



Influence of Bank-effect on Safety of Navigation of Full Form Vessels

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ABSTRACT

Bank effect, in most cases, has been analysed as hydrodynamic effect between fairway and vessel hull. This effect has been approximated with mathematical models or towing tank tests and applied in practice. Proposed models, which are verified and validated, may be used to estimate the vessel motion in the vicinity of the fairway bank. Application of the validated hydrodynamical models is most tangible through the navigational simulators. It is important that simulator is reliable and realistic in order to assure the quality representation of realistic vessel movement. That allows us to use the simulator as a tool to estimate vessel trajectory in various conditions in order to determine the level of safety of navigation. This paper analyses the full form vessels trajectory in vicinity of the sloped banks, using navigational simulator, to determine the model for estimating the minimum distance between vessel and the bank to ensure adequate safety level of navigation.

1. Introduction.

Determining the level of safety of navigation is a process which requires application of all available data and models to estimate whether the passage of the vessel is safe or not. Modern tools, such as navigational simulators, enables reliable representation of the vessel motion which in some cases could lead to the accident. Currently, navigation and manoeuvring simulators are not only used for training. According to Czaplewski et al. (2021) They also may be used in research related to the broadly understood human activity in marine areas. One of the activities is a navigation in port approach where different effects on vessel hull may occur. Bank effect is a well-known phenomenon which occurs in vicinity of the fairway bank. It is described as the asymmetric flow around a vessel induced by the vicinity of banks causes pressure differences between port and starboard sides. Authors Lataire et al. (2007) indicate that

results in lateral force acting on the vessel, mostly directed towards the closest bank, as well as a yawing moment pushing the bow towards the centre of the waterway. That asymmetric flow and pressure differences may affect the manoeuvring performance of the vessel considerably, especially in extremely shallow channels and canals, making it difficult to steer. The vessel may collide with the side bank and/or run aground according to Serban et al (2015).

Distance between the bank and the vessel, to avoid adverse effect, is determined either by recommended guidelines or is modelled by specific case. Modelling sometimes can be time and budget consuming, so various guidelines have been developed. Some of the recommendations are PIANC (2014) Harbour Approach Channels Design Guidelines Report No. 121-2014, Puertos Del Estado Recommendation for Maritime Works ROM 3.1-99, Designing Maritime Configuration of Ports, Approach Channels and Floatation Areas, and the Japanese Ministry of Land, Infrastructure, Transport and Tourism. These recommendations are based on former research data and may differ on vessel type and used method. The distance from the bank to avoid the adverse effect is determined on vessel speed and the

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type of the slope. It has been noticed that in all recommendations the sloped bank is less present, however there has been accidents which disprove such recommendations. The most known is Ever Given in Suez Canal, and one similar which is analysed is APL Danube in Transport Malta report (2020).

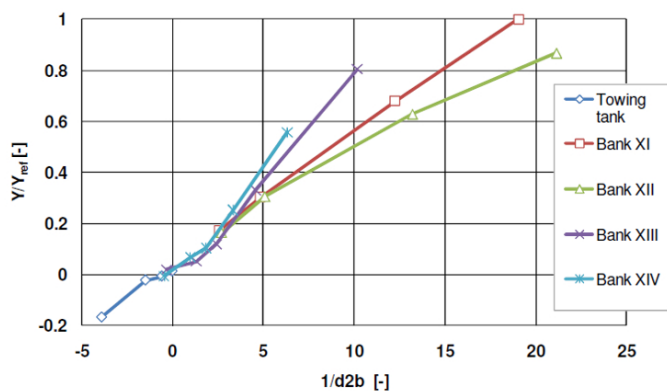
This paper analyses the additional distance between the vessel and the sloped bank, using navigational simulator, to avoid adverse effect. The result and proposed model are then analysed and presented in relation to vessel width, to make it easy to access and apply in practice.

