

Analysis of real underkeel clearance for Świnoujście–Szczecin waterway in years 2009–2011

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Abstract

The paper presents the practical using of model for underkeel clearance evaluation. Real data from Maritime Office concerning ships which enter ports was used to analysis of results first probabilistic model of underkeel clearance and next integrated system. During analysis mean probability that underkeel clearance will be less than zero was determined for ports in Świnoujście, Szczecin and Police. Results of this analysis can be used for further research connected with integrated system for underkeel clearance calculation.

Introduction

Underkeel clearance of ships (UKC) is the clearance between ship's hull and the bottom of water area, so it is the most important factor which determines the possibility of ships grounding. Maintaining safe clearance is the basic navigator's responsibility among his other usual duties. Traditionally, most ports in Poland and Europe have operated under fixed rules which govern the minimum underkeel clearance to permit safe transit during entrance into restricted areas. The determination of minimal UKC is especially important for these port which basing the existing meteorological conditions and the type of vessels, to load the vessel maximally [1].

Due to developments in shipping, ports are under continuous pressure to accommodate wider and deeper-draught ships. Good solution is dredging of the entrance to the port, but it is an expensive option. Therefore, very important task is to find maximum safe draught of a particular type of ship for an existing port entrance channel [2].

If UKC requirements are too conservative, ships carry less cargo than they could, and the operation is not as economic as it might be. At present in Poland all UKC calculations are done using method

of constant clearances whereby a minimum underkeel clearance is declared by the regulatory authority.

Some ports have special VTS procedures for entering and leaving, and Marine Authorities have problem with decision according to entrance big-draught vessels. The maximum draught is limited by the available water depth minus underkeel clearance [2]. Marine staff at the ports needs an adequate decision support system to allow them to take ship allowance decisions based on proper and reliable data [3]. So, in Maritime University of Szczecin first probabilistic model for underkeel clearance determination was created to determine safety for given ship and next Marine Traffic Engineering team rebuilt this tool and creates an integrated system for dynamic underkeel clearance. Both, model and system could be used to design port as a tool for calculating UKC and then safety depth for characteristic vessels which may be exploited in given water area.

Because safety level in port is very difficult to determine so in practice grounding risk is calculating. The paper presents results of verification of probabilistic model in safety evaluation at main ports Świnoujście–Szczecin waterway.

Probabilistic model for UKC determination

The main assumption of probabilistic method for UKC determination is that the model takes into account depth measurement uncertainty, uncertainty of draught determination in port, error of squat determination, bottom irregularity, tides and waves influence [4].

User-entered draught is corrected for draught determination error value, ship's heel error and wave clearance. Additionally, iterated draught (T_i) is calculated as follows:

$$T_i = T + r_{T_i} + r_{p_i} + r_{f_i} + S_i \quad (1)$$

where:

- T – ship's draught [m];
- r_{T_i} – draught determination error;
- r_{p_i} – ship's heel error;
- r_{f_i} – wave clearance;
- S_i – ship's squat.

Next water level can be automatically load from online automatic gauges, if such exists (Polish solution). In some researches, the level can be modelled as normal cut distribution with parameters ($0, \pm 0.1$ m).

Depth h_i was assumed as constant in given sections:

$$h_i = h_{s_i} + r_{s_i} + r_{m_i} + \Delta p w_i + r_n \quad (2)$$

where:

- h_{s_i} – depth of water area determined on the basis of cumulative distribution function;
- r_{s_i} – sounding error;
- r_{m_i} – mudding component clearance;
- $\Delta p w_i$ – change of water level;
- r_n – navigational clearance.

Squat (ship sinkage due to decrease of water pressure during movement) is calculated in three stages. It is based on six squat methods and standard deviations of factors which were obtained using real experiments.

$$O_{i+u} = O_{M_i} + u(O_{M_i}) \quad (3)$$

where:

$u(O_{M_i})$ is an uncertainty for the particular method used to obtain moving vessel squat (Huuska, Millward 2, Turner, Hooft, Barrass 1, Barrass 2)

Next, discrete distribution was generated with the following parameters:

$$O_{(i=1)+u} : O_{(i=n)+u}; \quad w_{i=1} : w_{i=n} \quad (4)$$

where w_i is weight of particular method.

