

Traffic engineering methods solutions of problems concerning ship's manoeuvres and sailing on the large rivers of Central America

Adam Kowalski

Polish Steamship Company
70-419 Szczecin, Plac Rodła 8

Key words: ocean going ships river's navigation, manoeuvres, traffic engineering, sea transport safety, navigational practice

Abstract

The paper introduces some aspects of maximum size ocean going ship's safety during the sailing on Central American rivers. Based on solution of above problems, presented necessary hydrographical information concerning River Orinoco, Mississippi, Rio Magdalena and the most biggest of the World – Amazon River. Solutions of several river's navigational and manoeuvres problems suggested by Traffic Engineering have also been presented. Independently, there are suggestions concerning improvements of the sea transport safety in the river's estuary.

Introduction

The center of global economy moves from stagnant traditional areas hitherto regarded as highly industrialized countries, in the direction of the dynamically developing countries of the Far East region. At the same time, economists see huge growth potential latent in the economies of Latin America. New economic centers are formed wherever it is possible to navigate the ocean-going vessels on tropical and subtropical waters and inland areas. Therefore, expansion of ocean going ships into areas of rivers and their river basins and estuaries to the sea is observed. The direct result of ocean going ships on these waters is the need to solve extremely important problems related to safety of navigation. Relocation of centers of global economy has an influence on safety of navigation in confined areas. These phenomena will be described in the paper on the example of the four rivers of Central and South America: the Mississippi, the Amazon, the Orinoco and the Rio Magdalena.

Threats to safety of navigation on the rivers

The Mississippi River

Transport of goods by means of a system of waterways of this river plays the major role in interna-

tional and internal trade of the United States. Ocean-going vessels arrive at a distance of more than 200 miles up the river. On this distance the river is completely settled. Mandatory fully professional pilotage concerns any vessel engaged in the international navigation on the river. U.S. Corps of Engineers and the U.S. Coast Guard maintain high safety standards throughout the basin. The intention of the services is, among other things, constant updating of hydrographic data. Formation and maintenance of waterways is carried out to meet all criteria for assessing the safety of navigation [1].

The Mississippi River along its length transports and deposits annually about 500 million tons of material. At the lower Mississippi, especially in the delta, there are areas of formation of new shallows and as a result of the shallows, the parameters of shipping areas are changed. Due to the lack of significant effect of tidal currents, the shallow effect is observed on the open sea near the mouth of the river. In these locations, a rapid slowdown of the current generates the deposition of heavier fractions of sediment. To bypass the silt deposition region lying opposite the mouth of the river, ships make a turn of about 45 degrees just before the entrance to the river track. Following the optimization of the costs, one of the arms of the Mississippi Delta,

South West Pass was selected for ocean-going vessels where, despite the continuous silting and the natural tendency for changes in river bed, safe dimensions of manoeuvring area are provided. According to the available nautical publications on board the ships, the Mississippi settlements take the form of gelatinous substance by an average of a meter thick. This occurs especially at low water level. Therefore, a systematic and extensive dredging involving the removal of sediment is conducted. The designed minimum depth of 13.70 m (2011) is kept. River current is adjusted by using hydro-engineering buildings. What is achieved, is a compromise between the capacity to carry sediment possible at high flow velocity and decreasing the current of the river that provides the required level of safety manoeuvre. This approach to the maintenance of water bodies manoeuvring enables to omit the impact of siltation of the navigable waters to the Mississippi River. Therefore, the accuracy of computational methods of resistance to motion, drive efficiency and settling vessel in force for clean waters available on the side of the ship are satisfactory [2]. When realization of a well-conceived plan, the manoeuvre on the Mississippi may proceed without excessive increase in risk of navigation.

The Rio Magdalena River

The mouth of the Rio Magdalena contrary to the Mississippi, has no features characteristic of delta. But there are many hydrographic similarities of this funnel-shaped mouth of the Mississippi branch of the river to South West Pass. The shape of the Rio Magdalena river generates high velocity of the stream, sometimes it exceeds 6 knots. The allowable safety draft on the river is 9.1 m (2011). This value may be changed at any time, depending on the conditions of the river. Similarly to the Mississippi delta, there are no significant tides and for this reason, the deposition of silt carried by the river is just at its mouth to the sea.