2. Application and Reliability of Navigational Simulators.

The navigational simulator is nowadays a resource which is developed to be used as teaching aid and research tool. That is possible due to reliable, proven and certified mathematical models used in simulation process. These models were developed by real vessel data or towing tank models by Lataire et al (2014). Every new generation of simulator is further developed and improved which allows the usage in evaluation phase of project evaluation state Senčič et al (2020). In this paper real time simulator Watsila Navi Sailor 5000 v5.35 was used in simulation process. According to the paper Senčič et al (2020) real time simulators represent vessel control as in real life. Also, real time simulator can be used for validation of mathematical model or to contribute studies in which a new navigational situation is created. Similar effects were researched, using navigational simulators, for container vessels in vicinity of sloped banks by authors Baric et al (2019, 2021).

In this paper validation was conducted through data comparison, between simulated data and towing tank results.

Figure 1: Values of vessel bank lateral forces for VLCC model at speed of 10 knots, and 50% of UKC in towing tank.



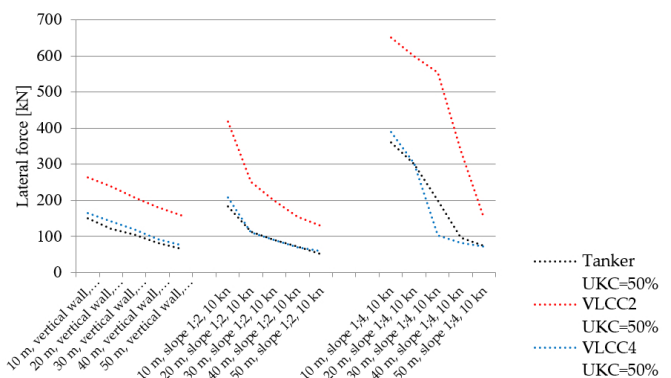
Source: Elliot et al 2011.

In figure 1 are the results of lateral vessel bank forces for the VLCC vessel model in towing tanks. In this research the different slopes of embankment were used. Towing tank is modified to simulate several types of the banks such as: Bank XI – 1/1 slope, Bank XII – Vertical wall, Bank XIII – 1/3 slope and Bank XIV – 1/4 slope. In this specific analysis, vessel model

was sailing at speed of 10 knots with 50% of UKC (the under-keel clearance was half of the vessel draft). The x axis represents the distance from the centre of the fairway, where the value 0 represents the middle of the fairway. The lateral force value in the y axis is defined as relative lateral force (the ratio of the maximum and measured force). The blue and purple lines are the forces results of the banks with larger ratio (the ratio of 1/4 represents that the bank slope is the 4 times larger than the bank height). The forces of sloped banks are close to the centre of the fairway because the test was conducted to the start of the slope (the vessel didn't cross over the embankment). However, if we compare the forces to those of the vertical wall and 1/1 slope it can be seen that the force trend of sloped banks is larger.

These data were compared to the simulated data gathered in similar conditions. Figure 2 represents the simulator derived lateral forces for three tanker models, at different embankment types. For the comparison, same vessel speed was taken and the same UKC condition. The only difference is that in simulated data, vessel was sailing over the embankment. It can be seen that the data trend is similar to data in figure 1. The larger leap in forces occurs in the moment when the vessel crosses over the embankment. This data proves the reliability of simulated data and confirms that the results can be used to estimate the vessel trajectory in the vicinity of the bank.

Figure 2: Values of vessel bank lateral forces for three tanker model at speed of 10 knots, and 50% of UKC in real time simulator.



Source: Authors.

3. Simulation Process.

Real time simulator uses validated models to represent reliable and credible navigation condition. In this research the full form vessels are three tanker models (Table 1).

The tanker models were tested in fairway with sloped bank. For the purpose of the research only one bank fairway was used, due to the conclusion that if the vessel approaches one bank other one is far away to produce significant force. That conclusion was drawn from the simulations which showed that distance larger than 50 meters from the bank doesn't produce force large enough to impact on vessel trajectory. Distances

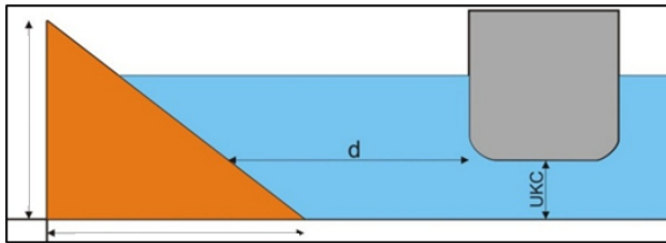
Table 1: Tanker models, used in simulations, detailed information's.

