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Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/99869

Vorgeschlagene Zitierweise/Suggested citation:
Redondo, R.; Atienza, R.; Trejo, I.; Verdugo, I.; Iribarren, J. R. (2016): Bank Effects Modelling in Real-Time Manoeuvring Simulations. In: Uliczka, Klemens; Böttner, Carl-Uwe; Kastens, Marko; Eloot, Katrien; Delefortrie, Guillaume; Vantorre, Marc; Candries, Maxim; Lataire, Evert (Hg.): 4th MASHCON - International Conference on Ship Manoeuvring in Shallow and Confined Water with Special Focus on Ship Bottom Interaction. Karlsruhe: Bundesanstalt für Wasserbau. S. 217-224.
https://dx.doi.org/10.18451/978-3-939230-38-0_26.

4th MASHCON, Hamburg - Uliczka et al. (eds) - © 2016 Bundesanstalt für Wasserbau ISBN 978-3-939230-38-0 (Online)
DOI: 10.18451/978-3-939230-38-0_26

BANK EFFECTS MODELLING IN REAL-TIME MANOEUVRING SIMULATIONS

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SUMMARY

Navigation in restricted waters or within a fairway with asymmetrical banks might be exposed to additional "undesirable" external forces. The forces produced by bank effects can reach considerably high values and therefore bank effects should be included in manoeuvring models. Modelling of bank effects can be performed by using specific numerical models which can be used to obtain the six degrees of freedom hydrodynamic forces over the vessel hull. Those forces are then used to estimate the bank coefficients of the numerical model of the vessel for a specific fairway-vessel configuration which can be used as input parameters in real-time manoeuvring simulators. An example of the beneficial use of bank effects to keep a vessel within the fairway with reduced usage of vessel rudder, as performed by Pilots in real manoeuvres, is explained within the paper. Nevertheless, using bank effects (i.e. using the yaw moment created by bank effects to turn at the bends) should only be performed by trained and very experienced Pilots or Masters, as suction/repulsion forces can reach values higher than those the vessel rudder is able to compensate.

NOMENCLATURE

B	Vessel's beam (m)
w	Width of the channel (m)
h	Mean depth of the channel (m)
β	Blockage parameter (-)
α	Asymmetry parameter (-)
μ	Moment multiplication factor (-)
u	Vessel's forward speed (m/s)
v	Vessel's lateral speed (m/s)
UKC	Under Keel Clearance
CFD	Computational Fluid Dynamics
ROPES	Research on Passing Effects of Ships
MARIN	Maritime Research Institute Netherlands
PIANC	The World Association for Waterborne Transport Infrastructure
CEDEX	Centro de Estudios y Experimentación de Obras Públicas

1 INTRODUCTION

Navigation in restricted waters or within a fairway with asymmetrical banks might be exposed to additional "undesirable" external forces due to an asymmetry on the flow surrounding the vessel on her movement. The forces produced by bank effects over the vessels can reach considerably high values and therefore bank effects should be included in manoeuvring models both for port design and training and education of Pilots and Masters.

Modelling of bank effects can be performed by using specific numerical models which can be used to obtain the hydrodynamic forces over the vessel hull. Those forces are then used to estimate the bank coefficients of the numerical model of the vessel for a specific fairway-vessel configuration which can be used as input parameters in real-time manoeuvring simulators.

As any external force, bank effects usually force the vessel to use her manoeuvring means (rudders and propellers) to compensate the deviation from the desired track produced by the force.

Sometimes, in port design processes these effects are not taken into account and afterwards a safety margin is included in the fairway width in order to avoid its occurrence. At least some estimation on bank effects should always be done to be sure if it is really relevant. Nevertheless the bottom configuration of some areas does not allow the designer to avoid bank effects, therefore it should be properly modelled so that minimizing the effects or using them in favour of the vessels can be considered.

In general terms bank effects produce undesired forces and under a new fairway/harbour/port design the aim is to reduce these effects by increasing the channel width.

Nevertheless there are certain bottom configurations where it is very difficult to reduce or minimize bank effects at reasonable costs, as in those very shallow flatland areas (just some 3 to 5 meters depth below sea level), like river deltas or estuaries where no navigational channel is present and therefore a complete artificial dredged fairway has to be done. In those cases the costs are directly proportional to the width of the fairway, meanwhile bank effects are indirectly proportional.

