

Experimental Study of Forces Exerted on Ships Due to the Vertical Walls of Navigation Channels

M. Fathi Kazerooni & M.S. Seif
Sharif University of Technology, Iran

ABSTRACT: Ship maneuvering in restricted waters of harbor basins and navigation channels had been the main concern in recent years due to sudden increase of ship's size. When the ship enters a navigation channel the lateral boundary of the channel exerts a transverse force and turning moment on the ship hull. These forces are so important in the analysis of safety of ship navigation in the channels. Ship model test in the towing tank is a reliable method to evaluate these forces. Therefore systematic model tests are held for modeling of the forces exerted on the tanker ship and dhow model traveling alongside a vertical wall. A database of the interaction forces is developed and the specific hydrodynamic effects related to the phenomena are discussed. The results can be used for simulation of ship maneuvering and assessment of safety limits for navigation of ships alongside the quay walls and breakwaters.

1 INTRODUCTION

One of the parameters affecting ship maneuvering in restricted waterways is the influence of quay walls, channel banks or the stationary or moving ships in the vicinity. The hydrodynamic forces of ship interaction with boundaries in restricted waters have been known to sailors for years. When a ship moves along a wall the sway force and yawing moment is produced that would result to dynamic instability of ship steering.

The physical concept of interaction is based on the transformation of energy in famous known modified Bernoulli equation. According to Bernoulli equation the summation of potential and kinetic energy of flow particles on a streamline remains the same. As the ship moves in the sea high pressure regions is induced in the fore and aft part of the ship. It is obvious that the pressure of the aft is less than the pressure of fore due to the friction along the hull. The

water that displaces in the ship fore, flows toward the aft under the hull. Therefore the pressure drops in the middle of the hull. If a ship is located in a certain enough distance of the bank, it feels no effect of the bank. But if the ship moves a little toward the bank, a low pressure region is produced among the ship and the wall.

The bank effect phenomena depends on various parameters such as bank shape, water depth, distance of the ship to bank, ship characteristics, ship speed and propeller performance. There is a limit for ship navigation in the waterway that this limit could be obtained by analysis of bank effect. It should be mentioned that the bank material can affect the bank effect too. For example the bank effect is more in the sandy banks.

There have been so many experimental studies of bank effect in the literature. Fujino 1986 studied the effect of water depth, distance to bank, ship speed, bank slope, propeller action, drift angle and rudder

angle on the hydrodynamic loads on the ship maneuvering in the approach channel through the model test of tanker and cargo ships. Eda 1971 represented the hydrodynamic coefficients of tanker ship for three ratios of water depth and distance to nearest bank. Norrbin 1974,1986 had a comprehensive study on ship maneuvering in general and bank effect in detail. These tests are based on a tanker model and empirical formulae are presented for vertical, sloped and submerged banks. Fuerher and Romisch 1978 discussed hydrodynamic forces, trim, sinkage and channel reverse flow. Comprehensive model tests of general cargo ship and container carrier in performed by Dand 1981.

The result of captive model tests formulates the forces exerted on the vessel and they can be used in development of maneuvering computer simulations as indicated by Gronaz.

In recent years CFD approach is used for calculation of bank effects. Zhou et al (2012) proposed potential theory to estimate the forces on ships in restricted water. However Wang et al (2010) emphasized that viscous effect should be accounted for through Reynolds averaged Navier-Stokes equations.

Some references as Lee 2008 have assumed that the free surface is rigid and shown that the ratio of ship draught to quay wall depth can influence the forces.

It is completely obvious that the subject of ship-bank interaction is studied in only few research institutes all around the world and little experimental data is published. Empirical expressions that formulate the interaction forces as a function of ship parameters are so needed in application. The relations that are presented so far are based on few experiments and specific models are tested. Therefore the reliability of these expressions is in doubt when used under different conditions. Therefore the systematic model tests of bank effect in towing tank are performed to develop the experimental database.

2 RESEARCH METHODOLOGY

2.1 Bank effect

Almost all the sailors have experienced the suction force Y and yawing moment N from the near bank as ship navigates in shallow channels (Figure 1). The force exerted from bank has an influence point that is near the ship stern because commonly the ship stern is bluff.

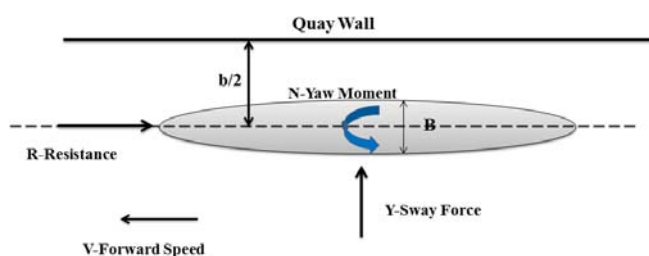


Figure 1. forces exerted on a ship moving along a bank

2.2 Experimental Facilities

The towing tank in Sharif University of Technology has capability to perform ship hydrodynamic model testing. In order to evaluate forces exerted in the model in the vicinity of vertical wall in shallow water it is essential to reduce the water depth and ship-bank distance.

The main concern of restricted water testing is the towing tank dimensions that this towing tank has 25m long and 2.5m wide.

Artificial bottom and side wall is manufactured by plastic plates that are fitted on the aluminum frames to ensure the sufficient strength as shown in figure 2.



Figure 2. the manufactured restricted waterway

The vertical quay length is 8m and the shallow water is extended in 10m length of the towing tank. The ship model is attached to the carriage unit and is restrained in all the degrees of freedom except sinkage and trim directions.

