TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 14
Number 3
September 2020

DOI: 10.12716/1001.14.03.05

Limitation for Inland Ships in the Area of Planned Multimodal Port on Vistula River

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ABSTRACT: Location study for the investment project entitled Multimodal Platform considering the area of the city of Bydgoszcz and commune of Solec Kujawski last year was published. The examples of existent multimodal ports in Europe show a growing demand for goods transport by the inland waterways. On the basis of the Multimodal Port, it is planned to export cargo from the ports in Gdansk and Gdynia. So, on the Vistula's waterway between Gdansk and Bydgoszcz is the basic rule for navigators is to keep safety distance to the river bottom and on the other hand, to bridge structures. The paper presents limitation for inland ships in the area of planned multimodal port near Bydgoszcz. The analysis of navigation conditions was carried out using probabilistic model of underkeel clearance to verify typical inland vessel traffic on planned port approach. Results of this analysis can be used for further research connected with minimal safety depth determination and risk analysis in study area.

1 INTRODUCTION

A dynamic growth of demand for transport and limited possibilities in the scope of continuous increase of the capacity of the inland transport infrastructure determine the need of providing an alternative, which may be inland water transport. Location the multimodal port in the region of Bydgoszcz and Solec Kujawski ensure for using various modes of transport, which will improve the effectiveness of transshipment process from the area of the Tricity ports. On the basis of the multimodal port, it is planned to export cargo especially container and non-standard load transport from the ports in Gdansk and Gdynia [5]. For safe navigation on restricted area which are rivers is to keep safety distance to the river bottom and on the other hand, to bridge structures. Therefor vertical and horizontal parameters of water area determine safety navigation in stretch Vistula's waterway [2]. In relation to transport for multimodal platform location most important parameters are vertical. Important from one side is minimal safety depth and on the other hand proper vertical clearance under navigational obstructions - power transmissions lines and bridges. Previous research of the Vistula River showed irregularity of hydrological conditions, so ship navigation in particularly large-scale loads transport on long distance is a crucial problem. Bridges, natural rapids and riffles between sandbars are the one of the most important obstacles [3,8]. Navigation on the Vistula River is possible only during strictly defined hydrological conditions (above of average water level in the riverbed). In the paper limitation for inland ships in the area of planned multimodal port in Solec Kujawski was presented. The analysis of navigation conditions was carried out for typical characteristic inland vessels, which could be operated in reviewed stretch of Vistula River. Research results will be used for further analysis underkeel and vertical clearance in study area.

2 STUDY AREA

The importance of the Vistula River as a inland waterway in goods transport is marginal. In the distance Solec Kujawski - Gdańsk (approx. 180 km) there are insufficient navigational conditions for IV class international waterway (Figure 1 A). On the research section Vistula River corresponds to two classes of navigability: II (from km 718+000 to km 910+000) and III (from km 910+000 to estuary to the Gdansk Gulf) [6]. Lower Vistula include approx. 350 km part of river from Narew river. The hydrological regime of the lower Vistula is mostly defined by water flows prevailing in the mid-section of the river as well as the inflow of water from the Narew river. High water levels tend to occur in March and April, less frequently in summer. The former are related to early-spring melt-water runoff, the latter – usually short-term – result from summer rainfalls. In both cases flood waves are formed with a relative height of 3–5 m, maximum of up to 7 m [3]. In this time inland navigation is impossible. The lowest water levels on the Lower Vistula are from August to November, the second part of the navigation season. The annual average water level (AWL) of the Vistula in the Fordon (Bydgoszcz) gauging station for the years 1984–2015 amounts to 319 cm [7]. In this period water levels below AWL was observed for less than 50 days in fourteen navigational seasons. Also in the same period water levels below AWL was observed for more than 120 days only in two years. So generally the average amount of days favorable for navigation in the navigational season is only 59 days. Currently an additional problem is hydrological draught. Drought is defined as a stage below-normal water availability [9]. While this time there are channel forms fragment featuring mid-channel, near-island and lateral sandbars, which modify the depth conditions in waterway, so navigation in this area is very complicated [5, 8].