To obtain squat distribution, bootstrap method was used, which can be used as estimator and statistic distribution approximation. When assumption that population is used due to random variable O_i with unknown distribution F , let $O_i = O_1, \dots, O_n$ will be a simple sample drawn from the set, (O_1, \dots, O_n) – trial o realization, and $R(o, F)$ – statistic estimated at trial series. Probability distribution called bootstrap distribution from trial (marked \hat{F}) is described by the following formulas:

$$P(O_B = o_k) = \frac{1}{n} \text{ for } k = 1, \dots, n \quad (5)$$

Statistic R bootstrap distribution is given in the form:

$$R^* = R(o^*, \hat{F}) \quad (6)$$

Basic rule of bootstrap method is that statistic R distribution is approximated by random value R^* . When Monte Carlo method is used, it is important that statistic R^* histogram is generated from the distribution \hat{F} , which is based on N trial realization. The assumption is that $n = 1000$ [5]. Ship's squat O_i is determined from this distribution.

Finally underkeel clearance UKC_i is determined by using draught, depth, water level and squat results which were calculated before. Underkeel clearance is defined as:

$$UKC_i = (h_{s_i} + r_{s_i} + r_{m_i} + \Delta p w_i + r_n) + (T + r_{T_i} + r_{p_i} + r_{f_i} + S_i) \quad (7)$$

where:

- h_{s_i} – up-to-date depth;
- r_{s_i} – sounding error (normal cut distribution with 0 and ± 0.1 m);
- r_{m_i} – mudding component clearance (normal cut distribution with 0 and ± 0.1 m);
- T – ships draught;
- r_{T_i} – uncertainty for draught determination ($0, \pm 0.10$ m);
- O_i – iterated squat (bootstrap model);
- $\Delta p w_i$ – change of water level;
- r_n – navigational clearance (const. = 0.3 m);
- r_{f_i} – wave clearance (wave height for particular weather conditions).

Program is capable to consider above mentioned uncertainties using distributions and their parameters. Where uncertainty is greater for certain factor components due to less available data or data accuracy, it is possible to make grater allowances in that factor. The remaining necessary data are taken from

