**Scientific Journals**
**Maritime University of Szczecin**

**Zeszyty Naukowe**
**Akademia Morska w Szczecinie**

**2009, 18(90) pp. 59–65**

**2009, 18(90) s. 59–65**

# Prediction of drift of disabled tankers – preliminary tests

# Prognoza dryfu uszkodzonych zbiornikowców – wstępne wyniki

**Lech Kobyliński, Jacek Nowicki, Jerzy Oleksy, Tomasz Jaworski**

Foundation for Safety of Navigation and Environment Protection, Iława, Poland

**Key words:** disabled ship, tankers, model of drifting

**Abstract**

Tanker casualties cause often serious environment pollution with disastrous effects. The important issue is to perform successful salvage operation and in order to do so, it is necessary to forecast the exact position of the disabled ship at each point of time. Programme of research was installed in the Ilawa Ship Handling Research and Training Centre (SHRT) with the aim to develop a computer code for prediction of the path of disabled tankers after casualty in various damage conditions, partially flooded or broken down in parts. Those are realistic situations that may happen after collision or serious damage to the hull as did show casualties of tankers ERICA or PRESTIGE. Mathematical model of ship drifting motion under the influence of wind, waves and sea current was developed that, requires, however, knowledge of force coefficients, in particular hydrodynamic and aerodynamic force coefficients for damaged ship. Model tests intended to estimate these coefficients were performed in the towing tank where the model was in different damaged conditions. Developed computer code is intended to be validated by tests of the large model in semi-natural scale in natural wind and waves on the lake. Suitable testing methodology and measuring system were developed and preliminary tests were performed in the lake Silm in SHRT where the model was drifting freely in intact condition or with partially flooded compartments, heavily trimmed to the bow.

**Słowa kluczowe:** statek unieruchomiony, tankowce, model dryfowania

**Abstrakt**

Wypadki tankowców powodują często poważne zanieczyszczenia środowiska morskiego mające katastrofalne skutki. Ważnym zagadnieniem jest przeprowadzenie działań ratunkowych zakończonych sukcesem. W tym celu niezbędne jest określenie pozycji unieruchomionego statku w każdym okresie czasu. Badania przeprowadzone zostały w ośrodku manewrowania statkami pod Iławą. Celem było stworzenie kodu komputerowego pozwalającego na predykcję trasy uszkodzonego tankowca, częściowo zalanego lub przełamanego. Sytuacje te są bardzo prawdopodobne i mogą się przydarzyć po kolizji lub poważnym uszkodzeniu kadłuba statku. Przykładem są wypadki tankowców „Erica” i „Prestige”. Stworzono matematyczny model statku w dryfie, który poddany został działaniu wiatru, falowania oraz prądów morskich. Model wymaga również znajomości współczynników sił hydrodynamicznych oraz aerodynamicznych dla poszczególnych modelów uszkodzenia statku. Testy modelowe, mające na celu określenie tych współczynników, zostały przeprowadzone na modelu holującego tankowca, dla różnych typów uszkodzenia. Opracowany kod komputerowy sprawdzono za pomocą testów na dużym modelu w skali naturalnej, w warunkach naturalnych, przy wietrze i falowaniu na jeziorze Slim. Odpowiednia metodologia testowania oraz system pomiarowy zostały opracowane i wstępnie przetestowane na jeziorze Slim w ośrodku manewrowania statkami. Model dryfował swobodnie w nienaruszonym stanie lub z częściowo zalanymi przedziałami, z dużym trymem na dziób.

## Introduction

Large ships carrying huge quantities of dangerous goods, like tankers, gas carriers and similar ships pose serious danger to people and environment in case of casualty. During last years several such casualties happened with tanker ships where the hull of tanker was seriously damaged and subsequent leakage of thousands of tons of oil products caused tremendous pollution of the sea.

In the table 1 there are listed the most serious casualties that happened since the year 1978 with the amount of oil spill given.