In those cases where an increase of fairway width, aimed at avoiding bank effects, cannot be performed it is required to assess manoeuvre simulations considering bank forces in order to check the behaviour of the vessel and the vessel manoeuvring means required to counteract bank effects, as this will have a direct impact on the reserve of manoeuvre to achieve certain operational limits.

Several locations around the world (dredged navigation channels as in river deltas or estuaries like cases in Colombia, Argentina, Pakistan, artificial canals as Panama or Suez, and several Ports around the world …) suffer these effects and Local Pilots learned to deal with them. Moreover, in some cases they learned how to manage in order to use the bank forces and moments on their benefit in order to sail towards vessels' calling ports.

An example of the usage of bank effects on benefit of the vessel to keep her within the fairway with reduced usage of vessel rudder, as performed by Pilots in real manoeuvres, will be explained. Nevertheless, using bank effects on favour should only be performed by trained and very experienced Pilots or Masters, as suction/repulsion forces can reach values higher than those the vessel rudder is able to compensate.

2 CASE ASSESSED

2.1 VESSEL

The vessel considered in the case described within this paper is a typical LNG carrier with prismatic tanks and single propeller and rudder. This is the "Spirit of Hellas", shown in Figure 1, whose main particulars are: 285 m length and 50.0 m beam.


Figure 1. LNG carrier "Spirit of Hellas"

2.2 FAIRWAY

The fairway considered in the example that is described within this paper is a 10.5 m deep channel with banks on both sides of the channel with slopes close to 1:4. Due to the restricted depth of the fairway, the vessel navigates in the area in partially loaded condition in order to cope with the minimum UKC required. In this case, normal navigation draught of LNG carriers is 9.3 m.

The general layout of the fairway considered has one main straight section which is diverted into a second section, dividing the traffic in two ways, as shown in Figure 2. The first one keeps the straight line heading towards a main port in the area, meanwhile the second one heads towards the mouth of an affluent river. In order to navigate towards the mouth of the river a bend has to be taken in order to change the course of the vessel some 40º.

The following image shows the configuration of the fairway selected for this example.

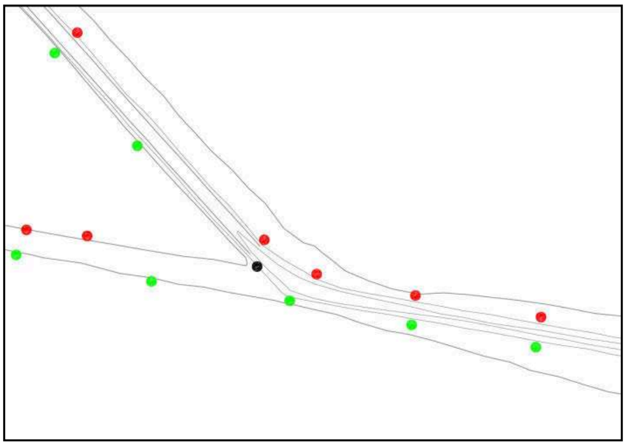


Figure 2. General layout of the fairway considered

This fairway is artificially dredged and it is continuously maintained upon a certain width. Further from this maintained area the surroundings correspond to the natural depth of the river, which is a flatland of some 3 to 5 m depth. As it can be understood this narrow fairway surrounded by shallow flatland waters results in bank forces over the sailing vessels, moreover when the usual navigation speed is approximately 10 to 12 knots.

The bank forces produced by the particular bathymetry over each of the vessels sailing through the fairway has to be considered when manoeuvring in the area, therefore deriving the bank forces is crucial for a proper manoeuvring assessment.

The following section describes the computation of the bank forces by means of specific numerical models and how bank coefficients are derived from those forces.

3 BANK FORCES COEFFICIENTS

3.1 DERIVING BANK FORCES BY NUMERICAL MODELS

Specific numerical models allow us to evaluate the hydrodynamic interaction (forces and moments in six degrees of freedom) that one or more passing vessels generate on one or more moored vessels on the specified area, as well as over the mooring structures, when sailing at navigation fairways (access channels, inner channels, rivers ...), specially in narrow and constrained depth areas.

