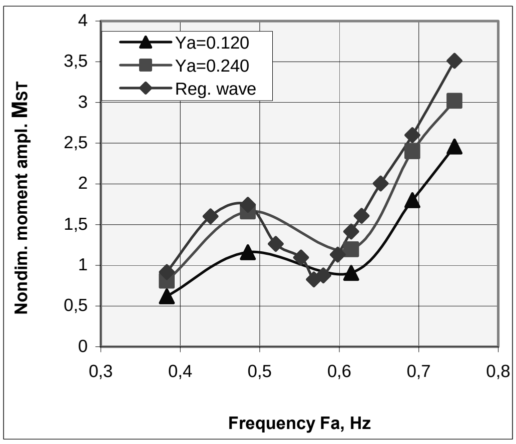

Figure 17. Stabilizing moment

Additional tests have been then performed, tuning the tank parameters on the ship model to get exactly the same moment as predicted by stand tests, taking the latter as a bench-mark in corresponding scale. Results, as illustrated in Fig. 18, show that actual tank effectiveness is slightly less than predicted by model tests in waves, thus approaching the design value.

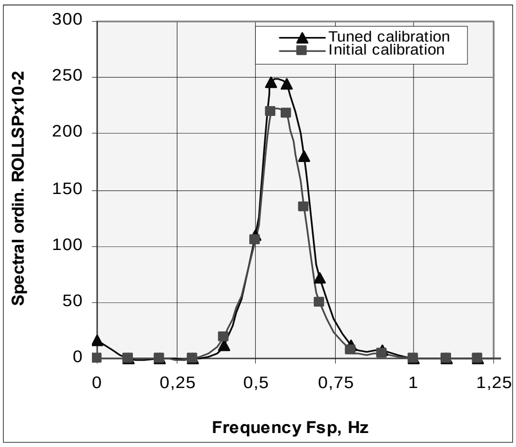

Figure 18. Stabilized roll spectra by initial and tuned tank conditions

6. ANALYSIS OF UNCERTAINTIES

Both testing schemes have been evaluated from the viewpoint of experimental accuracy, following the procedure described by Kishev (1998).

The accuracy of physical model’s production has been compatible in both cases and amounted to:

Characteristic value	Uncertainty
Model/tank breadth	0.2% B
Weight displacement	0.5% Δ
Mass moment of inertia in roll	1.0% I

The accuracy of direct measurements has been estimated to:

Measured value/ method	Uncertainty
Forced oscillations on stand	

Roll motions/potentiometer	0.8% max
Roll moment/strain gauges	1.0% max
Sway force/strain gauges	0.07% max
Free-running model in basin	
Wave height/wire probe	0.6% Hmax
Roll motions/gyro/potentiometer	1.3% max
Heave motions/accelerometer	1.4% Zmax
Roll moment/strain gauges	1.0% max
Sway force/strain gauges	0.05%Fmax

Accounting for uncertainties due to limiting record length, discretization, numerical integration and introduction of cut-off frequencies in case of spectrum analysis, final accuracy of estimation becomes:

Estimated value	Uncertainty
Forced oscillations on stand	
Roll amplitude	2.2% Φmax
Roll moment amplitude	2.6% Mmax
Free-running model in basin	
Wave spectral estimates	1.7% Hmax
Roll spectral estimates	3.3% Φmax
Roll moment estimates	4.2% Mmax

7. CONCLUSIONS

The comparative tests on roll stabilizing tanks carried out with a single tank on stand as well as with a model equipped with the same tank in waves, allowed following conclusions concerning data correlation to be drawn:

- The stand tests, due to large model tank size, reduce scale effect influence and allow direct application of results in practical estimation of rolling behavior of the stabilized ship;
- Generally, there is good coincidence of measured stabilizing moment values on stand and on model in the basin, at exact modeling of tank geometry and damping parameters. However, certain differences in tank effectiveness can be observed;
- Tuning of the tank parameters in case of model testing in waves, aiming at matching the corresponding stabilizing moment on stand, improves the accuracy of tank effectiveness prediction;
- Availability of series stand data for stabilizing tank parameters and responses can ensure significant support to the optimal design of roll reduction device, therefore stand tests are recommended as expedient and bench-mark;
- Accuracy of measurements is enough to accept data as a benchmark for similar model test investigations in the future.

8. NOMENCLATURE

C	Tank free surface arm
EST	Stabilizing moment phase lag
Fo	Tank free surface area
Fm	Average frequency of oscillation
ho	Initial metacentric height
H	Air gap
Hw	Tank water depth
Hs	Significant wave height
I	Mass moment of inertia in roll
$\bar{K}$	Tank effectiveness coefficient
MF	Roll moment amplitude at “frozen” water surface condition
MSW	Roll moment amplitude at “free” water surface condition
MST	Tank stabilizing moment
$n\phi$	Natural roll frequency
$N\phi$, $\nu\phi$	Roll damping coefficients
(O,x,y,z)	Model / tank fixed coordinate system
Tz	Average wave period
αm	Wave slope
Δ	Weight displacement
λ	Wave length
μ	Wave heading angle
φs	Static tank characteristic

Φ	Roll amplitude in general
Φo	Roll amplitudes measured at "frozen" water surface condition
Φm	Mean roll amplitude
$\Phi 1$	Roll amplitudes measured at "free" water surface condition
σ	Wave frequency

9. REFERENCES

Bosh J.J. and Vugts J.H., 1966, "Roll damping by Free Surface Tanks", Shipping World and Shipbuilder, Vol. 158, No. 3792

Honkanen M., 1986, "Water Tanks as Heel and Roll Stabilizers", Hansa, Vol 123, No.17

Kishev R., 1998, "Uncertainty Analysis of Dynamical Model Tests and its Application to Capsizing Simulation in Waves", Proceedings Int. Workshop on Modeling of Ocean Environments, Taejon, Korea

Morenshild W., 1968, "Comparative Investigations on Stabilizing Tanks", Sudostroenie, No.4 (Russian)

Rakitin V. and Tzvetanov Tz., 1988, "Computer-aided prediction of the Stabilizing Tank Moment", Proceedings of CADMO'88 Int. Conference, Southampton, UK

Rakitin V., Nachev R., Tzvetanov Tz., 1990, "Series Stand Tests with Passive Stabilizing Tanks", Proceedings of STAB'90 Int. Conference, Naples, Italy

Zdybek T., 1980, "The use of Bench tests results for calculating Roll response of a Tank Stabilized Ship", International Shipbuilding Progress, Vol. 27, No. 369