A considerable stream, severe weather, lack of direct shelter at the mouth of the river from the prevailing strong north-easterly winds entail considerable difficulties in carrying out any of engineering works. On the other hand, definitely inadequate is the accuracy and timeliness of maps and navigation aids. Relying on them can cause serious accidents during navigation. The entrance to the Rio Magdalena, as the entrance to SW Pass, is preceded by the sudden 45° change of the course. Just before this manoeuvre, the ship, in accordance with the local regulations should reach a minimum speed of 10 knots. This should provide ship handling at the edge of six knots outgoing river current. Accel-

eration of the ship is possible only at the distance of a few cables before the entry into the head of the breakwater. In this area ships encounter shield from heavy sea waves caused by the previously mentioned north-east winds. For this underwater breakwaters that are piled up with mud shoal are responsible. This shows that the strong shallows caused by deposition of sediments in the immediate vicinity of the mouth of the river do have also their positive side. The manoeuvre to enter the river is difficult because of the following reasons:

1. The limited available distance to accelerate the ship to the required by the rules speed of 10 knots.
2. The narrow, 150 meter deep channel limited by the breakwater heads just after the sudden 45° change of the course.
3. The phenomenon of strong asymmetric squat in the bow area of the vessel and the drift of the bow when entering into six knots current of the river
4. The strong river current that interferes with ship's turn at a critical moment in the heads of the breakwater.

Provisions for the pilotage are defined in tabular form binding the basic data with acceptable performance of the vessel drafts at different states of the river. The rules are based on practitioners' experience rather than theoretical calculations. At the expense of limiting the size of vessels and reducing the allowable squat, a satisfactory level of safety of navigation is achieved. Lack of accuracy of hydrographic data and notices to mariners, the difficulty of maintaining manoeuvring areas result in the need to enter the port of Barranquilla not fully loaded vessels. Lack of precise sources of the Port Regulations imposes the necessity of tightening the criteria which allow ships to navigate the river. Liberalizing the restrictions may improve the situation and provisions will be based on the calculation methods of marine traffic engineering [3]. The phenomenon of a substantial safety margin in determining the rules were observed during entry on the Rio Magdalena by ship m/v "Podlasie": $L = 190$ m, $B = 28.5$ m, $T = 9.1$ m. According to current regulations, in the described conditions, this ship was close to the maximum sizes for that basin.

The Amazon River

Fluctuations up the river reach several meters. This seasonal phenomenon typical of tropical regions is reduced in the lower reaches of the river. The effect of changes in water level is strong erosion of the river which is, next to the continuous

washing away of the soil due to rainfall, the cause of siltation of the Amazon River (Fig. 1).



Fig. 1. Cliff on Amazon River

500 miles upstream from the mouth of the river water level changes can be observed due to tides. The first 300 miles up from the mouth the river, the current also changes its direction to the rhythm of tidal currents. In these places the strongest effect of silt deposition in the river occurs. The greatest changes in the river delta area are especially dangerous for ocean-going vessels. The responsibility for navigation on the last 170 miles of the river lies mostly on the ship's captain – there is no requirement of local pilot jobs. In addition to the shallowing caused by deposition of river silt, fast migrating shoals is an additional obstacle for navigating ships. In the absence of sufficient available depth examination, the knowledge about the phenomenon is usually discovered during subsequent accesses to the grounding. This happens several times in a month. During the ship's passage on the river, the navigational notices concerning another ship aground are usually obtained. For the vast delta of the Amazon, it is difficult to accurately determine the place where the stream experiences rapid slowdown. The mass of waters and the presence of tidal currents (tide up to several meters) create in the edge of the open sea shallows – Barra Norte. It is a vast sandy and muddy bank, where according to navigation maps the available depth is about 7–8 meters. The maximum permissible draft in ports across the Amazon reaches over 10 meters. In such cases, the passage through the heavily silted area is possible only at high water. The designation in this area the recommended two-way approach fairway, may be helpful as a method of providing navigable depth. Such action may allow the maintenance of and continuous leaching of the sediment. It is noteworthy that on the Amazon there is no systematic

dredging conducted for the maintenance of navigable depth. In part, this approach to maintain the navigability is dictated by the fact that in compulsory pilotage on the river area depths are sufficiently large, sometimes reaching well over 100 meters. Also, in view of the large width of the naturally-shaped fairway, there is usually no need to use day or night marking for navigation.