Therefore the forces and moments produced over the navigating vessel due to the constrains caused by the bathymetry restrictions and the banks can be obtained.

In order to assess the bank forces and moments produced over a vessel under different speeds, at different passing distances and at different drift angles, the numerical model ROPES, developed by PMH BV (Pinkster Marine Hydrodynamics BV, The Netherlands), has been used. An example screenshot of ROPES is shown in Figure 3.

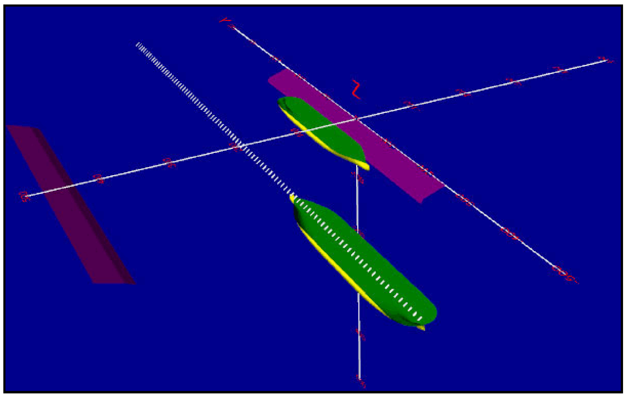
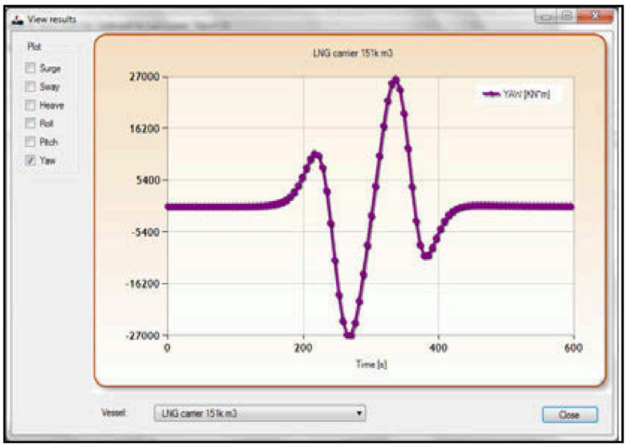


Figure 3. **Image of ROPES software of a sailing vessel**

The model takes into account the specific hull forms of each vessel, on a established load condition, considering the effects of bathymetry changes and lateral restrictions (navigation channels, vertical structures, slopes,...), and allows the calculations of bank forces and moments for a wide range of passing-distances, even when this passing distances is small (i.e. less than one beam).

The system calculates the forces on the vessels in all 6 degrees of freedom (surge, sway, heave, roll, pitch and yaw) in the time domain, as for example shown in Figure 4. The computations are based on 3-dimensional flow calculations for real hull forms. These flow calculations are based on the double-body flow method.



Plot
☐ Surge
☐ Sway
☐ Heave
☐ Roll
☐ Pitch
☑ Yaw

Vessel: LNG carrier 151k m3

Figure 4. **Example of yaw moment time series output of the numerical model ROPES**

Once all bank forces and moments are obtained from the numerical model ROPES, the bank coefficients for surge, sway and yaw can be estimated in order to introduce them into the Real-Time Manoeuvring Simulator.

The time series of forces obtained from ROPES have to be transformed into a global singular value; as the geometry is the same, the forces and bank coefficients should also be the same. This singular value is therefore the average force produced over the vessel due to the presence of the bathymetry configuration, including banks.

In order to get the average singular force from the time series it has to be filtered in advance, in order to remove the undesired peaks of the time series produced at the beginning and the end of the banks.

3.2 EXTRACTING BANK COEFFICIENTS FOR REAL-TIME MANOEUVRING SIMULATORS. BANK COEFFICIENTS ESTIMATION

The knowledge of equations governing the computation of bank forces in the Real-Time Manoeuvring Simulator allows us to get the required bank coefficients in order to introduce the bank forces, derived from the numerical model, into the Real-Time Manoeuvring Simulator.

