Open water seakeeping model tests in the research work of the Gdansk University of Technology Shipbuilding Institute in the 1960s

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Abstract

The paper discusses technical facilities and methodological foundations for the seakeeping model tests of ships carried out on Jeziorak Lake in the 1960s by the Ship Hydromechanics Department, Shipbuilding Institute, Technology University of Gdansk. Major achievements in the research programmes performed then are also mentioned.

Keywords: *seakeeping, dynamic stability, Ilawa lake*

INTRODUCTION

The shipbuilding industry, as other sectoral industry branches, needs own research and development facilities for its existence and development. The Polish shipbuilding industry, developing rapidly at the turn of 1950s, lacked such facilities. Their development would require many years. Therefore, efforts were made by the industry and by the Shipbuilding Faculty of the Technical University of Gdansk (TUG) to fill the gap. The steps taken were transforming the Shipbuilding Faculty into the TUG Shipbuilding Institute and also initiative of the Chair of Theory of Ships, transformed then into the Department of Ship Hydromechanics, to substitute a lake for the non-existent ship model towing tanks. Thus a conception was born to carry out ship model tests on a lake, which led to establishing the Shipbuilding Institute Experimental Model Testing Centre in Ilawa, on Jeziorak Lake.

At the beginning, the ship model resistance-propulsion and manoeuvring tests were carried out in the Centre, but relatively early, at the beginning of 1960s, a conception was developed of performing the ship seakeeping model tests, including dynamic stability. This type of research work was connected with the activities of the Polish government delegation first to IMCO and then to IMO, where intensive work was conducted on the new stability criteria to improve the safety of life at sea. That work included development of new stability criteria separately for merchant ships and fishing vessels. Incidentally, the Polish delegation to the meetings of IMO subcommittees working on those criteria was chaired by Professor Lech Kobylinski, at that time head of the Department of Ship Hydromechanics and director of the TUG Shipbuilding Institute.

Performing the seakeeping and dynamic stability model tests on the natural lake wind wave required a range of methodological and technical problems, not met in the towing tank conditions, to be first solved.

Conception of the investigations

It was decided to carry out the seakeeping model tests in large broads of Jeziorak Lake, close to the Gierczaki, Lipowy Ostrow and Bukowiec islands, near the Siemiany village, some 20 km from Ilawa (Fig. 1), with a camp set up on the Lipowy Ostrow island serving as a base. Natural waves are generated in those broads by wind.

An evident advantage of such conception is that no complicated and expensive special test tanks are needed. Its disadvantage is dependence on the atmospheric conditions and hence seasonal work, difficult planning and non-repeatability of the measurements. Lack of proper laboratories in Poland at that time and increasing interest of the shibuilding and shipping industry in the ship seakeeping qualities caused acceptance of the conception. Its implementation involved setting up original measurement stations with proper equipment and the measurement and recording apparatus and also development of measurement methods and the result processing and interpretation procedures.