Currently it is believed that Brazil has strong potential for economic development. Huge business opportunities exist particularly throughout the Amazon basin. Since in this region there is practically no alternative to water transport, the transformation of the Amazon waterways to the level of use such as the Mississippi River in the United States seems to be inevitable. Not all engineering methods used in the USA will apply to the Amazon. It is possible to avoid the errors committed there, mainly because of advances in science and the need to take into consideration the protection of sensitive equatorial rain forest area. The problem may be lack of capacity of the organization of work and systematic activities of all the services and coordination such as is the case of the Mississippi.

The Orinoco River

This river has long been used for the transport of goods by ocean-going vessels. Its basin is much smaller than the Amazon, all the phenomena previously signaled to the river can also be seen on the Orinoco. Similar to the Amazon's Barra Norte shoal is Orinoco Boca Grande shoal. Passage through is possible along the deepened fairway. The river, due to a smaller size, has not been such potential for development of transport as in the case of the Amazon. The maximum draft of vessels that can reach the Matanzas is 12.7 m. This value is significantly reduced in some cases up to around 9 m in the case of low water levels.

The maximum draft in force is available on a daily basis and is published in regular messages. Maintaining proper depth is provided by dredging being carried out continuously. One unit of a fleet of dredgers with low speed 1–2 knots proceeds along a nearly 200 mile waterway intended for ocean-going vessels. Sediments are pumped from the middle of the channel outside the fairway, kept in motion, and thus maintaining the proper navigable depth. On its way to Matanzas, large ocean-going vessels meet many shallows and river meanders. The fairway although sometimes quite narrow, is the most well marked by light buoys. The river no longer has any natural reserves to increase the scale of ocean-going ships. Maintaining navigable Orinoco requires currently incurring large

financial outlays. Because of the tendency towards the shrinkage of rain forests, tributaries of the Orinoco provide less and less water. In such a situation the costs of maintaining the waterway will be increasing.

The problems of navigation of ocean-going ships in the muddy waters on the example of Barra Norte and Boca Grande shallows

It is difficult to find in the available literature, satisfactory and universal mathematical description of the behavior of the ship's hull during navigation on muddy areas. At the same time the complexity of hydrodynamic phenomena that occur between the hull, the propeller and the muddy environment are observed. The problems are compounded by changes in the distribution of mud density for different water bodies. Practitioners should also be aware of the fact that the same density distribution and the same depth of the reservoir do not guarantee the similar manoeuvrability of the ship. The reason for this phenomenon is the difference in the composition of the mud, and thus different properties in different waters. According to the PIANC [4], two conditions for the safe bottom have been defined:

1. The hulls of ships may not be subject to damages even if their immersion depth reaches the full value of nautical depth;
2. Manoeuvrability of the vessel cannot be in such conditions considerably limited.

In view of the set of individual characteristics on several areas safe depth of navigational areas is defined on the basis of long-term hydrographic surveys in close relation with indication of practice [2].

For non muddy areas formulas, graphs and tables are available enabling to describe the behavior of the ship to shallow waters. In this case, the speed achievable, taking into account the maximum speed of gravitational waves for the parameters of the vessel can be described and is capable of being used in practice by the formula:

$$V_{OS} = \sqrt{gh_o} \left(\frac{h_o L}{80BT} \right)^n \quad (1)$$

where:

$n = 0.125$ for shallow waters;

$n = 0.24(L/b)^{0.55}$ for the channel;

b – the width of the dredged channel.

The speed of the Polish Steamship Company bulk carrier m/v "Podlasie" (2012) $L = 190$ m, $B = 28.5$ m, $T = 9.5$ m during the transit at high

water in the most shallow Barra Norte (the Amazon) does not exceed 6 knots. The attainable speed value calculated from the formula applicable to clean water at shallow waters was about 9 knots. The speed of the same vessel m/v "Podlasie" (2012) during the transition time at high water for most shallow depth of the fairway leading through Boca Grande (the Orinoco) was about 5 knots. The achievable speed rate V_{OS} calculated by the formula applicable for clean water in the canal is about 7 knots. The attainable speed value V_{OS} should be lower because the Boca Grande has in-depth seaway. The difference in the calculated attainable and observed speed in reality for the Amazon and the Orinoco, in both cases can be explained by the influence of significant silting.