Table 1. Most serious oil spills from tankers in the years 1967–2002
Tabela 1. Największe rozlewy olejowe spowodowane przez tankowce w latach 1967–2002

| Month/Year | Ship's name | Oil spill ($t \cdot 10^3$) |
|---|---|---|
| 03 1978 | Amoco Cadiz | 223 |
| 08 1983 | Castillo de Belveder | 190 |
| 07 1979 | Atlantic Empress | 160 |
| 03 1967 | Torrey Canyon | 119 |
| 11 2002 | Prestige | 77 |
| 02 1996 | Sea Empress | 72 |
| 03 1989 | Excon Valdez | 38.8 |

One of these casualties involving Greek company owned tanker "Prestige" in Atlantic Ocean close to Spanish shores may be considered as serious warning to other countries which are close to tanker routes. On November 13th 2002 one of the tank of "Prestige" became damaged and started leaking oil. Because no port was prepared to receive damaged tanker with oil leaking the master was forced steer away from the shoreline. On November 19th during stomy weather the tanker was broken down in two parts that drifted separately spilling oil, Rescue action was not successful and after some time both parts foundered. About 70 thousands tons of spilled oil drifted towards the land causing the worst in history pollution of the Spanish shores [1].

Figure 1 shows tanker "Prestige" after it had been broken down in two parts still holding together, where figure 2 (prepared on the basis of available information) shows the path of drifting tanker between 13 and 19 November 2002.

Similar casualties where tankers were broken down in two parts happened with the tanker "Erika" and "Nakhodka" [2].

Fig. 1. Tanker "Prestige" broken down and drifting [1]
Rys. 1. Przełamany i dryfujący tankowiec „Prestige" [1]

Baltic Sea represent closed sea particularly vulnerable to pollution. There are several routes used for transporting oil through Danish Straits to Russian and other ports. If disaster of the scale of "Prestige" happens the results would be catastrophic to the countries surrounding Baltic Sea. Therefore it is extremely important to assess risk of such a situation and to prepare of the appropriate salvage action.

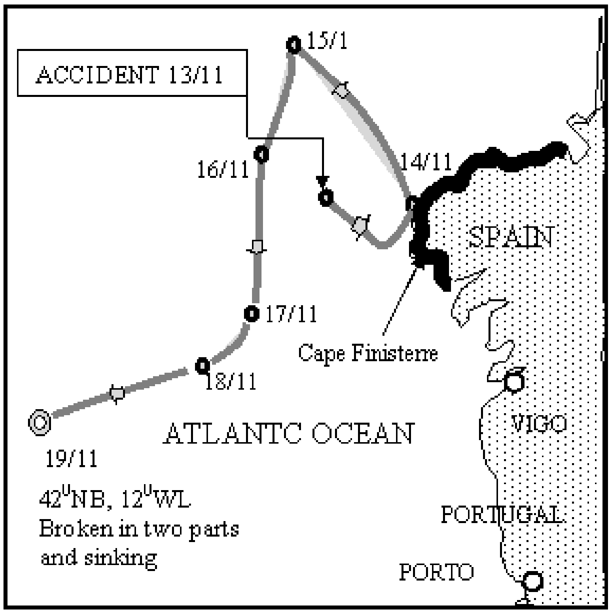


Fig. 2. Path of drifting tanker "Prestige"
Rys. 2. Trasa jaką przebył tankowiec „Prestige" w dryfie

## Aim of the project and programme of research

In order to properly and timely organize salvage operations it is necessary:

- Developing fast, reliable and accurate method of predicting drifting path of damaged ship or its part when afloat.
- Estimation of forces necessary for towing of the disabled ship or its parts in rough sea.
- Development of guidelines for the salvage operation consisting of guidelines on the methods of towing disabled ship and performing containment, neutralizing and removal of spilled oil or other products.

The main aim of the research project is related to the first task mentioned above, i.e. the developing computer code for prediction of the path of disabled ship The ship disabled, partially flooded, broken down and without propulsion is drifting freely under the action of wind, waves and current. Prediction of the path of such ship or its parts is possible if all forces acting on such a ship are known, that is hydrodynamic forces acting on the submerged part of the ship, aerodynamic forces (wind forces) acting on the above water part of the ship, wave forces acting on the ship and current forces.