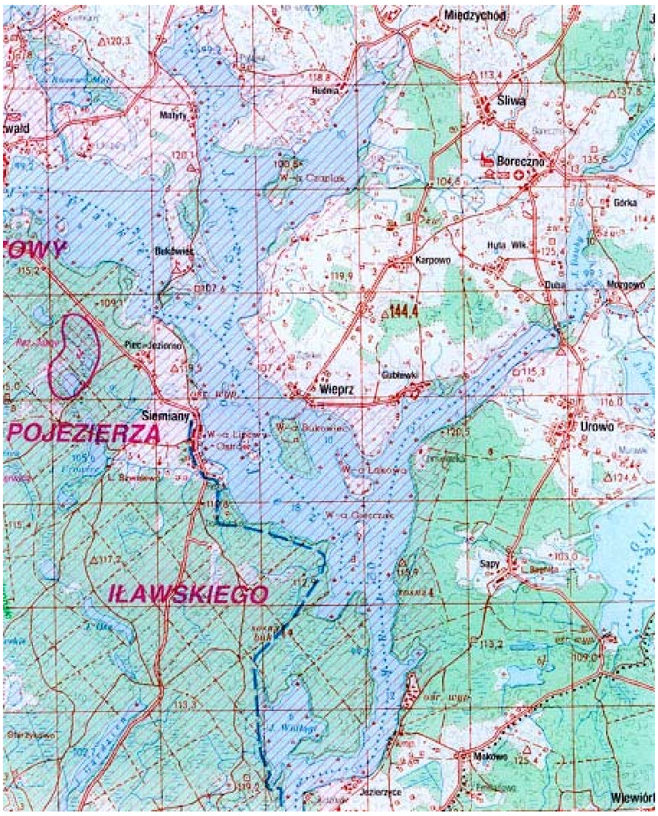

Fig. 1: *Map of broads in the northern part of Jeziorak Lake*

The seakeeping model tests are carried out, as a rule, on the irregular stationary wave. For the stationary waves to develop in an open water stretch at a given wind speed, a minimum time and a minimum water area in the direction of wave propagation are required. In the lake conditions, the stationary waves seldom appear in a given area and time. Most often developing or vanishing waves occur, with characteristics depending on time and place and also on additional factors, e.g. shore configuration. A relatively short time is needed to determine behaviour characteristics of a ship model in irregular waves, usually not exceeding 10 minutes. Within such a short time the waves may be considered as approximately stationary. Water areas with approximately constant wave characteristics should be chosen for ship model tests.

Wave measurements carried out for the first time in 1964 allowed to determine wave characteristics, such as effective wave height, mean wave period, frequency range of the energy spectral concentration function etc., which in turn allowed to determine the maximum model scale that may used for tests on the lake. The scale was from 1:20 to 1:15.

In the seakeeping model tests the natural lake waves may be considered a sea waving model or stochastic excitation whose characteristics may be determined from measurements. The former approach may be applied in exceptional cases: probability of encountering waves that may be considered, in the ship model scale, a model of sea waves is extremely small. Therefore, the lake waves are usually interpreted as a stochastic exciting force. Such approach, with an assumption that the ship-wave system is a linear system, allows either to determine experimentally the frequency characteristics (within a limited range of ship model heading angles in relation to the wave direction) or to verify the stochastic characteristic calculation methods by comparing the results of experiments and calculations. Such an approach provides also some premises to the development of new calculational methods describing the behaviour of a ship in waves, with an assumption that accuracy of the theoretical description of some phenomena in the model scale guarantees also accuracy of the description of similar phenomena in nature.

The lake conditions cause that apart from action of the generalized forces of waved water, also generalized forces of wind act on the model. This makes the conditions closer to the real ones but causes additional difficulties in the interpretation of results as the wind impact on the model has a different scale than the wave impact. This can be observed when wind influences significantly the behaviour of the model, e.g. with beam waves and wind.

Measurement stations

In the seakeeping model tests on lake most often the self-propelled models are used, sometimes also the towed models. Self-propulsion ensures full freedom of motions, without limitations on the degrees of freedom or additional impact of the towing devices. Two solutions are possible: entirely free radio-controlled model or a model connected by an elastic cable. Towed model requires also a special floating measurement station. On a free model, apart from the propulsion and steering gear, also the measurement apparatus, transmission-receiving devices and sufficiently strong power sources have to be installed. Measurement results may be recorded on the model or transmitted by radio to a shore or floating station. The former solution may appear technically difficult due to shortage of space in the model and its limited weight. Therefore the latter solution was chosen, where only the driving motor, steering gear and measurement apparatus were in the model. The floating measurement station was a catamaran carrying the power source to feed the model, model steering panel and some measurement devices together with the data recorders. Also additional environment (wind, waves) measurement equipment was placed on the catamaran, which played a similar role to that of the test tank towing carriage. General arrangement of the catamaran is shown in Fig. 2.

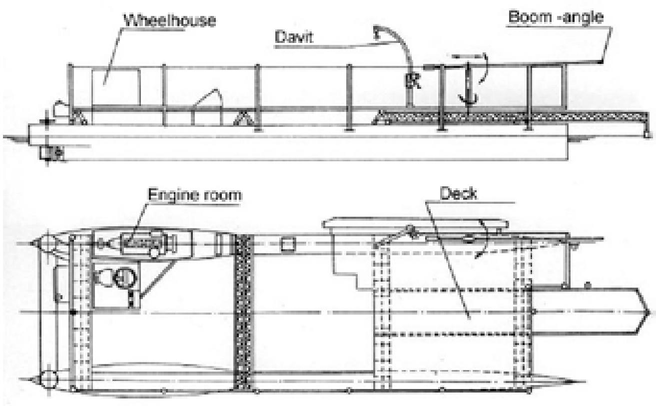

Fig. 2. Measurement platform - catamaran for seakeeping model tests on lake

In order to eliminate the catamaran impact on the model movements, the model was towed on the left hand side of the platform, slightly ahead of its bow, at a 2.5 - 3.0 m distance from the side. The cables were led to the model from the tip of a ca. 4 m long light boom (thin-walled steel pipe) fixed with an articulated joint (three degrees of freedom) to a special column in the fore part of deck on the left side. During measurements the end of boom was easily kept over the model in such a way that the connecting cable was all the time hanging loosely above the model. This is shown in Fig. 3.