Vessel model	Displacement (t)	DWT (t)	LOA (m)	Breadth (m)	Draft (m)	Displacement coefficient
Oil tanker	77,100	67,980	242.8	32.2	12.6	0.82
VLCC 2	321,260	279,400	332	58	20.82	0.81
VLCC4	137,092	116,000	249.9	44	15.5	0.83

Source: Authors.

were measured from the point of grounding to the vessel hull at frequency of 10 m (Figure 3).

Figure 3: Measured distance from the sloped bank to the vessel.



Source: Authors.

The one of the main purposes of this research was to determine if trajectory in the vicinity of the bank, at different sailing speeds and at which distance, imposes a risk to safety of navigation. That risk to safety of navigation would occur in situations when vessel cross track error exceeds vessel bank distance “d”. Simulated vessels speeds were 5, 7.5 and 10 knots and UKC were 50% of the draft and 20% of the draft.

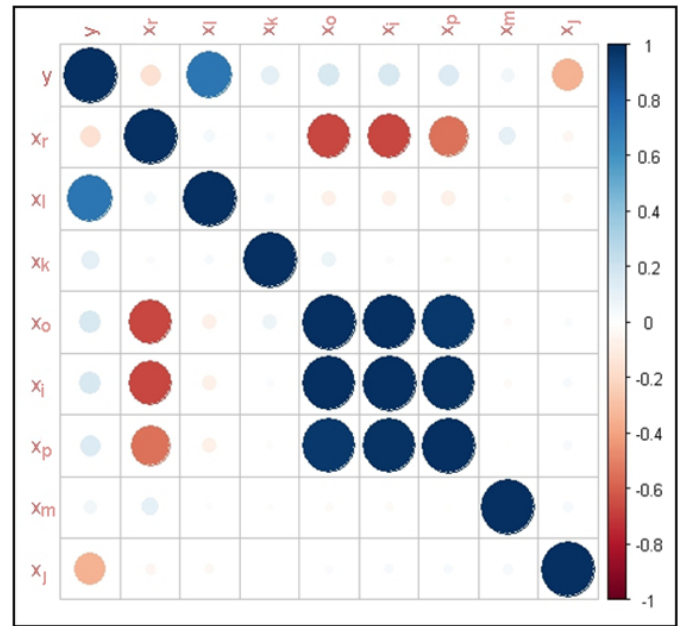
To eliminate human error and to achieve uniformity of the simulation's vessel steering was set to auto pilot. The auto pilot has two settings, head control and track control using PID regulators. In head control vessel is set to maintain determined course and in the track control vessel is set to maintain predetermined track. In track control the autopilot will react in case of vessel yawing and drifting, while in head control that will occur only in case of a yawing. The helmsman at the wheel will also react on vessel yawing and drifting and that is the reason why the track control setting was used in simulations.

Described scenarios were simulated in over 500 real time simulations which took over 250 hours.

4. Results Discussion.

To understand and to evaluate the results, Pearson correlation analysis between fairway and vessel elements was conducted (Figure 4). The blue dots show positive correlation and red dots negative correlation, and the size of the dot show the amount of correlation. Analysed elements were cross track error (y), lateral distance to grounding point (xj), bank slope (xk), vessel speed (xl), depth draft ratio (xm), vessel displacement and LOA ra-tio (xn), vessel displacement (xi), LOA (xo), vessel breadth (xp) and displacement coefficient (xr).

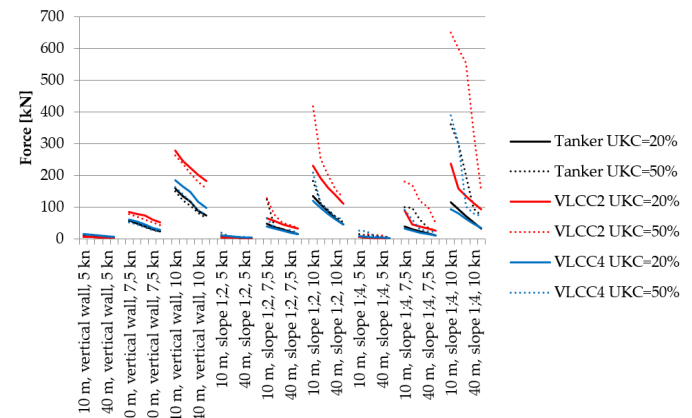
Figure 4: Pearson correlation diagram for simulation parameters.