Some categories of the above mentioned forces could be calculated using known methods, however with respect to others there no available data. This in particular applies to hydrodynamic and wave forces.

Some data on hydrodynamic forces acting on the underwater part of the hull for the drifting undamaged ship are available [3], but for ships damaged, partially flooded, broken down or for parts of the ship particularly in vertical position there are no such data available. Within the scope of the project attempt was made to estimate resistance coefficients for the damage ship in different conditions on the basis of model tests. The model test were arranged in the towing tank owned by the Technical University of Gdańsk.

Similarly model tests were performed in order to estimate wave force coefficients for the damaged ship in different states of damage.

Aerodynamic force (wind force) could be calculated using well known methods used for other purposes, for example for calculation of heeling moment in consideration of stability requirements. Although form of the above water part of the damaged ship in different conditions is different from the above water part for the intact ship, the differences of the wind force coefficient are not very different as shown by data available from aerodynamic tunnel tests [4].

Once all forces acting on the damaged ship are estimated they may be used in the computer code for prediction of the path of drifting damaged ship. It is planned, that the computer code will be validated by specially arranged model tests. In these tests large scale (8 m long) model of the tanker of the selected for this purpose size (average tanker of the type met in Baltic Sea) will be allowed to drift freely in strong wind and wave conditions in the lake with its path recorded and wind, wave and current characteristics measured. The model will be tested in several damaged states including partially flooded state, broken down state and stern part floating in vertical position (see fig. 5). These tests are planned for summer 2009.

## Equations of motion of the drifting damaged ship

Disabled ship under action of wind, waves and current reaches equilibrium drift direction, speed and heading that may be calculated by solving the following set of differential equations [5, 6]:

$$\begin{aligned} X_H + X_W + X_A + X_G &= 0 \\ Y_H + Y_W + Y_A + Y_G &= 0 \\ N_H + N_W + N_A &= 0 \end{aligned} \qquad (1)$$

In the above set of equations $X_G$ and $Y_G$ are the surge and sway force components arising from the effect of the Coriolis acceleration

All other force and moments components are functions of several variables. Thus we have:

Hydrodynamic components:

$$X_H = X_H\,(U, \beta, L)$$

Wave force components:

$$X_W = X_W\,(X_S, T_z\ U, \mu, L)$$

Wind force components:

$$X_A = X_A\,(U, \gamma_R, AW, V_W)$$

Identical expressions are found for $Y$ and $N$ components.

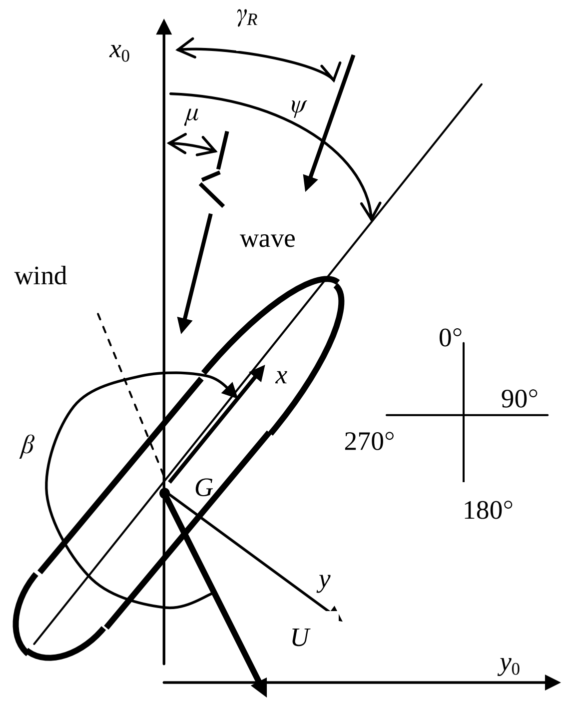


Fig. 3. System of reference axes (earth fixed)
Rys. 3. System osi odniesienia (stały wzgl. Ziemi)

In the above equations (fig. 3): $H_S$ and $T_Z$ – significant height and period of waves, $\mu$ angle between symmetry plane of the ship and direction of incoming waves, $A_W$ – projection of windage area.