Based on research conducted by the Ghent University, Maritime Technology Division and the Flanders Hydraulics Research in Antwerp in 2010, the mathematical model applicable for muddy areas [5] was published. The model was developed for the outer harbor of Zeebrugge. It was built on the basis of data from the years 1997–1998. Attempting to use the model, difficulties may be encountered due to the lack of availability of data that characterize other than Zeebrugge areas of silting.

In the available English language nautical publications the subject of the impact of sediment on the shipping speed of the pilot areas does not go beyond the fact of the occurrence of the phenomenon of silting. The information on the subject is skimpy. Only in the British Admiralty Sailing Directions there is a brief record of the possibility of slowing down the speed of the vessel up to 50 percent, when entering the Orinoco river.

No approximate data on the subject, with poorly planned high water transit through extensive shallows may result in running the ship aground. In the case of Barra Norte on the Amazon it will only result in a threat to one unit. At Boca Grande vessels follow a one-way narrow channel deepened during high water. Not only may transition delay result in the grounding of the ship going at the beginning of the group. For subsequent ships it can cause a very dangerous situation, it may threaten their grounding.

The increasing influence of silting of navigable waters, together with the increasing size of vessels and the increasing intensity of shipping may result in multiple violations to the considered safe bottom area [4]. In such situations, even without a ship touching the ground, the damage to the structure of the ship's hull may occur. The occurrence of risks can only be manifested by larger than usual speed slow down in muddy areas.

Conclusions

It seems to be necessary to carry out an analysis of the impact of siltation on the safety of ocean-going vessels on inland muddy waters by the relevant departments, research centers and hydrographic offices from the interested countries. Influence of the deposition of mud on the practice of inland shipping is also important, however, touching the bottom of ocean-going vessel, which is acceptable for barges, is in any case a serious danger for the ship and brings in consequence the loss of the ship class. The difficult navigation of the muddy areas should force the hydrographic offices to pay particular attention to the up-date maps and nautical publications. The level of safety of navigation, may also be increased by means of marine traffic engineering methods. An example is described in this paper, a proposal to establish two-way water path leading through the Barra Norte. With the appropriate technical and financial resources, methods carried out on the Mississippi River may be followed by maintaining a high level of care for the shipping waters.

Another type of action should aim to present to the navigators the knowledge of the phenomena occurring in the muddy waters. Mandatory presentation on charts or navigational publications the graph with sediment density as a function of depth seems to be advisable for individual areas. The graph should indicate water density levels on for the designated safe depth of the basin and values of density for which echo sounders receives the echo of the acoustic waves of the bottom. This information, in addition to knowledge concerning single

area, would allow captains to work out on the basis of previous experience and reviews for own ship manoeuvring the characteristics of a new, hitherto unknown muddy area. Additional benefit of the publication charts indicating the density as a function of depth is that the ship's crew will be able to anticipate possible problems with the engine cooling regarding the minimum height of water intake from the bottom.

A major challenge for theorists and practitioners is to develop and publish, as soon as possible, the graphs for the individual muddy waters enabling the inference of reducing the speed of the main types of ships as a function of drafts taking into account the different levels of tide. In studies for tropical rivers, seasonal changes in the composition of the mud will have to be taken into consideration. Failure to research the solution to the set of problems may have serious consequences for the economy or environmental disasters in the areas of special importance for the global climate.

References

1. GUCMA S.: Inżynieria ruchu morskiego. Okrętownictwo i Żegluga, Gdańsk 2001.
2. NOWICKI A.: Manewrowanie w warunkach specjalnych. Oderraum Ltd., Szczecin 1992.
3. GUCMA S. (red.): Morskie terminale promowe – projektowanie i eksploatacja w ujęciu inżynierii ruchu morskiego. Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2012.
4. Praca zbiorowa: Navigation in Muddy Areas. PIANC Technical Committee II Working Report, 1985.
5. DELEFORTRIE G., VANTORRE M., ELOOT K., VERWILLIGEN J., LATAIRE E.: Squat prediction in muddy navigation areas. *Ocean Engineering* 37 (2010).