When the model was towed by means of a special transverse equalizing bar and rope then the rope was fastened to a vertical boom placed on an additionally mounted 2.5 m long transverse platform. The platform was placed in the catamaran fore part on the left side. It could be raised (e.g. when closing the shore). The platform with towed model is also shown in Fig. 3. The catamaran was additionally equipped with a davit, winch and a cross-bar for easy and quick launching or lifting the model. During measurements, in the fore part of the deck were: the model steering stand with a special control panel on the left side, measurement and recording equipment in the middle, power sources (batteries) on the right side.

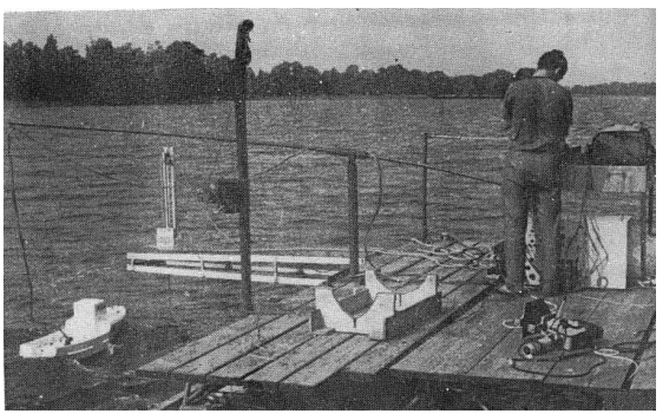

Fig. 3. Towed model of a stern fishing cutter during measurements

In the fore part of the catamaran were measurement instruments for the speed and direction of wind and wave and speed of the measurement platform, which was assumed to be a mean speed of the model. The power sources were: 220 V, 50 Hz, 0.5 kW alternating current generating set and large capacity 12 V and 24 V batteries. Total power consumption for propulsion, steering and feeding the measurement equipment was 0.6-0.7 kW.

During measurement the course and speed of the catamaran were kept constant (there was a speed indicator at the driver's stand). The measurement results were recorded only when the model moved freely and at a proper distance from the catamaran.

Measurement of the external conditions (wind and wave) was not very precise due to the motion and rolling of the platform. Therefore an additional measurement stand was constructed: a steel pontoon - island with a triangular deck (triangle height and base 5 m and 4 m respectively) and 7 m long steel pipe legs in the corners. In the floating condition the legs were elevated and could be lowered to the lake bottom at a depth not greater than 5 m. The pontoon could then be raised above water by means of manual winches, steel ropes and blocks, to form a fixed reference point for measurement of external conditions. Pontoon had a sheltered compartment for the measurement apparatus and power sources. It didn't have propulsion and was towed to the measurement region. The pontoon is shown in Fig. 4.

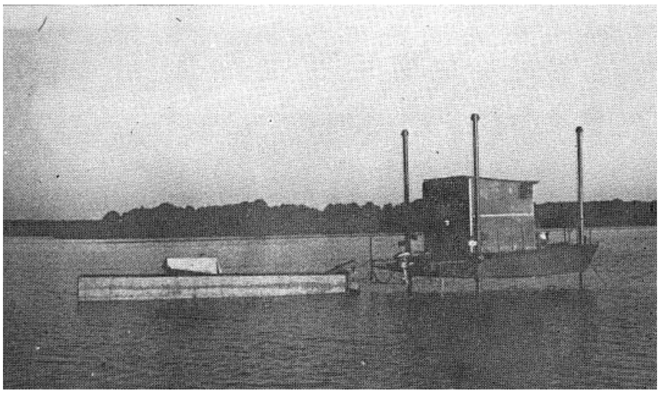

Fig. 4. *Pontoon - island positioned on the lake bottom*

Model propulsion and steering

Models were driven by the electric alternating current motors fed from the generating set through an autotransformer mounted in the control panel. The motor drove the propeller through a mechanical transmission. The autotransformer ensured infinitely variable motor rotational speed adjustment and therefore the required speed of the model.

Model was steered by means of one of the following solutions:

- step-by-step system
- continuous follow-up system
- „pulse" system.