3 AIM AND METHODS

The location of the Multimodal Platform has possibilities to be connected to the national road (highway A1 Gdansk-Lodz; express way S5 Poznan-Nowe Marzy and main road no. 10 Szczecin-Warszawa) and rail main line network (no. 201 Nowa Wies Wielka – Gdynia; no. 18 Kutno - Pila) so is possibility to increase the importance of the Vistula River Waterway in good transport [5].

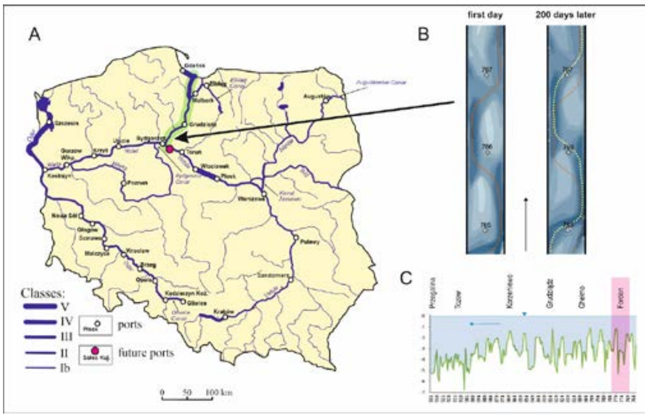


Figure 1. The main study area. (green line) against the background of a map of inland waterways in Poland (A), a diagram of the dynamics of changes in the depth of the riverbed and the location of the Vistula navigation route (B) and depths on the Vistula navigation route from Solec Kujawski to Gdańsk (C) (area for analysis of underkeel clearance highlighted in red).

The aim of this work is assessment of limitation for inland ships in the area of planned multimodal port near Bydgoszcz. The analysis of navigation conditions was carried out to verify typical inland vessel traffic on the Vistula stretch from Gdansk to Bydgoszcz-Solec Kujawski (Figure 1 A). On this stretch of shipping lane is 9 bridge structures and 6 power transmission lines located [10]. Height of power transmission lines is more than 14 m, so they are omitted in this research. Bridges are characterized by highly diversified technical parameters, in particular vertical clearance - from 5.28 to 12.5 m. On the other hand hydrological condition in this place are very specific. For example, average water levels drop below mean low water stages 90 days a year - in dry years, this occurs on 200 days per annum. The lowest water levels are recorded in August, September and November. In addition hydrological regime of the lower Vistula is mostly defined by water flows prevailing in the mid-section of the river as well as the inflow of water from the Narew river. High water levels tend to occur in March and April, less frequently in the summer [3]. The Lower Vistula in study area is characterized by high dynamics of riverbed movement and channel depth changes, which results from the transport of sandy material on the bottom (Figure 1 B).

3.1 *Underkeel clearance analysis assumptions*

In research the own data from depth measurements Vistula River in 36 cross-sections and in the longitudinal profile of the shipping lane were used for determination of mean actual depth in given sections between km 766.0 and km 775.0 (fragment of a waterway - representing small depths at average Vistula’s water flow - Figure 1 C). Channel depth and geodetic measurements were performed in June 2016 using a motorboat equipped with the following devices: single-beam echo sounder (SBES) Teledyne ODOM ECHOTRAC E2 and geodetic rover GPS GNSS Trimble 5800. The morphological mapping were conducted on a digital terrain model (DTM) of the bathymetry based on the collected depth data and geodetic surveys in the field. We used an open-source Geographic Information System software QGIS 2.16.3.

Example of selected cross section is presented on Figure 2.

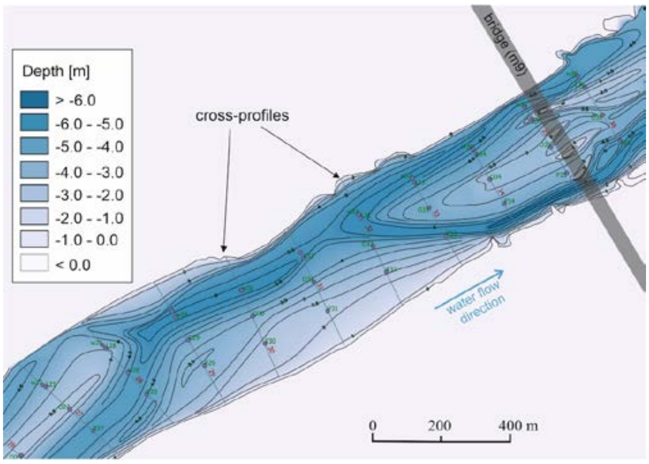


Figure 2. Fragment of the bathymetric map of the Vistula section with marked cross sections and characteristic points using for UKC analysis.