Source: Authors.

The results in figure 4 show positive correlation between vessel dimensions itself. However, the main purpose of the simulations was to determine vessel cross track error (y) caused by bank effect. It can be seen that positive correlation was detected with vessel speed (xl) which means that if the vessel speed is increased then the cross-track error will be also increased. The slight indication of positive correlation was detected with vessel dimensions. The negative correlation was detected with the vessel lateral distance from the grounding point (xj), which indicates that lowering the distance from the bank in-creases vessel cross track error.

Figure 5: Values of vessel bank lateral forces for three tanker model at speeds of 5, 7.5 and 10 knots, 50% AND 20 % of UKC in real time simulator.

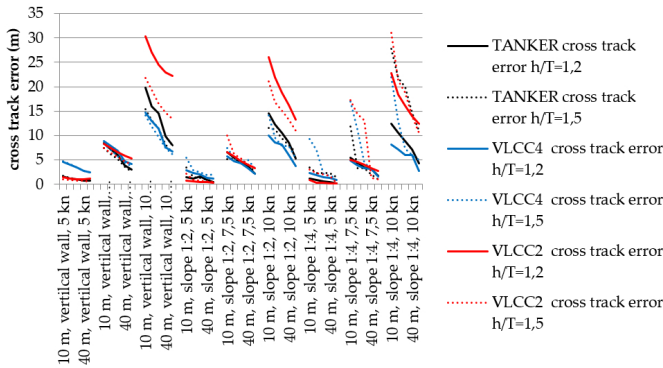


Source: Authors.

In figure 5 are shown lateral ship bank forces generated in

simulations. It can be seen that lateral force between vessel and the bank increases significantly with vessel speed and larger UKC. Larger UKC increases forces due to the fact that, due to greater distance from the seabed (UKC), vessel is able to cross more over the slope. With the larger UKC, the vessel can significantly cross over the fairway embankment and increase blockage factor as approaches the grounding point. Larger lateral forces will generate larger cross track error, ie. vessel will oscillate in its trajectory what in final could end up in grounding. Figure 6 shows cross track error caused by generated lateral force between the vessel and fairway bank.

Figure 6: Simulation gathered full form vessels cross track error.



Source: Authors.

Simulated data was used to define the model, for the similar vessel types and fairway conditions. In this case multiple polynomial regression was used. This regression use unknown parameters and their estimation using least squares method. In this model the estimation of coefficients is made using the given expression:

$$\varepsilon(a) = \sum_{1 \leq j, X_j, X_k, X_l, X_m, X_n \leq 5} (y_1 - y_{X_j, X_k, X_l, X_m, X_n})^2 = \min_a. \quad (1)$$

where term y_1 represents results from measurements and terms $y_{(X_j, X_k, X_l, X_m, X_n)}$ are modelled results using input parameters. The model is validated using the adjusted multiple correlation coefficient defined by the following expression:

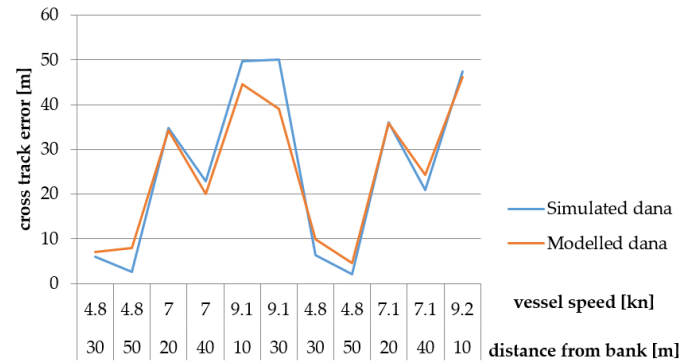
$$R_{\text{corr}}^2 = 1 - \frac{y_1 - \hat{y}_1}{y_1 - \bar{y}_1} \cdot \frac{n-1}{n-k-1}. \quad (2)$$