The equations describe situation, where the ship reaches equilibrium state, i.e. where the resulting moment of all forces acting on the ship is equal to zero. This is quasi-static situation that happens shortly after the ship starts drifting in stationary conditions of the environment, i.e. wind, waves and current. Because changes of the environmental conditions are rather slow, and their periods are much greater than period of yaw then in the short period of time those conditions may be assumed as stationary [5, 7]. When they change, the ship after short transitional period reaches another stationary situation. Thus the drifting path could be divided in a number stationary situations and in each of them the equations (1) could be applied. This is schematically shown in figure 4.

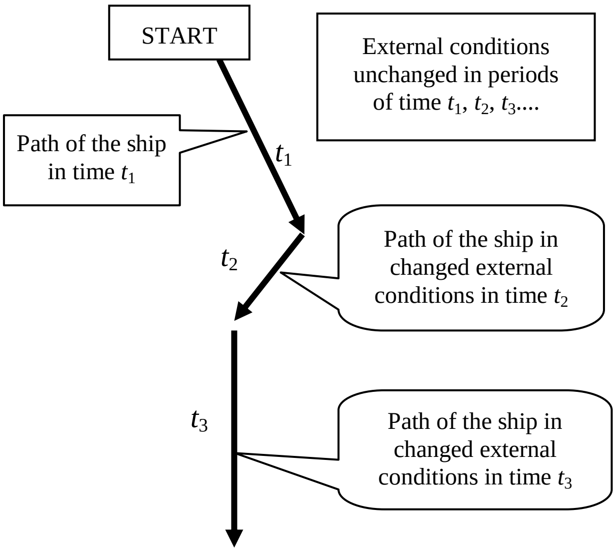


Fig. 4. Scheme of calculation of predicted path of the drifting ship
Rys. 4. Schemat obliczeń przewidywanej trasy dryfującego statku

Adoption of this assumption simplified the calculations apparently without any loss of accuracy. This was confirmed by preliminary experiments with drifting partially flooded model of the tanker performed in the autumn 2008 in the lake Silm.

In case of the situation where the ship is in the transitory period where the external forces and moment do not balance to give a steady-state situation, dynamic situation exists and the following equations of motion in the body axes are valid:

$$\begin{aligned} m(\dot{u} - vr) &= X(u,v,r,\dot{u},\dot{v},\dot{r},H_S,\dot{T}_z,V_W...) \\ m(\dot{u} + ur) &= X(u,v,r,\dot{u},\dot{v},\dot{r},H_S,\dot{T}_z,V_W...) \\ I_\psi r &= N(u,v,r,\dot{u},\dot{v},\dot{r},H_S,\dot{T}_z,V_W...) \end{aligned} \quad (2)$$

Where: $\dot{u},\dot{v},\dot{r}$ are perturbation velocities in surge, sway and yaw. Solution of such equations is possible if all coefficients and all perturbation velocities are known. This is not possible without extensive model tests of ships in various damaged conditions using planar motion mechanism in towing tanks. Practically such possibility does not exist and obviously funding for financing such a project is not available.

Dand (1981) when discussing possibilities to use equation (2) pointed out that simplified quasi static approach is sufficiently reliable if aerodynamic and hydrodynamic data is available for the ship in question. Knowing the vessel's actual drift vector and heading over the previous period it is also possible to deduce the wave effects by default. Then those values are assumed to be unchanged over the forecast period.

Aerodynamic (wind) forces are calculated employing standard method used for example in weather criterion when assessing stability. The wind force is proportional to windage area and to the wind velocity squared, where wind force is assumed to act at the centre of windage area [8]. The formula for wind force coefficient is:

$$X_A = C_{XA} \cdot 1/2 \cdot \rho \cdot A_W \cdot V_W^2 ... \quad (3)$$

and similarly for the $Y_A$ and $N_A$ components.

It is assumed that Coriolis acceleration is changing linearly with drift velocity and

$$a_C = 2U\omega \cdot \sin\varphi \quad (4)$$

where: $\varphi$ – latitude, $\omega$ – angular velocity of eart rotation.

