Bank effect and operation of inland waterways vessels

Lech Kobyliński
Foundation for Safety of Navigation and Environment Protection
80-278 Gdańsk, Chrzanskiego 36, e-mail: lechk@portilawa.com

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Abstract
Inland waterways vessels operate in waters of restricted depth and restricted width with cross-section of the waterway of different profile. These conditions affect hydrodynamic forces acting on the vessel and in consequence they affect their operation. There are several hydrodynamic effects present in inland waterways. Restricted depth and cross-section of the canal or river affects resistance of the vessel and hydrodynamic characteristics of the propeller and in consequence propulsive efficiency. Another effect is caused by modification of pressure distribution around vessel body resulting in change of draft, so called squat. Finally in narrow fairway lateral forces on the vessel are created and in case of non-symmetrical position of the vessel, those forces are also non-symmetric and causing that the vessel is pushed to one side. This affects safe handling of the vessel and requires understanding and skill of operator. This problem is discussed in the paper.

Introduction
Amongst other causes of accidents at sea casualties related to manoeuvrability happen quite often and analysis of casualties shows, that CRG casualties (Collisions-Ramming-Groundings) constitute about 53% of all serious accidents leading to ship loss [1]. This figure applies to deep sea navigation and similar data for inland navigation are not available, but it may be assumed, that also in inland navigation the proportion of CRG casualties could be similar. Collisions may happen more often in restricted waterways and canals and in particular in areas, where additional external factors, as e.g. current, make handling of ships more difficult.

The system of safety against CRG casualties, as shown in figure 1 is rather complex [2], because of numerous interrelations between various sub-systems. However, restricting only to ship operation it would be necessary to consider only the part of it, as marked in figure 1 by thick lines.

According to the Payer [2] and also to other sources human and organization errors (HOE) are constituting major causes of CRG casualties (about 70 to 80%) they require special attention. HOE may be the result of design and construction faults (bad manoeuvring characteristics of ships) and force majeure, that are responsible for about 20% of all HOE casualties, the rest may be attributed to operational factors that include the following [3]:
- society and safety culture;
- organization;
- system;
- human performance (individual).

Fig. 1. Safety system for CRG casualties (after [2])
Amongst other factors, human performance and safe operation strongly depends on operator understanding of physical phenomena governing vessel motions in shallow water areas, canals and rivers with restricted depth and width, with bends and often also with current present. This is even more important than in open sea navigation, because in inland navigation vessels are always manoeuvring in conditions, where close proximity interaction effects are strong. This understanding may be achieved by proper education and training. The training is particularly important, it could be performed on board ships or on simulators, either Full Mission Bridge Simulators (FMBS) or on Manned Models Simulators (MMS). In this paper, stress is put on consideration of training using MM simulators.

There are two important features of navigation environment in inland waterways: shallow water and proximity of shore, recently often defined as bank effect. The purpose of this paper is to consider, how to achieve the understanding bank effect as a physical phenomenon and to consider ways, how to teach vessel operators to use manoeuvre vessel in proximity of the bank.

**Bank or wall effect**

The well known phenomenon occur, when the vessel is sailing close to a solid wall or bank or shore line. In this case force and yawing moment are created usually trying to push it towards the bank and to reject the bow from the bank causing the vessel swing, that may result with stern hitting the bank. Experienced mariners know that, if they use the rudder towards the bank, it will counteract the swing and the passage will be safe.

This phenomenon may be explained in a simple way.

When the ship is close to the bank, then counter flow is created between the bank and side of the ship and because of the reduction of the flow cross section area between the ship and the bank. This effect is governed by the continuity law. On the other side of the ship, the flow cross-section area is not reduced and the water velocity does not change (when comparing to the open-water situation).

If water velocity increases, then according to the Bernoulli’s law the dynamic pressure increases and in consequence static pressure is reduced causing the water level sinkage. The difference of pressures on both ship sides creates a force, that is directed from the higher static pressure area towards the lower static pressure area. This is the suction force drawing the ship closer to the bank (Fig. 2).