where n represents the number of input data, k the number of regression coefficients, $\hat{y}_1$ are modelled data and $\bar{y}_1$ represents arithmetic mean of the dependant input variables. The best result for the model was generated using multiple polynomial regression of the fourth degree, and the model final expression is:

$$y = a_0 + \sum_{j=1}^5 a_j x_j + \sum_{1 \leq j, k \leq 5} a_{jk} x_j x_k + \sum_{1 \leq j, k, l \leq 5} a_{jkl} x_j x_k x_l + \sum_{1 \leq j, k, l, m \leq 5} a_{jklm} x_j x_k x_l x_m + \sum_{1 \leq j, k, l, m, n \leq 5} a_{jklmn} x_j x_k x_l x_m x_n. \quad (3)$$

where a represents regression coefficients. There are 92 regression coefficients in this ex-expression. The accuracy of the model expressed by the corrected multiple correlation coefficients is 0.9746. To validate the model, a comparison between certain modelled and simulator gathered vessel cross track error (vessel movement from the desired track due to vessel bank forces) is shown in Figure 7.

Figure 7: Comparison between modelled and simulated data.



Source: Authors.

Data obtained from simulator, and consequently for similar vessel types in similar conditions from proposed model, can be used to estimate safe sailing distance from the bank in order to avoid adverse effect of bank effect. Also, that data can be compared to vessel bank distance proposed by fairway design recommendations. Table 2 shows comparison between the modelled vessel bank distance for full form vessels and existing vessel bank distance recommended by fairway design standards. The distance is showed as relation of vessel breadth.

Table 2: Comparison of sailing distance from the bank for full form vessels.

SPEED [KN]	Bank type	20 % UKC					50 % UKC					FAIRWAY DESIGN RECOMMENDATIONS		
		10 m	20 m	30 m	40 m	50 m	10 m	20 m	30 m	40 m	50 m	PIANC	ROM 3.1	MLIT
5	Vertical wall	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.5 B		
7.5		0.2 B	0.2 B	0.2 B	0.1 B	0.1 B	0.2 B	0.2 B	0.1 B	0.1 B	0.1 B	1.0 B		1.1 B
10		0.7 B	0.6 B	0.6 B	0.5 B	0.5 B	0.5 B	0.4 B	0.4 B	0.3 B	0.3 B	1.3 B		
5	Slope 1:2	0.1 B	0.1 B	0.1 B	0.1 B	0.0 B	0.1 B	0.1 B	0.1 B	0.1 B	0.0 B	0.3 B	0.6 B	
7.5		0.2 B	0.1 B	0.1 B	0.1 B	0.1 B	0.2 B	0.2 B	0.1 B	0.1 B	0.1 B	0.5 B	1.0 B	
10		0.5 B	0.5 B	0.4 B	0.4 B	0.3 B	0.5 B	0.4 B	0.3 B	0.3 B	0.2 B	0.7 B	1.4 B	
5	Slope 1:4	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.1 B	0.0 B	0.0 B	0.0 B	0.3 B	
7.5		0.2 B	0.1 B	0.1 B	0.1 B	0.1 B	0.4 B	0.3 B	0.2 B	0.1 B	0.1 B	0.1 B	0.5 B	
10		0.5 B	0.4 B	0.4 B	0.3 B	0.3 B	0.7 B	0.5 B	0.4 B	0.3 B	0.2 B	0.2 B	0.7 B	

Source: Authors.

It can be seen that recommended distances are larger for vertical wall than the sloped banks. The results show that sloped bank is, in particular cases, far more dangerous than vertical wall. The sloped bank sailing distance should be considered specifically for each situation, particularly its adverse effect in case of sailing over the bank slope. Such situations, as results showed, increase risk of grounding significantly.

5. Conclusions.

The influence of bank effect on safety of navigation may be significant. Vessel grounding may not be caused just by bank effect; however its influence can be crucial. Verified bank effect model applied through navigation simulator showed that sloped banks, contrary to some recommendations, can be significant in causing vessel cross track error and consequently cause its grounding. Understanding the bank effect in sloped banks, especially when sailing over the slope, can improve the safety of navigation. Proposed model and derived distances may be used in determining the adequate level of navigation. It is necessary to take in consideration all available data and models and apply them to prevent situation which could lead to increased navigation risk levels.

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