## Model tests for estimation of hydrodynamic and wave forces

As there are no data available on the hydrodynamic forces acting on drifting damaged ship, model tests were performed in order to estimate those forces. Model test were carried on in the towing tank owned by the Technical University of Gdansk of the dimensions: length $L$ = 30.00 m, breadth $B$ = 3.00 m and depth $h$ = 1.5 m. Model of the dimension suitable to the size of the towing tank of the tanker chosen was made in the scale 1:150. Model was divided in several compartments and prepared to be tested in four different damage states:

1. Model not damaged, in intact condition.
2. Model with flooded forward tanks, trimmed to the bow, the bow submerged.
3. Model broken down in the middle, both parts still holding together.
4. Stern part of the model separated, floating vertically.

Main dimensions of the ship chosen and models are shown in the table 2.

Table 2. Main dimensions of the ship chosen and its models
Tabela 2. Główne wymiary wybranych statków oraz ich modeli

| | Ship [m] | Model 1 [m] | Model 2 [m] |
|---|---|---|---|
| Scale | 1 | 1:41.06 | 1:150 |
| $L_{PP}$ | 306.0 | 7.45 | 2.04 |
| $L_{OA}$ | 324.0 | 7.89 | 2.16 |
| $B$ | 54.9 | 1.34 | 0.366 |
| $H$ | 32.25 | 0.785 | 0.215 |
| $T_1$ | 15.50 | 0.377 | 0.103 |
| $T_2$ | 21.50 | 0.523 | 0.143 |

Sketch of the model in intact state, broken down in the middle and stern part floating separately is shown in figure 5.

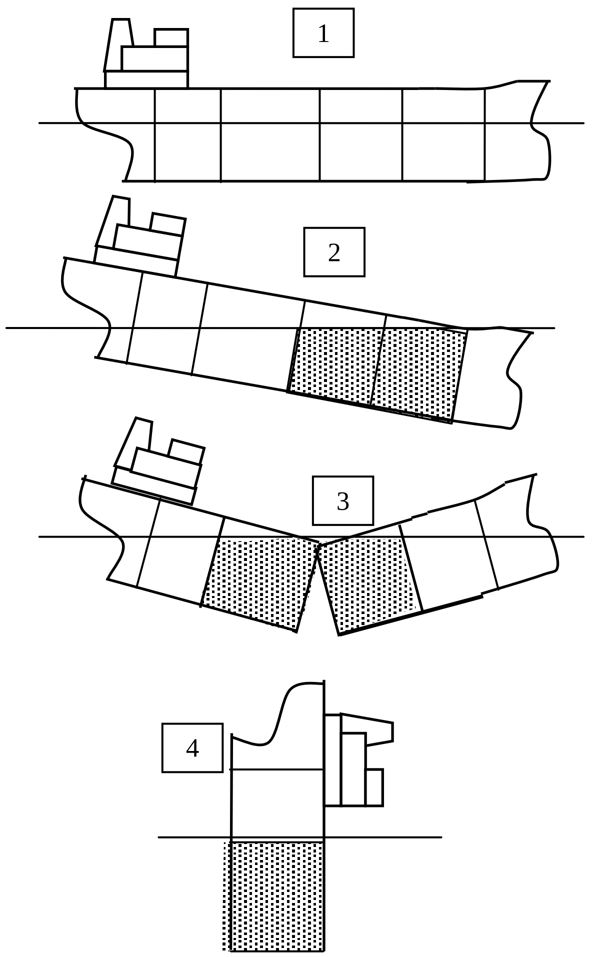


Fig. 5. Models in different damage conditions
Rys. 5. Modele dla różnych stanów uszkodzeń