The bow of the ship on the other hand is rejected from the bank because of the increased pressure around the bow (bow cushion) of the moving ship and proximity of the bank. As a result a yawing moment is pushing its bow away from the bank (Fig. 2).

This is simple explanation of the bank effect as it is experienced in majority of cases, but in does not include the possible effect of propeller race. The propeller race caused by the working propeller may affect the flow around the ship in situation, when the under keel clearance (UKC) is very small and the suction force towards the bank may then actually became repulsion force pushing the ship away from the bank. Also with very small UKC and close proximity to the vertical bank, there is the possibility, that suction force could become negative and repulsion occurs. In that case it was observed that the wave created in the space between the bank and the ship is larger as on the other side [4].

**Estimation of the suction force**

The general bank effect is proportional to the speed of the ship squared and inversely proportional to the distance from the bank. However, it is influenced also by other factors.

Figure 2 shows the simplest case, when ship is sailing close to the vertical wall with quite large under the keel clearance (UKC). However, in practice this situation happens rarely, and usually shape of the river or canal bank is different. Some other possibilities are shown in figure 3.

Figure 3A shows canal with large UKC and sloping bank. Figure 3B shows sloping bank but small UKC. Figure 3C shows canal with sloping bank with step. Figure 3D shows canal with sloping bank dredged in shallow water. Obviously, there are many more arrangements and also the sloping
banks may be different inclinations. All of these factors may influence the suction force and yawing moment.

![Different forms of banks](image)

Fig. 3. Different forms of banks (draw by the author)

The effect of the bank form was investigated by several authors. Duffy [5] investigated bank effect experimentally. Model of a bulk carrier without propulsion was tested in 60 m long towing tank. The model was attached to the towing carriage and was fully constrained in surge, sway and yaw and towed parallel to the bank with different values of UKC. The distance to the nearest vertical bank was equal to the half breadth of the model. The results obtained are shown in figures 4 and 5 (after [5]).

In figure 4 non-dimensional sway (or suction force) is plotted against the vessel draught to UKC coefficient (d/UKC). It may be seen, that sway force is positive (repulsion from the bank) when the d/UKC coefficient is higher than about 5.2, in other words, when UKC is very small. Otherwise attraction towards the bank occurs as anticipated. On the other hand yawing moment (Fig. 5) was always positive, that means that bow is always rejected from the bank.

However, in the test referred to, the model was restrained. UKC was measured at zero speed.

![Effect of vessel draught to UKC ratio on sway force](image)

Fig. 4. Effect of vessel draught to UKC ratio on sway force (after [5])

![Effect of vessel draught to UKC ratio on yaw moment](image)

Fig. 5. Effect of vessel draught to UKC ratio on yaw moment (after [5])

At speed squat is reducing UKC, but this effect was not considered. Also the model was without propulsion, but in reality propeller race may affect sway force and yawing moment. This was pointed out by Lataire et al [6, 7].

The important conclusion from the tests performed was the effect of flooding of the bank of the canal. If the bank is flooded there occurs rapid decrease of sway force and yawing moment and this effect depends strongly on the depth of the water above the bank.

Lataire et al [6, 7] investigated effect of bank slope and of the bank with platform submergence on suction force and yaw moment acting on the passing ship. Table 1 provides overview of the tested banks. They included two types of banks, namely (Fig. 6):

- Surface piercing banks, characterized by a constant slope from the bottom up to the free surface;
- Banks with platform submergence, composed of a sloped part with height $h_0$ and a horizontal submerged platform at a depth $h_1$ ($h_1 = h - h_0$).

![Overview of the tested banks](image)

Table 1. Overview of the tested banks (after [6])