The best results were achieved with the continuous follow-up system which gave smaller angular errors and smaller delay of the rudder movement to the „steering wheel" movement comparing with the first solution.

The measurement and recording apparatus

The measured values may be subdivided into two groups:

- parameters of the external conditions
- parameters of the model behaviour.

The external conditions were characterized by the speed and direction of wind. The model behaviour was described by: model speed and heading angle in relation to the wave direction, angular oscillations (rolling, pitching, yawing), accelerations of linear oscillations (surging, swaying, heaving), relative changes of the water level in specific points of the hull, resistance due to waves etc.. As steering had an impact on the model behaviour, the rudder angles were recorded.

Parameters of external conditions could be measured in a stationary system (pontoon) or in a moving system (catamaran). For that purpose the pontoon was equipped with: wind speed measurement - vane or hot-wire anemometer, wind direction - weathercock with potentiometric transducer, waves - resistance wave probe. The measured values were absolute values.

The same values were measured on the catamaran in a moving system. The measurement gave a relative wind speed and relative wind direction. As the catamaran rolled on waves, the wave probe situated on the left side of catamaran bow measured relative vertical movements of the water level at that point. The wave probe movements due to catamaran rolling may well be considered vertical. In order to determine the wave characteristics in a stationary system, measurement of those movements was necessary. A vertical accelerometer placed exactly above the probe was used for that purpose. The catamaran vertical accelerations at the probe installation point and catamaran speed were the moving system defining parameters.

Measurement of the external parameters from catamaran had the following advantages:

- simple and time-saving procedure,
- simultaneous measurement of external conditions and model behaviour,
- close distance of the measurement points of external conditions and model behaviour.

The model behaviour parameters were measured in the following way:

- mean model speed, assumed equal to the catamaran speed - with an impeller pulse log placed in the fore part of catamaran,
- model heading angle in relation to wave direction - visual estimation,
- rolling and pitching - with a gyroscopic vertical of a vertical rotation axis, with two measurement axes and potentiometric transducers,
- yawing - with a gyroscopic vertical of a horizontal rotation axis and a potentiometric transducer,
- linear oscillations - accelerometers with potentiometric transducers: vertical (heaving) and horizontal (surging and swaying) rigidly connected with the model;
  the accelerometers measured also the gravitational acceleration component acting on the measurement axes due to angular movements of the model,
- relative movements of water level on the catamaran side - resistance wave probes placed at different points on the model (bow, stern, sides),
- rudder angles - potentiometer on the rudder stock,
- resistance due to waves - dynamometers with potentiometric or tensometric tranducers (used only on towed models).

Elements of the individual measurement systems, power source, recording output channel and a common time marker were placed in a panel box.

Depending on the wave intensity, speed and heading angle, the measurement gauge sensitivity could be changed stepwise by means of switches installed in the panel box. The measurement systems were each time prepared in accordance with the test character and programme. Measurement results were recorded on a loop oscillograph and paralelly on a magnetic recorder. Besides, there were indicators of the instantaneous wind speed and instantaneous catamaran speed installed on the catamaran (the latter at the driver station).

Recording on the light-sensitive paper was troublesome in processing (the tape required developing and fixing) and in further use, but it allowed visual evaluation of the results. Magnetic tape recording made the processing (determination of individual run characteristics) much easier but visual evaluation was not possible.

The measurement apparatus required careful calibration.

Filming was also widely used in the seakeeping model tests.

Models and preparing them for tests

The tested models had usually reproduced abovewater hull shapes, such as sheers, bulwarks, superstructures and deckhouses. Models were fully watertight, which made e.g. capsizing tests possible. Inside models, apart from measurement apparatus, driving and steering devices, there was ballast fastened to the model structure in a movable manner, so that proper static and dynamic balancing was possible. Ballasts were also placed on the deck and on vertical masts, easily movable vertically and horizontally, which allowed to change quickly, in a limited range, the ordinate of the centre of gravity and the moment of inertia in relation to the longitudinal axis. Additional displacement of ballast inside the model allowed to change the centre of gravity position in a wide range. Models were statically and dynamically balanced. Static balancing was performed by means of scales and inclining test, dynamic balancing - by measuring the rolling period on a special cradle (determination of the moment of inertia in relation to the transverse axis) or by suspension on prisms (determination of the moment of inertia in relation to the longitudinal axis).