In the towing tank model towed by the carriage was free to roll and pitch with drift angles changing within the limits ±180°. Longitudinal force $F_X$, transverse force $F_Y$, moment $M_Z$, and heel angle $\varphi$ were measured and recorded. Test were carried for the basic carriage velocity $v_m = 0.126$ m/s and for some chosen drift angles also for the velocities $v_{m2} = 0.07$ m/s and $v_{m3} = 0.126$ m/s. Tests were performed in calm water in order to estimate hydrodynamic forces and in regular waves of the following parameters: $h = 0.037$ m, $T = 0.5935$ s and $\lambda = 0.55$ m in order to estimate wave forces. Parameters of the wave were adopted to correspond to the significant heght of maximum waves in Baltic Sea equal to: $h_S = 5.5$ m and $\lambda_S = 82.5$ m. Measurements of forces and moments were presented in the coordinates system $xyz$ fixed to the towing carriage (fig. 7). Typical plot of measured quantities is shown in figure 8.

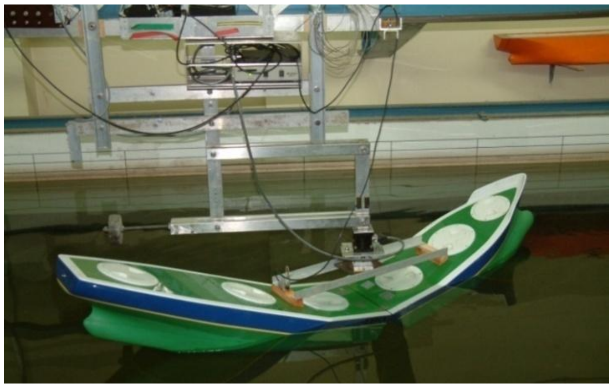

Fig. 6. Model in condition 3 tested in the towing tank
Rys. 6. Model dla stanu 3, testowany na holującym tankowcu

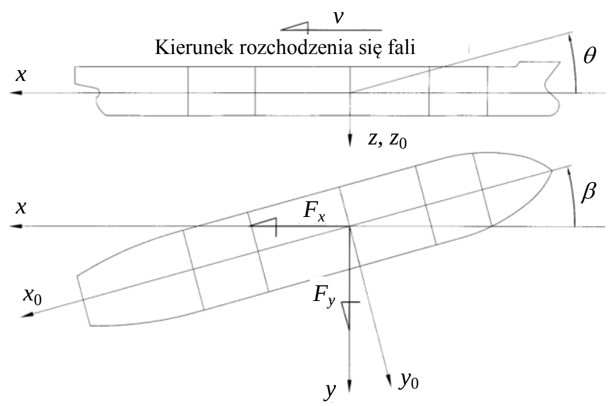


Fig. 7. System of reference axes
Rys. 7. System osi odniesienia

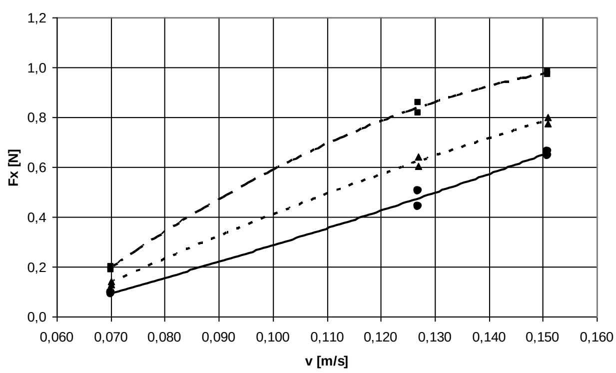


Fig. 8. Typical plot of forces measured in the towing tank
Rys. 8. Wykres sił zmierzonych dla holującego tankowca

## Preliminary tests of drifting model at lake silm

Preliminary tests of drifting model at lake Silm were performed in the autumn 2008 with the purpose:

- to check reliability of the measuring system,
- to check the practicability of testing method,
- to verify the adopted method of development of the computer code for prediction of drift.