<table>
<thead>
<tr>
<th>Name</th>
<th>$h_0$</th>
<th>$\alpha$</th>
<th>Define $y_{oa}$</th>
<th>$y_{sub}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Surface piercing</td>
<td>Vertical wall</td>
<td>2.830 m</td>
<td>–</td>
</tr>
<tr>
<td>II</td>
<td>Surface piercing</td>
<td>1/5</td>
<td>0.530 m</td>
<td>–</td>
</tr>
<tr>
<td>III</td>
<td>0.120 m</td>
<td>1/5</td>
<td>0.530 m</td>
<td>2.370 m</td>
</tr>
<tr>
<td>IV</td>
<td>0.150 m</td>
<td>1/5</td>
<td>0.530 m</td>
<td>2.220 m</td>
</tr>
<tr>
<td>V</td>
<td>Surface piercing</td>
<td>1/8</td>
<td>0.530 m</td>
<td>–</td>
</tr>
<tr>
<td>VI</td>
<td>0.150 m</td>
<td>1/8</td>
<td>0.530 m</td>
<td>1.770 m</td>
</tr>
<tr>
<td>VII</td>
<td>Surface piercing</td>
<td>1/3</td>
<td>2.230 m</td>
<td>–</td>
</tr>
</tbody>
</table>

Bank I is a vertical wall analogous to berthing quay wall. Bank VII is surface piercing with slope of 1/3 which is common slope in man made canals. Slope 1/8 is very common for natural river banks.
In the test programme three models were used: container, LNG and tanker ship. All tests were executed in the towing tank belonging to Flanders Hydraulics Research – Ghent University.

The models were tested for each loading condition in different values of UKC, usually 10, 35 and 100% of the draft.

Bank or wall effect will only be felt if the distance between the ship and bank is sufficiently small. The distance at which bank effect is practically felt, may be defined as the boundary between restricted and unrestricted water. This distance is defined as a horizontal reach [6]. Systematic tests conducted by allowed to develop expression for horizontal reach, that depends on ship speed. Those tests were performed with a tanker model at combination of speed and water depth and the results were plotted as shown in figure 7. In this figure three ranges were determined:

- if the distance to the bank is sufficiently large, the influence of the closest bank on the ship is negligible (∆);
- close to the bank, a significant influence is generated (□);
- in between, the influence is measurable, but not significant (◊).

The division in three ranges was carried out for all UKC-speed combinations and shown in (Fig. 7) as a function of the non-dimensional parameter defining the distance between the bank and the ship’s side relative to the ship’s beam and the water depth related to Froude number. The dividing line between combinations with significant influence and without significant influence shows dependency on the Froude number related to water depth:

$$y_{\text{inf}} = B(5F_{rh} + 5)$$

The above value may be considered as the half width of the influence zone for bank effects.

The figure 8 shows the relation of distance between the ship and the bank and suction (sway) force for seven different bank geometries tested by Lataire and al [6, 7] for the container ship at 10 knots speed (full scale), with 100% UKC. The distance from the bank is defined at half draft of the ship as shown in figure 6.

Lataire et al [6, 7] and also Chen & Sharma [8] presented mathematical model simulating the above described phenomena, however, these models had severe limitations. The models are not valid for extreme situations where the ship is very close to quay or wall or where it is going aground. The mathematical model by Lataire is based on the results of model tests where the ship is moving forward with positive propeller revolutions (quadrant 1), therefore is not applicable to manoeuvring situations and therefore only with limited possibilities to be used in manoeuvring simulators.
All the above considerations apply to ships fitted with conventional propulsion. There are virtually no data available with regard to vessels with other propulsion devices, for example Voith-Schneider propellers or water-jet propulsion devices. The forward rotating propeller changes the flow pattern around the vessel body and different propulsion devices may affect those changes to some extent, although it seems that this effect is small and possibly even negligible. There are, however, no data available to proof this conclusion.

When manoeuvring close to the bank it is important to assess the magnitude of the suction force, that depends mainly on the distance from the bank and speed of the vessel, but also from the shape of the bank as shown in figure 8. Experimental data or mathematical simulation may provide appropriate data, that could be used in programming manoeuvring simulators, but when handling the vessel helmsman must judge the forces himself on the basis of practical experience and training and accordingly use counter rudder.

Training for safe manoeuvring close to bank

For sea going ships training mariners in ship handling is required by the International Maritime Organisation. Seafarers’ Training, Certification and Watchkeeping (STCW) Code, Part A, which includes mandatory standards regarding provisions of the Annex to the STCW Convention. Apart from the training onboard ships, approved simulator training or training on manned reduced scale, the ship models are mentioned there, as a method of demonstrating competence in ship manoeuvring and handling for officers in charge of navigational watch and ship masters.