Different Real-Time simulators use different expressions for the bank forces. The governing equations of the bank forces in the case assessed within this paper (Real Time Manoeuvring Simulator MERMAID 500 developed by MARIN, The Netherlands) are the following:

$$X_b = X_{uvB/w} uv\,B/w + X_{uuu/hw}\,u^3/hw \qquad (1)$$

$$Y_b = Y_{uv\beta} uv\beta + Y_{\alpha uu} u^2\alpha + Y_{\alpha\alpha\alpha uu} u^2\alpha^3 + Y_{\alpha\alpha uv} uv\alpha^2 \qquad (2)$$

$$N_b = N_{uv\beta} uv\beta + N_{\alpha uu} u^2\alpha + N_{\alpha\alpha\alpha uu} u^2\alpha^3 + N_{\alpha\alpha uv} uv\alpha^2 \qquad (3)$$

All the parameters of these governing equations, except the bank coefficients, are known for every one of the simulations of the ROPES numerical model. Therefore these bank coefficients, related to the longitudinal and transversal forces, as well as the yaw moment, can be estimated.

Bank coefficients are dependent on:

- Vessel hull forms
- Vessel load condition (draught)
- Banks configuration (fairway slopes)
- Blockage parameter
- Mean depth

Vessel's bank coefficients are independent of:

- Vessel speed
- Vessel drift angle (small angles)
- Asymmetry parameter

Performing a series of different runs for the same bank coefficients dependant factors (vessel, banks, depth, ...) and different independent factors (vessel speed, vessel drift angle and asymmetry parameter) allows us to both, assess the effect of asymmetry parameter, speed and drift angle in the bank forces and estimate the bank coefficients by minimizing the averaged mean quadratic error of the series of forces derived in ROPES and the estimated forces obtained trough successive estimations of the bank coefficients.
Figures 5 and 6 show the variation of the bank force as function of different parameters.

The bank coefficients derived based on a series of different runs with different distances to the banks, drift angles and vessel speeds are assessed at the same time, therefore the forces derived from the estimated coefficients will have a certain error versus the actual results obtained from the numerical models.

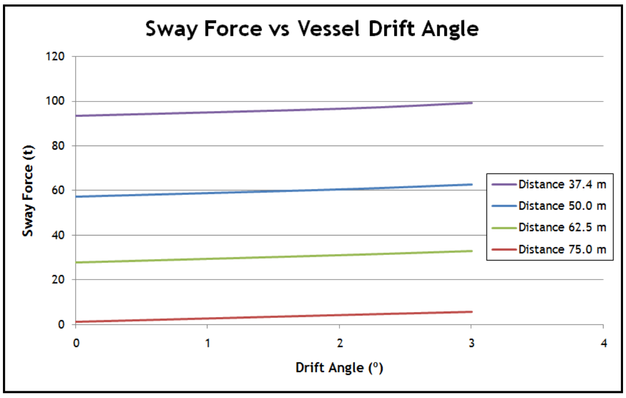


Figure 5. Bank sway forces as a function of vessel drift angle for different distances to the banks

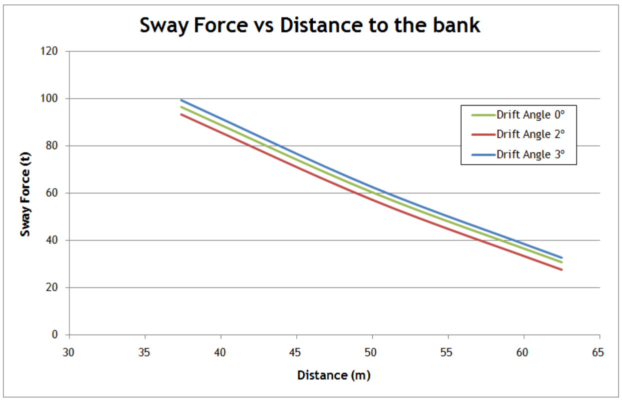


Figure 6. Bank sway forces as a function of distance to the banks for different vessel drift angles

As a reference the errors between the forces obtained in the numerical model ROPES and the forces derived trough the estimated bank coefficients in the assessed case are shown in Table 1.