Result processing technique

The functions recorded on the loop oscillograph paper tape or on magnetic recorder tape were realizations of the respective stochastic processes of ship seakeeping properties. Further processing of those results depended on the character of functions measured. Two extreme cases may be distinguished here:

- the model phenomena (movements, flooding, increased resistance) are within a linear theory,
- the phenomena are clearly non-linear.

In the case of phenomena described by the linear or linearized theory, processing of the recorded data was performed in accordance with a standard procedure. Its objective was to determine characteristics of the external forces acting on a ship (wind, wave) and characteristics of the ship responses (movements, movement speed, acceleration, green water shipment, etc.), which further allows to determine ship dynamic characteristics such as the frequency characteristic. The so determined characteristics may be used for finding parameters of ship behaviour in different environment conditions (sea states) or they may be compared with similar calculated characteristics.

Processing of the measurement results was carried out on a special analogue computer ISAC. For each measurement data set it could calculate: autocorrelation function, spectral concentration function, ordinate distribution function and also mutual correlation function of any two data sets simultaneously recorded on magnetic tape. The processed data sets might have different lengths. Usually from a 10-minute recording a 6-7-minute section was chosen for processing, which for an average case (model size, heading, wave) corresponded to 100-400 relative periods. Such data set ensured sufficient statistical accuracy of the results, but there was a possibility of extending or shortening of the measurement runs.

Difficulties occurred when the model moved with a speed V and the heading angle b in relation to the wave direction. Then instead of w we had the encounter frequency we equal to

$$\omega_e = \omega\left(1 - \frac{V\omega}{g}\cos\beta\right) \qquad (1)$$

and after the computer processing all the spectral concentrations were obtained as functions of we. Transition to an absolute system, i.e. to functions of w, is possible in a general case only for heading angles b from the bow sectors:

$$\beta \in \left[+\frac{1}{2}\pi; +\frac{3}{2}\pi\right]$$

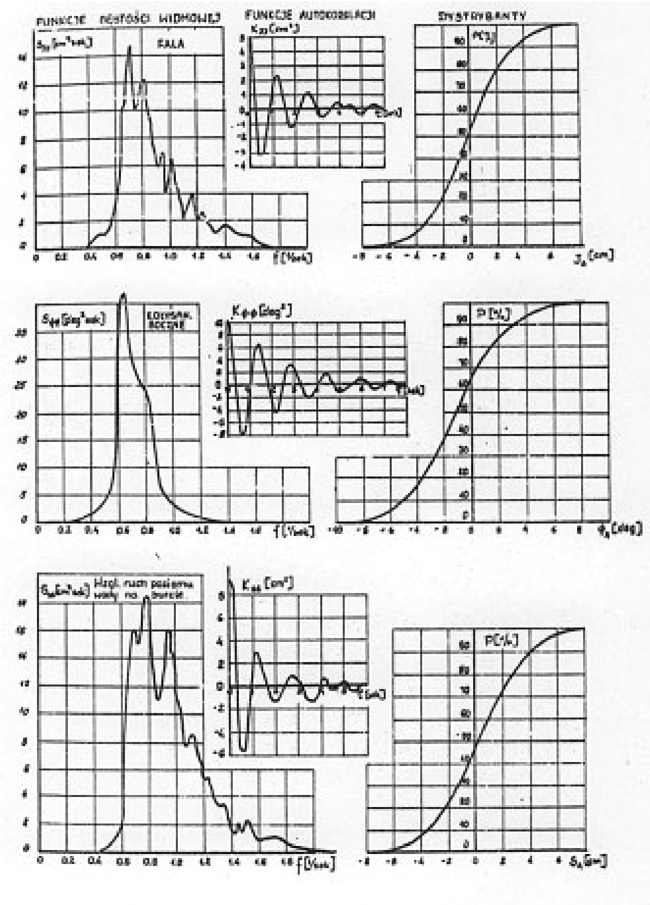

Fig. 5. Example of measurements processed on the analogue computer

The conclusion is that the amplitude characteristics of those phenomena could in the general case of $V \neq 0$ be determined only for waves coming from the bow sectors. This limits to a degree the possibilities of seakeeping testing but this limitation applies equally to lake and to the test tank.

When clearly non-linear phenomena were tested, such as e.g. ship capsizing, the above described processing methods were of little use. In such case the phenomenon was tested in a narrow time interval as determined, occurring in stochastic external conditions. The testing methodology of such phenomena was not mastered fully.

Fig. 5 and 6 present examples of the results of such investigations. Fig. 5 presents partial results of the analogue computer processing of the recording of model rolling and deck flooding in beam waves; Fig. 6 shows recorded capsizing of a model in following waves and in beam waves.