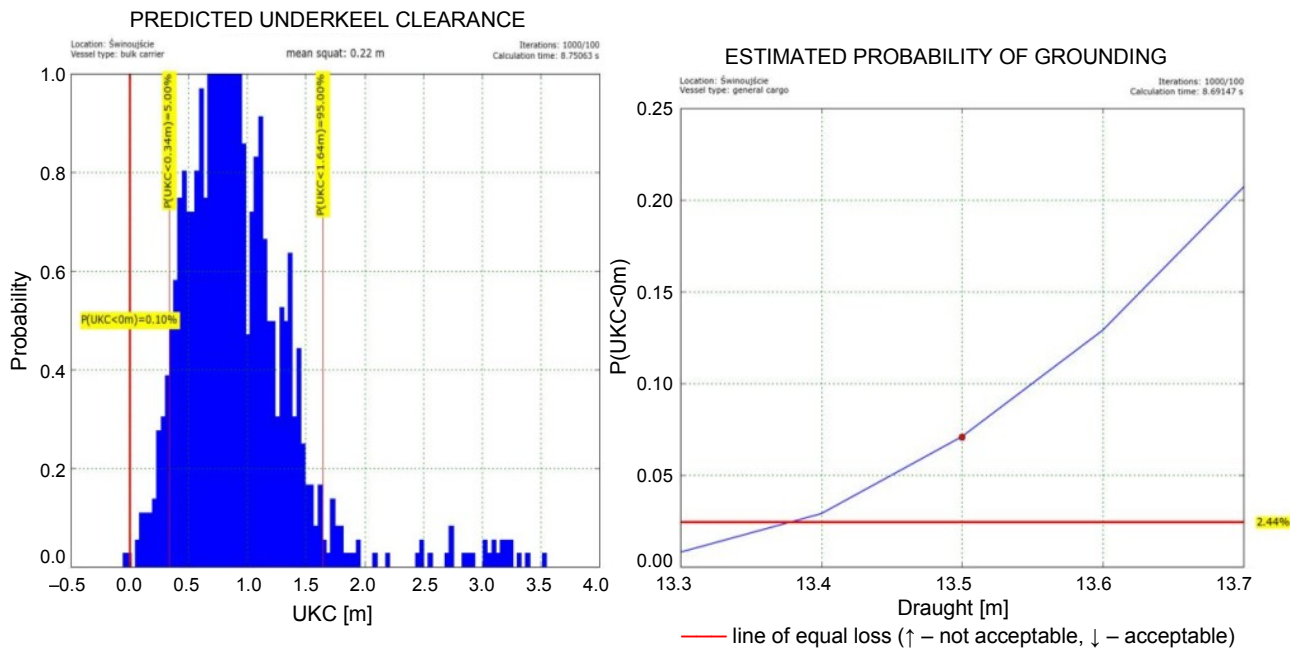


Fig. 1. Example of results probabilistic model of UKC and decision support application for one of ships which entered Świnoujście Port in 2009

XML file located from the server and this file could be modify.

Decision model results was added to making application user friendly. Simplified decision model is based on mean expected value. Decision-maker receives suggestion which concerns to level of acceptable risk for given situation.

The model UKC evaluation was implemented using Python compiler and it is available “on-line” on Maritime Traffic Engineering Institute web site. Form for entering parameters permits to enter the basic ship and water region data.

Model underkeel clearance is evaluated after running the application. The results are presented as a histogram and diagram $P(UKC < 0)$ in function of ship’s draught with level of acceptable risk grounding in figure 1.

Analysis of results

The analysis covers a period from 2009 till 2011 (to August). Probabilistic model and integrated system were used for all ships equal or longer than 180 m, which entered to ports: Świnoujście, Szczecin and Police. Parameters of each vessel were entered together with appropriate hydro-meteorological conditions as water level and wave height, which were checked in Vessel Traffic System database. Research was carried out on the basis of 168 simulation (Świnoujście: 96, Szczecin: 41, Police: 31). In simulations 6 knots speed was used. The results of using model are presented in table 1.

Table 1. Results of using probabilistic model for UKC determination for particular ports

Port	Świnoujście	Szczecin	Police
Mean $P(UKC < 0)$	0.019	0	0
St.dev $P(UKC < 0)$	0.072	0	0
Mean UKC 95%	1.640 m	1.796 m	1.09 m
St.dev UKC 5%	1.771 m	0.518 m	0.372 m
Mean UKC 95%	3.006 m	4.699 m	4.025 m
St.dev UKC 5%	1.769 m	0.508 m	0.437 m

The biggest number of ships entered Świnoujście Port, and from 96 ships which entered this port in period January 2009 – August 2011 – 11 ships had no acceptable level probability of grounding. In Szczecin and Police the probabilistic model has confirmed decisions of Port Captain. Next, for 11 situations in Świnoujście speed was decrease to 3 knots. Values of $P(UKC < 0)$ for two different speed are presented in figure 2.

At reduced speed results of decision module in system were acceptable with the exception of two ships. There are two situations, first for ship “Drake” with length $L = 225$ m and draught $T = 13.18$ m at water level 509 and wave height about 1 m and the second for ship “Ocean Breeze” with length $L = 225$ m and draught $T = 12.8$ m at water level 532 and wave height about 1.5 m when result according to permission for safety entrance to the port is negative. Examples of situation when approaching speed in simulation was decreased are presented in figures 3 and 4.