Table 1. Errors between ROPES forces and forces derived trough bank coefficients estimation

Distance (m)	Speed (kt)	Drift (°)	ROPES Output		Estimated Forces		Differences	
			Y (t)	N (t m)	Y (t)	N (t m)	Y	N
12.5	10	0	27.7	-1550	28.0	-1235	-1%	25.6%
12.5	10	2	31.0	38502	30.4	38626	2%	-0.3%
12.5	10	3	32.8	58536	31.6	58497	4%	0.1%
25.1	10	0	57.2	-2634	58.6	-2569	-2%	2.5%
25.1	10	2	60.5	37879	60.8	37834	0%	0.1%
25.1	10	3	62.7	58134	61.8	57976	1%	0.3%
37.6	10	0	93.5	-3927	95.1	-4119	-2%	-4.6%
37.6	10	2	96.7	37412	96.8	37459	0%	-0.1%
37.6	10	3	99.3	58075	97.5	58188	2%	-0.2%

As can be seen in Table 1, these errors are small for the transverse force (less than 5%). For the yaw moment the errors are very limited in terms of percentage in those cases where the force and moment values are quite high in absolute terms (green dotted square), meanwhile the relative errors are higher in some cases when the forces and moment values are small in absolute terms (red dotted square).

This difference over 25% in yaw moment does not have a major impact on the results as the absolute value of the moment is very small, comparing it with the rest of the yaw moments.

Once the bank coefficients have been derived, and the differences in forces and moments have been checked to be limited to a certain percentage, or to a small absolute value, results can be considered to be accurate enough.

The coefficients derived are therefore introduced in the text data files of the Real-Time Manoeuvre Simulator in order to include the bank effects in the manoeuvres performed in the Real-Time Manoeuvre Simulation of the vessel. In this way, the bank forces that would be obtained when manoeuvring in the Real Time Manoeuvring Simulator will be quite close to those obtained in the numerical model, thus increasing the complexity and the accuracy of the simulated scenario.

4 REAL-TIME MANOEUVRE SIMULATIONS WITH BANK EFFECTS

Once the bank coefficients have been estimated for a certain vessel and bottom configuration, and it has been checked that the results are consistent with the forces and moments obtained in the numerical model, they can be introduced in the Real-Time Manoeuvre Simulation. This will allow checking the differences in manoeuvring when bank effects are present or not.

In order to check that the values introduced as input to the Real Time Manoeuvre Simulator derived from ROPES are accurate enough for manoeuvring some Pilots tested the ship behaviour.

A Local Pilot, used to sail considering bank effects and using them in benefit, performed some manoeuvres to verify that the effects produced by the banks and the forces and moments agree with his expertise and knowledge, and calibrate the derived bank coefficients of the vessel's numerical model if necessary, which was not, in this case.

The consequence of bank effect over the vessel is a more or less continuous use of the rudder and engine, required to counteract those external forces. The usage of a certain percentage of the vessel own manoeuvrability to overcome bank forces is directly translated in a reduced reserve of manoeuvrability to overcome the different met-ocean conditions and therefore an eventual reduction in the operational limits of a vessel calling at a certain port.

Figure 7 shows the track of two different manoeuvres in the same area. The first one (blue vessel contour) corresponds to the manoeuvre without considering the bank effects, the second one (red vessel contour) corresponds to the manoeuvre including bank effects.

As can be seen in Figure 7, in both cases the vessel navigates within the limits of the defined fairway, nevertheless the tracks are different as the manoeuvre is also different due to the external force added in the case of the red vessels. In order to properly assess bank effects these manoeuvres have been performed in calm conditions, thus no wind, waves or current were present.

Assessing the results over the mere track plots of the manoeuvres does not give much indication on its own, and results should be accompanied by the time series of the rudder and engine rpm in order to check how different the manoeuvre is.

Nevertheless by means of the track plot the different strategies used by the Pilot at the bend can be easily identified. In the case where bank effects are present the Pilot moves towards the southern bank, thus reducing the "Passing-distance" and therefore increasing the bank yaw moment towards the starboard side. This allows taking the bend without requiring more rudder than in the condition where no bank is present.