There are no such requirements for an inland waterways navigation, however, in some training centres, as for example in University of Duisburg skippers of inland waterways vessels are trained on Full Mission Bridge Simulator equipped for this purpose [9].

Obviously, the best way to train ship officers and pilots in ship handling and manoeuvring is to perform training onboard the real ships. Any use of simulators should be in addition to training onboard ships. However, gaining skill “on job” watching experienced practitioner working is a long and tedious process. Moreover certain handling situations including some critical ones, may never occur during the training period onboard ships and no experience, how to deal with such situations could be gained this way. When serving on ships engaged in regular service, there is little or no possibility to learn about handling in critical situations because such situations must be avoided as far possible.

There are two ways of training ship officers and pilots in manoeuvring and ship handling, apart from onboard training: using electronic bridge simulators or scale manned ship models. The simulator training is expensive, therefore the simulator courses must utilize time available in the most effective way. In order to achieve positive results simulator must be properly arranged and the programme of simulator exercises should be properly planned in order to achieve prescribed goals [10].

Ilawa Ship Handling Research and Training Centre (SRTC) uses manned models for training purposes. It is fully equipped also for training on models of inland waterways vessels, although currently no such model is available.

Manned scale models are used for training purposes in open water areas. Models are sufficiently large in order to accommodate 2–4 people (students and instructors) and are constructed according to laws of similitude. The models are controlled by the helmsman and are manoeuvring in the areas, where mock-up of ports and harbours, locks, canals, bridges piers and quays, shallow water areas and other facilities are constructed. In the certain areas current is also generated. As a rule, monitoring system allowing to monitor track of the model is available.

In the case of manned models the governing law of similitude is Froude’s law and all quantities for models are calculated, according to the requirements of this law. Important feature of the manned model exercises is that all manoeuvres are performed not in real time, but in model time which is accelerated by the factor $\lambda^{-1}$.

At present, the Ship Handling Research and Training Centre (SHRTC) represents a modern facility, perfectly capable to perform research projects related to manoeuvrability as well as training of ship masters and pilots in manoeuvrability.

As safe handling of ships is much more difficult in restricted areas and in presence of the current, in Ilawa Ship Handling Centre there are artificially prepared training areas, that apart from the standard model routes marked by leading marks, leading lights (at night) and buoys, also includes the routes, particularly suitable for training ship handling in the canals and shallow and restricted areas. They include:

- restricted cross-section canal of the length 140 m (corresponding to 3,5 km in reality);
- wide (corresponding to about 360 m width in reality) shallow water canal of the length corresponding to about 1,5 km, where current could
be generated from both sides, called Chief’s Canal;
– narrow fairway restricted from one side by the shore, called Bank Effect Route.

The above arrangement of training areas provide ample opportunities to train ship masters and pilots to handle ships in difficult navigation situations, in particular in those, that may be present in inland waterways, where strong interaction effects between ships and environment are present.

In order to show the arrangement of practical exercises that are performed during the standard five-days ship handling courses, one example is shown. This exercise intended to train passage in the proximity of vertical bank feeling bank effect.

Example: Feeling bank effect and suction force. The ship is sailing in the narrow fairway parallel to bank of the canal or river (Fig. 9). The suction force causes that the body of the model is sucked towards the bank and the bow of the model due to compression of the bow cushion is rejected from the bank having the tendency to swing. The trainee is instructed to counter this effect use the rudder towards the bank.

Conclusions

Training in ship handling is of ship masters and pilots generally, recognized as an important factor contributing to enhancing safety of ships at sea. However, possibilities of training using manned models are rather limited and currently, only three centres in the world well prepared to perform such training. One of these is Ilawa Research and Training Centre, the other two are in Timsbury – (Southampton area) – and the oldest one, Port Revel near Grenoble in France. During recent years, however, growing demand for such training may be noticed and advantages of it are recognized, although, training using manned model is not compulsory, but recommended only by the STCW Convention. Because of possibilities of training of mariners in ship handling in confined areas, canals and waterways, this type of training can be useful for ship masters and mates, handling inland waterways ships.

References