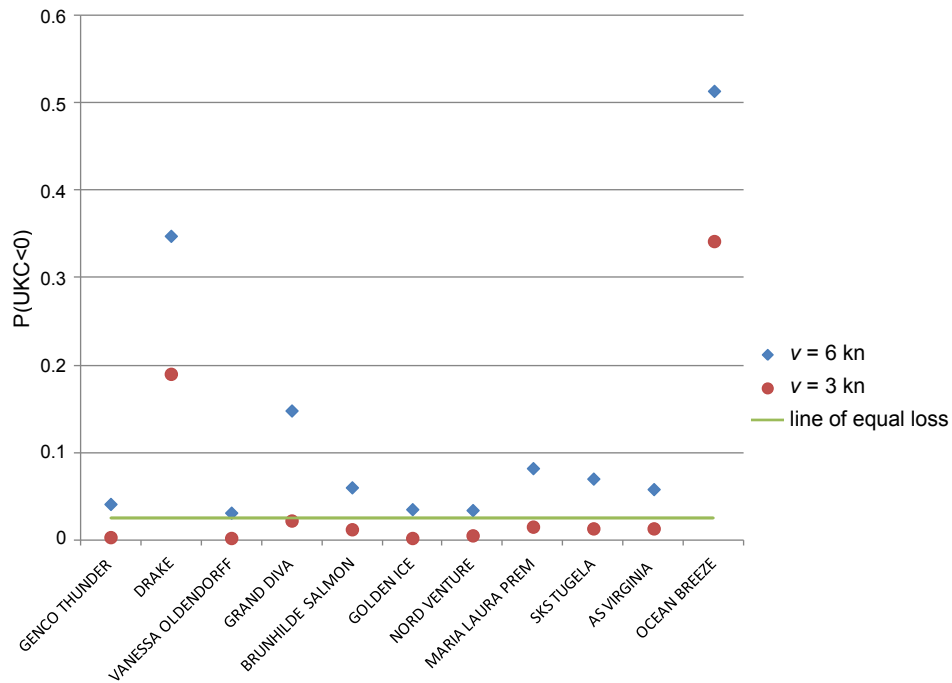


Fig. 2. P(UKC<0) for particular ships at speed 6 and 3 knots

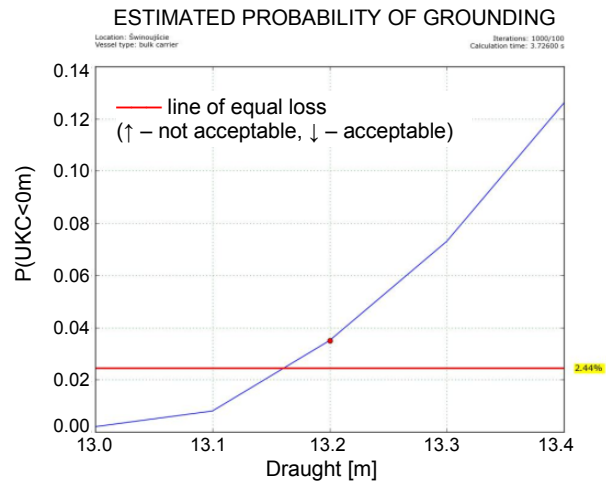
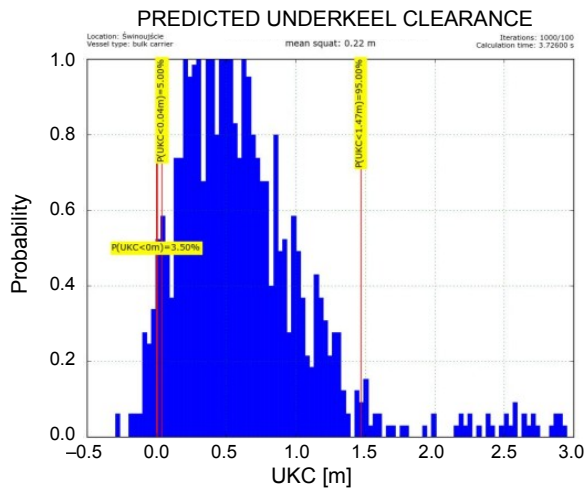