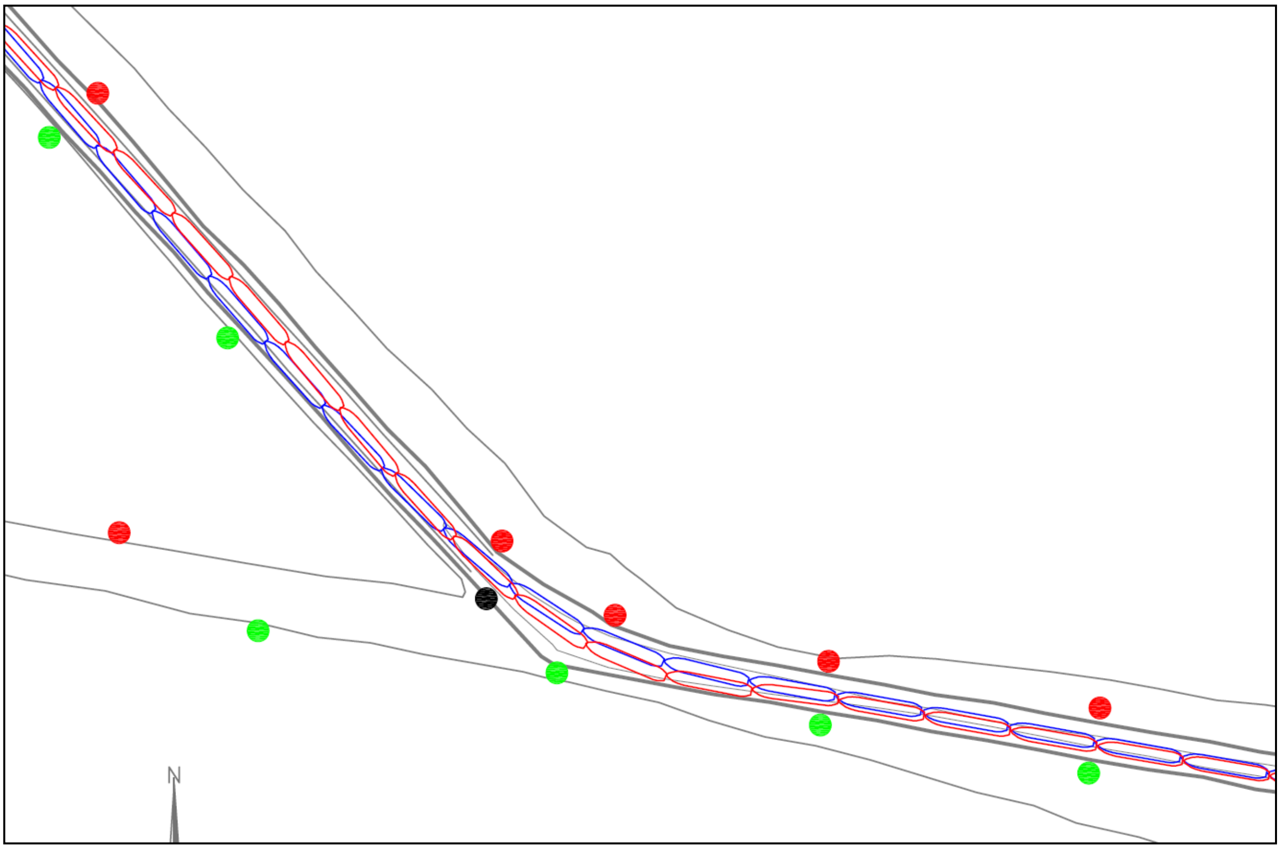


Figure 7. Manoeuvres track plots. Blue vessels = no bank effects. Red vessels = bank effects included

In order to counteract bank forces different rudder angles were required to be set in order to compensate the forces and moments created by the presence of the banks.

Figure 8 shows the rudder angle time series applied during both manoeuvres to safely navigate through the fairway (with and without banks) as a function of the position of the vessel.

The blue line corresponds to the manoeuvre where no banks were present and the red line corresponds to the manoeuvre were banks were present.