Because of the basic elements which decide of navigation safety in restricted waters is under-keel clearance [2], then next step the values for characteristic vessels for shipping lane were calculated. Next probabilistic model of under-keel clearance (UKC) evaluation for ships was used for safety navigation assessment and calculation probability of grounding.

The application allows to determine of probability of ship's hull contact with the bottom. Also will be helpful to assess whether inland vessels allowed to enter to the port. The model is based on the Monte Carlo method and takes into account depth measurement uncertainty of draught determination, error of squat determination, bottom irregularity, etc. The main assumptions of model was presented in research Gucma and Schoeneich [1]. The research was carried out for two water stages values 275 cm (represented average low water level) and 325 cm (mean water level) on Vistula in Fordon (Bydgoszcz) gauging station.

In navigation area technical – operative parameters of inland vessels determinate class of waterways, so in research typical characteristic inland vessels, which could be operated in reviewed stretch of Vistula River were used [2]. Basic data of the vessels is presented in Table 1. Example of using model for typical barge Zubr is presented on Figure 3.

Table 1. Characteristics of inland vessels using in the research

Vessel	Daniel	Zubr	Bizon	BP500	BM500
L [m]	10,5	20,69	23,6	45,1	57
B[m]	4,5	5,82	8,28	8,98	7,53
T[m]	0,9	0,78	1,15	1,6	1,7

Notifications: L – length, B – beam, T – draught.

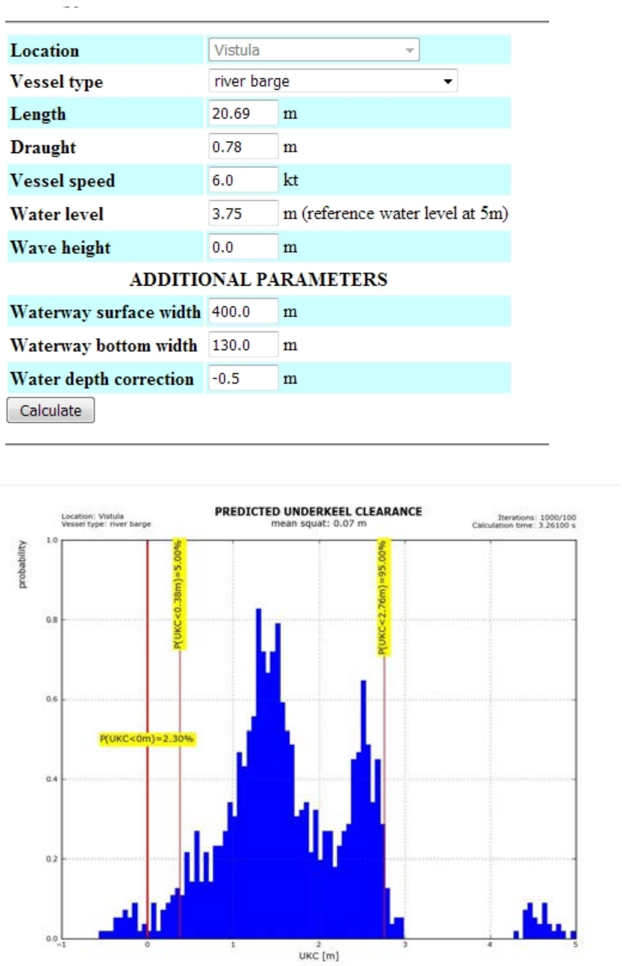


Figure 3. Example of data form and results probabilistic model of UKC application for one of ships which entered planned multimodal port near Bydgoszcz

3.2 *Assumptions for analysis of bridge passages*

Bridges are very important obstructions on inland waterway because potential bridge collapse due to vessel collision often leads to loss of life and significant economic and social consequences. Therefore load parameters in many risk and magnitude analysis for bridges are often controlled. Navigators used their knowledge during condition on particular area and if it if possible they adjust vessel draught [2,4]. In relation to crossing bridges, the initial boundary parameters of the load and barge draft depth - 1.0 m, loading height - 5.80 m (two layers of containers) were assumed. The water level / range of discharge values was determined to safely defeat 9 bridge objects by a barge with a specified load (Table. 2).