Fig. 9. Model during tests in lake Silm
Rys. 9. Model statku w trakcie przeprowadzania badań na jeziorze Slim

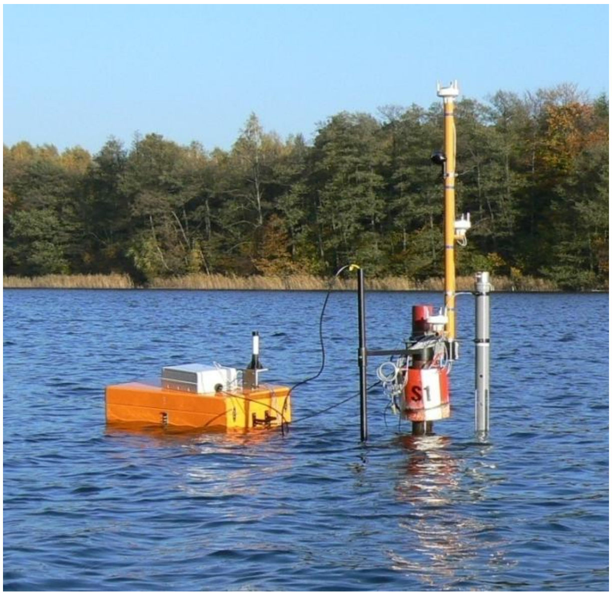

Fig. 10. Measuring apparatus in lake Silm
Rys. 10. Urządzenia pomiarowe na jeziorze Slim

Data of the model used for the tests are given in the table 2. Model was tested in two conditions corresponding to state 1 and 2 shown in figure 5, i.e. intact and partially flooded trimmed to the bow conditions. Figure 9 shows the model partially flooded during the tests.

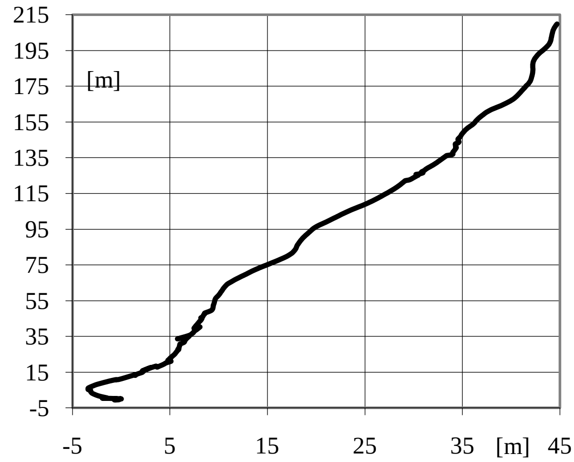


Fig. 11. Trajectory of drifting model. Condition 2
Rys. 11. Trajektoria dryfującego modelu dla stanu 2

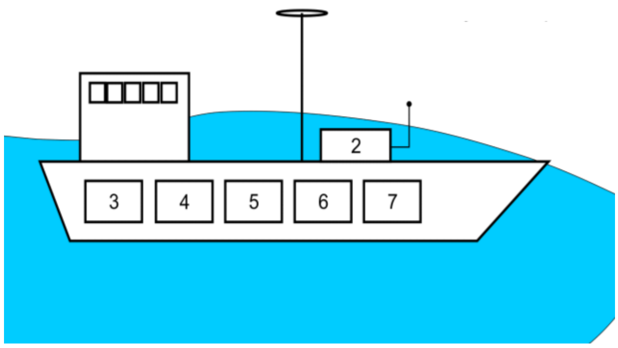


Fig. 12. Measuring apparatus in the model; *2* – radiomodem *3* – server, *4* – computer, *5* – battery, *6* – electronic compass, *7* – GPS receiver
Rys. 12. Urządzenia pomiarowe znajdujące się w modelu; *2* – modem radiowy, *3* – serwer, *4* – komputer, *5* – baterie, *6* – kompas elektroniczny, *7* – odbiornik GPS

System of measurements consisted of apparatus located in the model and apparatus for measurement of wind velocity and direction, current velocity and direction and wave elevation located at a fixed point in the lake in the area of experiments.

Those data are transmitted to the model and recorded there together with trajectory of the model taken from satellite receiver and electronic compass. The principle of the measuring system is shown in figures 12 and 13.

Figure 11 shows example of the trajectory of the drifting model tested in condition 2. As it may be seen after a very short transitory period that existed because the model was launched in accidental position, the position of the model stabilized and it was drifting along the almost straight line as long as the external conditions did not change.