The graph clearly shows that in the first part of the track plot (straight line) no rudder was required in the case where no external forces were present (blue line). Once the external bank forces are present a sort of "static" rudder angle close to some 4º was required to safely navigate through that straight section. This rudder angle was required in order to compensate the forces and moments produced by bank effects. And the same occurs in the second straight section.

Nevertheless in the bend a different behaviour is shown. In both cases the maximum rudder angle required is the same (a bit less when banks are present). No extra rudder was required as a certain bank yaw moment force was beneficial in order to initiate the turning towards the starboard side.

Both results, that are visible in the time series plot of the rudder angle, are consistent with the two main points that are the key of the paper.

First of all, the presence of the banks forces the vessel to use certain rudder angle to counteract bank effects, thus the manoeuvrability reserve of the vessel to navigate under different conditions (winds, waves, currents...) is reduced (undesired effects). As a consequence of the reduction of the reserve of manoeuvrability, a reduction in the operational limits for the vessels navigating through areas with presence of banks could be expected.

The second point is the possible use of those external forces in the benefit of the vessels at the bends, using part of the yaw moment created by the presence of the banks in order to limit or reduce the rudder angle initially required to take the bends, even forcing the yaw moment to increase prior to the bends by getting closer to the bank.

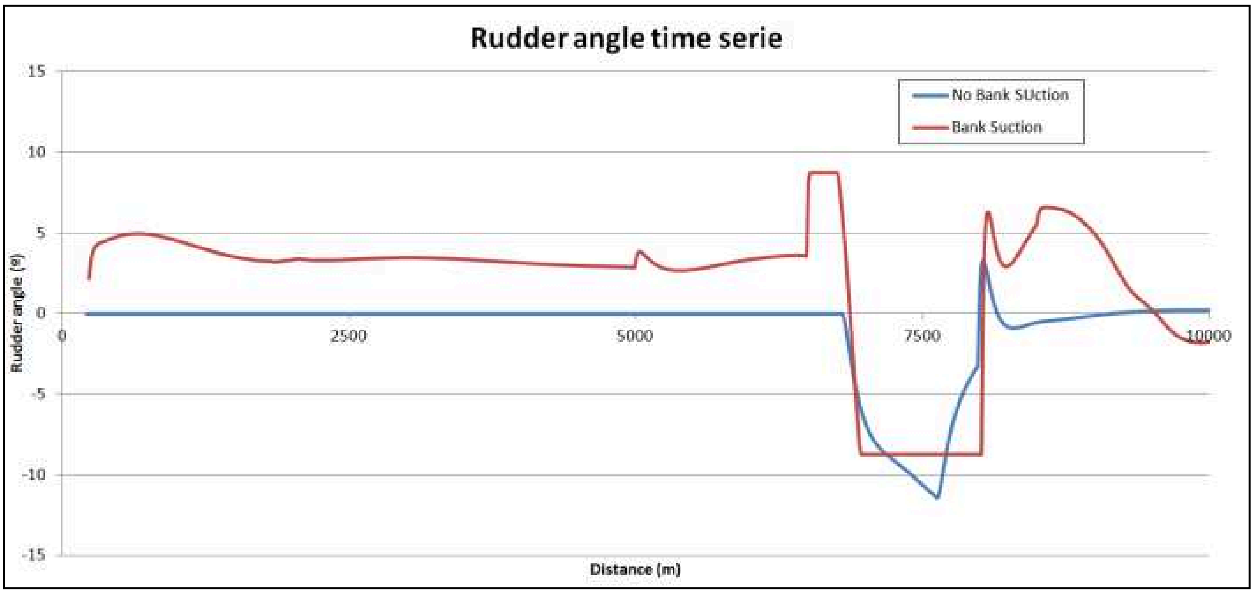


Figure 8. Time series of rudder angle during manoeuvres

Nevertheless, even if there is a part of the bank effect that could be used in the benefit of the vessel it has to be taken into account that bank forces and moments increase exponentially with vessel speed and the reduction of the distance to the banks. Those forces can reach extremely high values, even above those that vessel's manoeuvring means would be able to compensate. Therefore its usage is limited to very experienced Pilots or Masters with a very deep knowledge of the area, the vessel and the channel configuration.