Table 2. Bridges structures existing on the Vistula River stretch from Gdansk to Bydgoszcz and determined of vertical clearance and limit values for the high (HWL) and low (LWL) water for safe navigation.

Bridge location*					
code	KM	town/city name	Vertical clearance in meters*	High water level (HWL)	Low water level (LWL)
m1	929.951	Kiezmark	6.79	1.23	-0.80
m2	908.544	Tczew	7.50	6.42	1.75
m3	908.505	Tczew	7.16	6.08	2.73
m4	903.857	Knybawa	9.70	8.62	2.73
m5	868.252	Korzeniewo	12.50	20.21	10.30
m6	834.038	Grudziądz	5.28	18.79	16.43
m7	827.859	A1 Nowe Marzy	7.20	20.71	16.43
m8	807.588	Chełmno	7.80	26.46	21.30
m9	774.809	Fordon (Bydgoszcz)	5.55	29.79	27.00

Taking into account the dimensions of the load, limit values for the high (HWL) and low (LWL) water conditions were determined for 9 bridge objects. Thus, the range of Vistula water levels was determined at which it would be possible to cross the bridge.

4 RESULTS

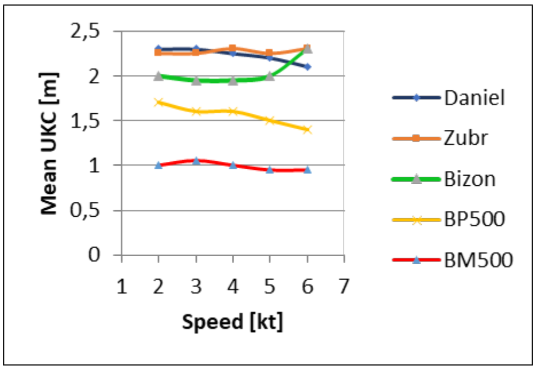
Most important task is to find maximum safe draught of a particular type of ship for port entrance channel. During analysis probability of ship's hull contact with the bottom P(UKC<0), mean squat, UKC on 95% and 5% level of confidence of characteristic inland vessels operated in Vistula stretch were determinate. The research was carried out for five different speed vessel (Table 3). The red color indicates probability of ships grounding accident during the port approach.

Table 3. Results of analysis under-keel clearance for chosen inland vessels at water level (275cm) in Bydgoszcz Fordon

Vessel	Daniel	Zubr	Bizon	BP500	BM500
Mean squat [m]					
at 2knots	0,02	0,02	0,02	0,02	0,02
at 3 knots	0,05	0,03	0,05	0,03	0,03
at 4 knots	0,07	0,05	0,08	0,06	0,05
at 5 knots	0,12	0,08	0,13	0,09	0,08
at 6 knots	0,18	0,12	0,19	0,13	0,12
P(UKC<0)					
at 2knots	0	0	0,006	0,045	0,058
at 3 knots	0,001	0	0,018	0,055	0,061
at 4 knots	0,001	0	0,022	0,053	0,07
at 5 knots	0,008	0	0,021	0,06	0,065
at 6 knots	0,013	0,003	0,023	0,05	0,087

Next probability of grounding in two water stages of Vistula River for real depth on August 20th 2015 was determined. Results of analysis of mean underkeel clearance for typical characteristic inland vessels are presented in Figure 4.