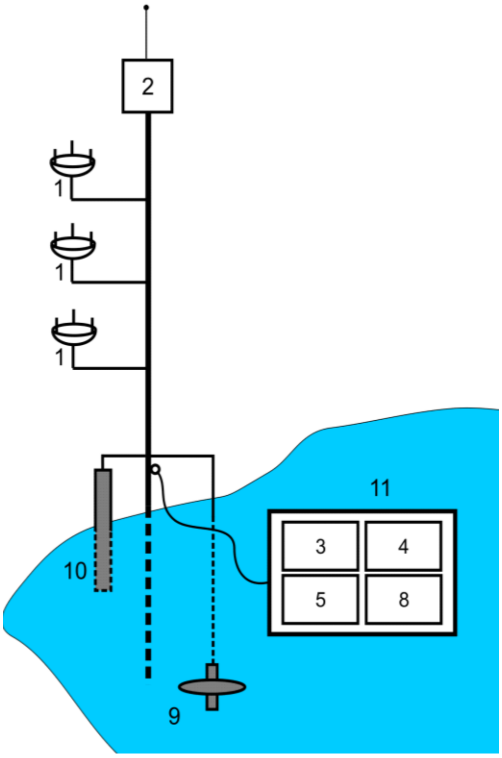


Fig. 13. Measuring apparatus in fixed position; *1* – wind sensors, *2* – radiomodem, *3* – server, *4* – computer, *5* – battery, *8* – przetwornik, *9* – doppler sensor, *10* – wave probe, *11* – container

Rys. 13. Urządzenia pomiarowe w określonej pozycji. *1* – sensory wiatru, *2* – modem radiowy, *3* – serwer, *4* – komputer, *5* – baterie, *8* – przetwornik, *9* – czujnik dopplerowski, *10* – sonda falowania, *11* – kontener

## Conclusions

The preliminary test of recording trajectory of drifting freely disabled damaged tanker model in the lake Silm showed that:

- The method of testing drifting model in natural conditions of wind, waves and current is reliable.
- The system of measurements and measuring apparatus is working properly.
- The assumptions taken in development of the computer code for prediction of the drift of damaged tanker are correct.

In spring or summer 2009 experiments with the same model in four different states as shown in Figure 5 will be performed with the aim to verify computer code developed for prediction of drift trajectory of the disabled ship. These experiment will be performed in the lake Jeziorak where in wider area larger waves are expected, of the significant height corresponding to waves met in the Baltic Sea. The same method of recording trajectory and to take measurements of wind velocity and direction, wave elevation and current velocity and direction, if any will be used. Those data will be then used for verification purpose of the computer code developed.

## References

1. Guardian Unlimited. Press release 7 May 2007.
2. From Nakhodka to Erika. Exchange of experience in at sea response to offshore oil spills by passing ships. Proceedings of the seminar between Cedre in France and SRI. 2003.
3. EDA H.: Course stability, turning performance and connection force of large barge systems in coastal seaways. Transactions SNAME, vol. 80, New York 1972.
4. BRIX J. (EDIT): Manoeuvring technical manual. Seehafen Verlag, Hamburg 1993.
5. DAND I.W.: Model studies of freely-drifting and towed disabled tankers. Joint RINA/RIN/NI Symposium on disabled large tankers. London 1981.
6. DAND I.W.: The drift of disabled ships in the vicinity of offshore installations: its prediction and correction. National Maritime Institute, Report OT-R8151. Feltham 1981.
7. DAND I.W., READ A.D.: The drifting vessel problem. Conference on emergency management offshore, EMO 81. Stavanger 1981, Norway.
8. AAGE C.: Wind coefficients for nine ship models. Report A-3, Hydro- and aerodynamic laboratory, Lyngby 1971.

### Other references

9. LEWISON C.R.G.: Experimental determination of wind, wave and drift forces on large tankers. Joint RINA/RIN/NI Symposium on disabled large tankers. London 1981.

*Recenzent:*
*prof. dr hab. inż. Bolesław Mazurkiewicz*
*Akademia Morska w Szczecinie*