Fig. 3. Results of simulation for ship “Golden Ice” which enter Świnoujście 06.07.2010 at water level = 509, wave height 0.4 m and speed 6 knots

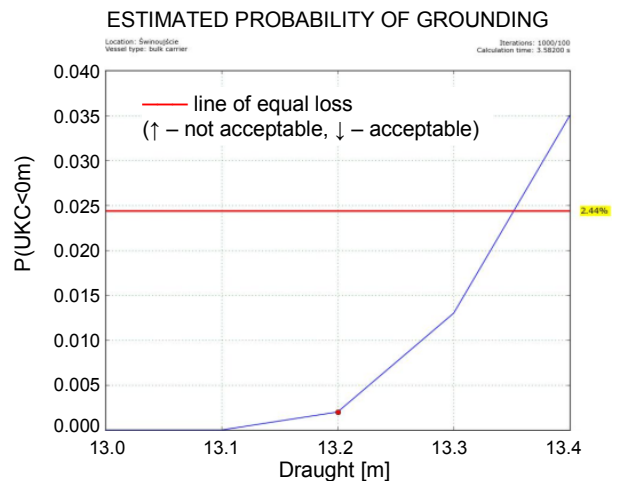
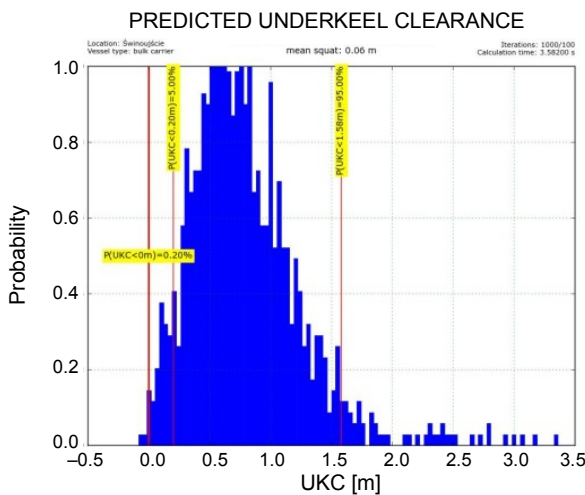


Fig. 4. Results of simulation for ship “Golden Ice” which enter Świnoujście 06.07.2010 at water level = 509 and wave height 0.4 m at speed 3 knots

Integrated system for dynamic underkeel clearance evaluation

On the basis of probabilistic model for UKC determination, Maritime Traffic Engineering Team from Marine University of Szczecin has created an integrated system for UKC evaluation. System was built as an integrated tool which consists of model for UKC calculating, decision model and communication module.

The main algorithm of integrated system is based on probabilistic method for UKC evaluation. In system program execution time was increased, moreover, wave and sedimentation model was rebuilt.

System used cluster for calculation, which main parameters are [6]:

- total logical core number: 40;
- total RAM: 40 GB.

Operating system installed on each cluster node is identical Debian GNU/Linux distribution.

Additionally library used MPICH 2 technology. Main advantages of MPI standard are [6]:

- good effectiveness on multiprocessors architectures;
- great amount of functions;
- good documentation;
- public domain status.

Finally system efficiency was improved. One simulation in probabilistic model for underkeel clearance evaluation is equal 52 s while with MPI non blocking technology it takes 5 s.

Actually research for verify system are carried out.

Conclusions

The model confirms decisions which were made by Port Captains or VTS operators.

Mean probability level of touching the bottom during ships' passages with length over 180 m in years 2009–2011 in Świnoujście is equal 0.018.

Integrated system for UKC determination efficiency was improved.

Further research is needed in reference to verification in case of level of grounding probability by using integrated system for UKC evaluation in Świnoujście port that was no acceptable.

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