A



B

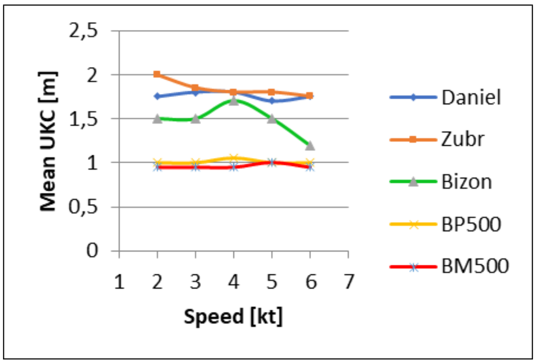


Figure 4. Mean UKC of selected vessels on planned area depending on speed in two water stages: A - mean, 325 cm and B – low 275 cm water level).

Further analysis was carried out for the biggest vessels BM500 and BP500 because estimated probability of grounding was too big and non-acceptable for safety navigation. Example results of analysis for one of the biggest ship which can operate in the study area are presented in Figure 5.

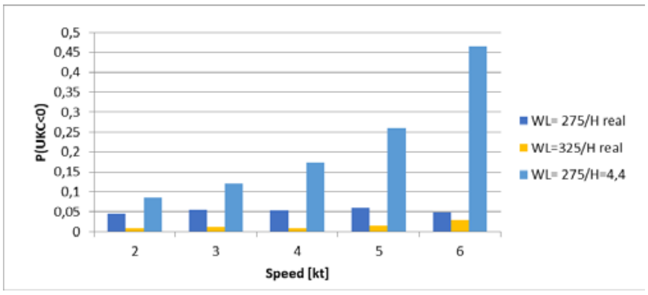


Figure 5. Results of analysis for barge BP500 at different water level and designed and real depth.

Refer to bridges for the period 1984 - 2015 the probability related to the occurrence of problems with crossing a section of the river for each bridge and the number of days allowing navigation was calculated. The research shows that the greatest probability of occurrence of bad conditions values for bridging the winter season occur on the section of the river between Grudziądz (834 km) and Fordon (775 km) (Fig. 6). On the basis of the calculated limits for the high (HWL) and low (LWL) water level, objects were selected for a detailed analysis of the probability of occurrence of bad conditions. The greater the layer thickness between HWL and LWL, the better the conditions for navigation with high load (layers of containers or non-standard loads).

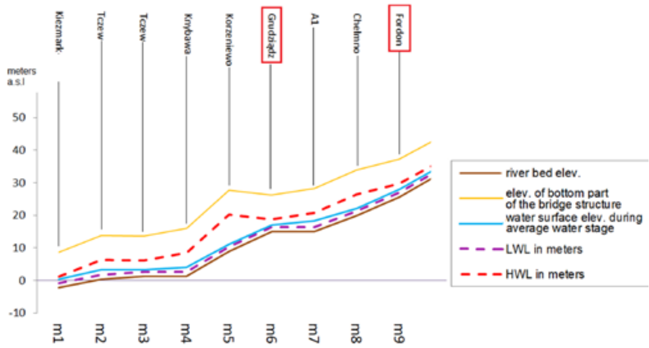


Figure 6. Assessment of navigational conditions on the Lower Vistula in the section from Gdansk to Solec Kujawski for vessels with load

In the tested section of the river there are 9 navigational obstructions (bridges). The biggest difficulties associated with overcoming bridges during non-standard load transport are the Vistula section in Grudziądz (m6) and Fordon (m9) (Fig. 6). In the years 1961 - 2016 for the object m6 on average for 99 days, the water level was too low and for 15 days too high. For the same period, in the winter season (September-April), for 27 days too low and for 11 days too high.

5 CONCLUSIONS

The paper presents assessment of limitation for inland ships in the area of planned multimodal port near Bydgoszcz in relation to vertical parameters.

On the basis of results using of probabilistic model for under-keel clearance evaluation probability of grounding typical inland vessel was determined.

For large inland vessel safety level in analyzed condition was insufficient.

A general analysis of hydrological data has shown that, the biggest difficulties associated with overcoming bridges during non-standard load transport are the Vistula section in Grudziądz, Fordon and Toruń. The probability of inconvenience is over 15% there.

Results of this analysis will be used for further research connected with minimal safety depth determination and risk analysis in reviewed area.

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