A deep knowledge of the bank effects together with the geometry and the bathymetry of the area allows Local Pilots of certain ports around the world to navigate through narrow fairways using the yaw moment created by bank effects to take bends by reducing the rudder angle that would normally be required, even, in some cases, with the rudder at midships.

5 CONCLUSIONS

Navigation in restricted waters or within a fairway with asymmetrical banks might be exposed to additional “undesirable” external forces due to an asymmetry on the flow surrounding the vessel on her movement. The forces produced by bank effects over the vessels can reach considerably high values and therefore bank effects should be included in manoeuvring models both for port design and training and education of Pilots and Masters.

Sometimes, in port design processes these effects are not taken into account and afterwards a safety margin is included in the fairway width in order to avoid its occurrence. At least some estimation on bank effects should always be done to be sure if it is really relevant. Nevertheless the bottom configuration of some areas does not allow the designer to avoid bank effects, therefore it should be properly modelled so that minimizing the effects or using them in favour of the vessels can be considered.

As any external force, bank effects usually force the vessel to use her manoeuvring means (rudders and propellers) to compensate the deviation from the desired track produced by the force.

One of the effects of navigating on the presence of banks, is a more or less continuous use of the manoeuvrability means of the own vessel, requiring a "static" rudder angle to compensate the forces produced by the presence of the banks. This reduces the "reserve" of manoeuvrability required to cope with the different met-ocean conditions (winds, waves and current) and therefore a reduction in the operational limits of the vessel at a fairway might be expected.

In such a way, introducing bank effects in Real Time Manoeuvre Simulators allows to asses this aspect, giving a more complete and accurate result, nevertheless a more complex one.

Modelling of bank effects can be performed by using specific numerical models which can be used to obtain the hydrodynamic forces over the vessel hull. Those forces are then used to estimate the bank forces coefficients of the vessel for a specific fairway-vessel configuration which can be used as input parameters in the Real-Time Manoeuvring Simulators. It is highlighted that during the development of ROPES several model tests and real measurements were carried out in order to validate the passing ship effect but validation against bank effects was not analyzed. Therefore, Siport21 validated ROPES based on Pilots' experience as mentioned above. From this point of view, it would be interesting to develop model tests and real measurements to increase the accuracy of the method proposed in this paper.

Nevertheless experienced Pilots with high knowledge of the vessels, the area and the bank effects can use part of the bank forces on their own benefit. In order to obtain this benefit Pilots might force the yaw moment created by the presence of the bank to increase prior to the bends by getting closer to the bank. In this way part of the yaw moment required to take the bend is produced by the banks therefore the rudder angle initially required to take the bends is limited or reduced.

An example of the usage of bank effects on benefit of the vessel to keep her within the fairway with reduced usage of vessel rudders, as performed by Pilots in real manoeuvres, has been described and assessed in this paper. Nevertheless, using bank effects on favour should only be performed by trained and very experienced Pilots or Masters, as bank forces can reach values higher than those the vessel rudder is able to compensate.

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Raul Redondo holds the current position of Project Engineer at Siport21. He performs the technical projects. He specializes on moored ship dynamics and ship manoeuvrability in port areas, both using numerical models and real-time simulation.

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Ignacio Trejo holds the current position of Project Manager at Siport21. He coordinates and checks technical projects. He is a specialist in moored ship dynamics and ship manoeuvrability in port areas, both using numerical models and real-time simulations. He has developed several numerical models for the resolution of hydrodynamics and ship dynamics problems. Specialist in CFD Numerical Models, instrumentation and software developer.

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Jose R. Iribarren holds the current position of General Manager at Siport21 and founded Siport21. He manages, plans and implements corporate policies and strategies. Before, he worked as a project engineer in the head of Port Research Program and Head of Technical and Scientific Program at the Maritime Research Laboratory (Port and Coastal Research Centre, CEDEX, Ministry of Public Works, Spain).

He is specialized in studies on moored ship dynamics and ship manoeuvrability in port areas, both using numerical models and scale models, wave penetration in port areas using scale model tests and “Fast-time” and real time simulation of ship manoeuvres.

In 1998 he was awarded the “Gustave Willems Prize” of PIANC for the paper “Determining the horizontal dimensions of ship manoeuvring areas. General recommendations and simulator studies”.