Test programme and major achievements

Tests carried out in the second half of 1960s were connected first of all with the stability safety of small ships, fishing vessels in the first place. Statistics of losses caused by the stability failure accidents show that the smaller the ship size the greater

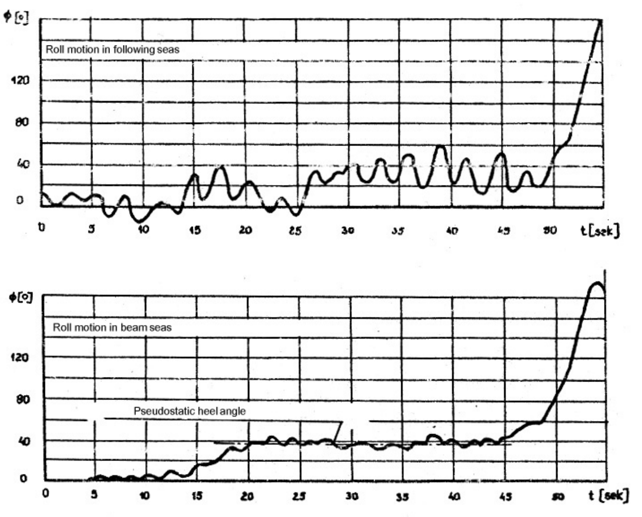

Fig. 6. *Examples of recorded model capsizing*

the number of ships sunk. A significant percentage of those are fishing vessels. The reason of that is not only small size of fishing vessels but also their specific functions. The increased fishing vessel safety hazard, comparing with other ship types, is connected with the fishing process when additional forces from the fishing tools act on the ship and the hold hatches are usually open which facilitates water penetration into the hull. The threat increases when fishing is continued at higher sea states and the ship overloaded with fish either because of desire to get higher profits or inadequate crew qualifications and control of the ship loading condition. That was the justification of research work aimed at increasing the safety of small ships, particularly fishing vessels. Three fishing ships were tested:

- the B-14 type side trawler,
- the B-10 type trawler-drifter,
- the TRT-18 type stern fish cutter,

operated by Polish fishermen or built by the Polish shipyards. The aim of investigation was not so much improvement of those ship types but drawing some more general conclusions regarding stability criteria, freeboard (amidships and at the bow) etc.. Particular subject of investigations was behaviour of the low-side fishing vessels in the beam waves and side wind as well as the following wave conditions. One of the interesting findings was that in the beam wave and side wind conditions the so called pseudo-statical angle of heel may occur due to asymmetric deck flooding, which quite often leads to ship turning over on the windward side (Fig. 6).

The test results were partly used in formulating the IMO recommendations regarding the freeboard height and protective freeboard as well as bow height of fishing vessels. (Those recommendations were later included in the Torremolinos Convention).

The tests allowed also to observe many phenomena connected with capsizing of non-damaged fishing ships. It is impossible to observe such events in nature. This is, for instance, capsizing caused by broaching, like that of the B-10 trawler-drifter. The mechanism of the event was the following: the ship sailed in a following wave; a group of waves appeared with relatively long crests and the wavelength approximately twice the ship length. The model speed was smaller than the wave phase velocity, i.e. the wave was overtaking the ship. When the model stern was on the wave crest and the bow in the wave trough, the model would lose its linear motion stability and sharply turn to the left. When the wave passed, the model returned to the original course but already second or third overtaking wave would cause another sharp turn to the left so that the model was almost broaching; flooded violently, the model heeled and capsized. The capsizing occurred always on the windward side, as in the case of deck flooding by beam waves, in spite of the contrary action of wind.

Concluding remarks

The fishing vessel stability safety model testing programme was not the only programme in the seakeeping domain. Commercial orders were also carried out, e.g. on the effectiveness of a special type of bilge keel (ordered by the Maritime Institute) or accelerations on the 10000 DWT general cargo ships (a Polish Ocean Lines order). Also a programme of model tests on ship damage stability was accomplished. Observations from that programme were used in other research work on the unsinkability and damage stability of ships.

In my opinion, full use of the model experiment results was somewhat limited by lack of appropriate mathematical models and respective computer programs and also by the research team personnel rotation. Nevertheless, it was an excellent school of practical execution of the seakeeping model tests and the experience gained there was later used by some members of the Jeziorak Lake test team in their work in other research institutions in Poland and abroad.

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