2.3 Ship Models

Two types of ship models are used here in order to compare the results and describe the effect of hull form on the forces exerted on the vessel in the vicinity of vertical wall. According to above discussion finally it had been decided to use a model of tanker ship as described in table1 and a traditional Persian Gulf cargo vessel which is called Dhow as in table2.

Table 1. Tanker & model specifications

	Tanker	Model Tanker
Length (m)	176	1
Breadth(m)	31	0.17
Draught(m)	9	0.05
Displacement	41523 tons	7 kg
F_n	0.06-0.27	

Table 2. Dhow & model specifications

	Dhow	Dhow model
Length(m)	28	0.71
Breadth(m)	8.87	0.225
Draught(m)	1.97	0.05
Displacement	306.5 tons	5 kg
F_n	0.06-0.27	

Figure 3 and Figure 4 shows the models that have been used.

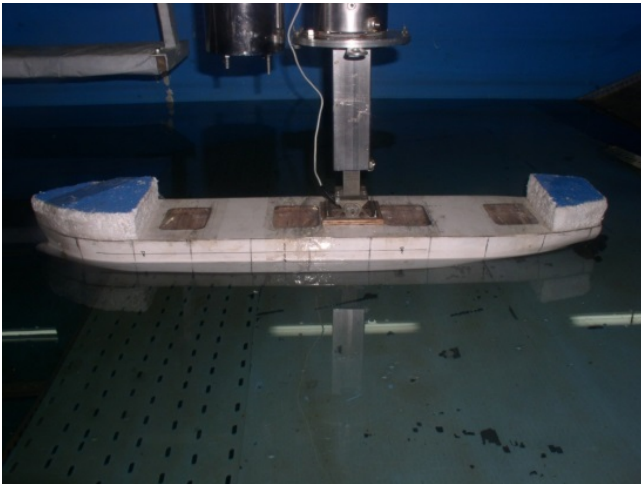


Figure 3. Tanker model

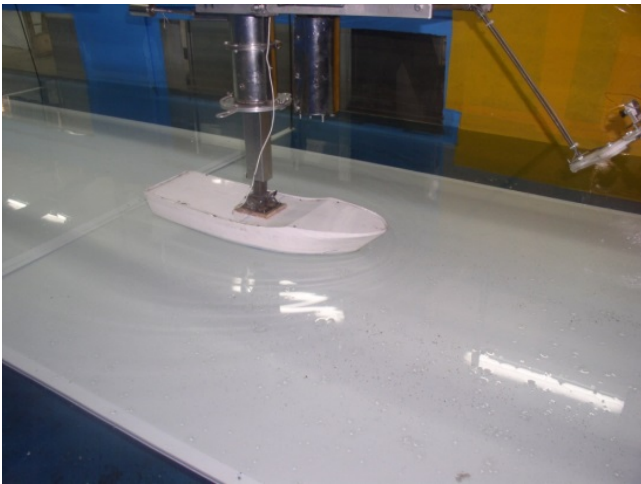


Figure 4. Dhow model

2.4 Model Test procedure:

Model tests are performed to evaluate the bank effect on tanker and dhow ship in the towing tank of Sharif University of Technology. The bank is considered vertical here and different distances of ship to bank are studied. Model tests are performed in shallow water condition. In each case the water depth is two times of ship draught. The changes of forces induced by vertical bank would be greater in shallow water. The magnitude of induced sway force and yawing moment is a function of ship speed too. Figure 5 and Figure 6 show the model test of tanker ship and dhow respectively. The ratio b/B is equal to 3.

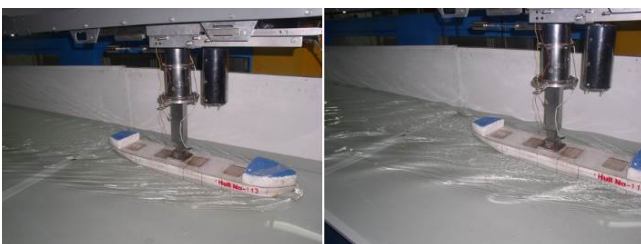


Figure 5. Tanker model test in vicinity of vertical wall, Left Moderate speed, Right high speed



Figure 6. Dhow model test in vicinity of vertical wall, Left moderate speed, Right high speed

3 RESULTS AND DISCUSSION

Sway force and yawing moment induced from vertical bank have a great effect in maneuvering analysis of ships in confined and laterally restricted waterways. It is common to express the sway force and yawing moment in non-dimensional form Y/m and N/mL in which Y is the sway force in kgf and m is the vessel mass in kg, N is yawing moment in kgf-m and L is the length between perpendiculars in m.

The non-dimensional Sway force exerted on the tanker ship model in different forward speeds is plotted in figure 7 for various distances to vertical wall. The respected induced yawing moment is plotted in figure 8.

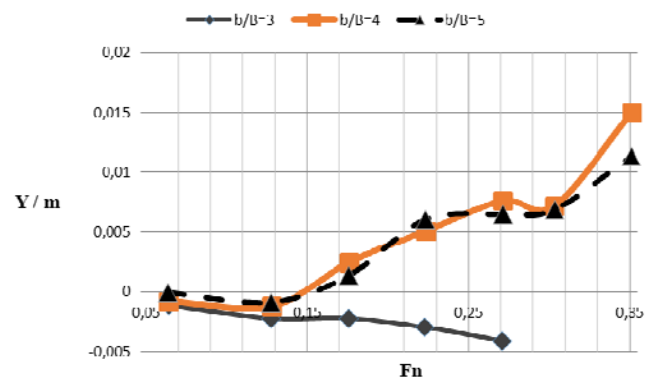


Figure 7. The sway force exerted on the tanker ship model in the vicinity of vertical wall

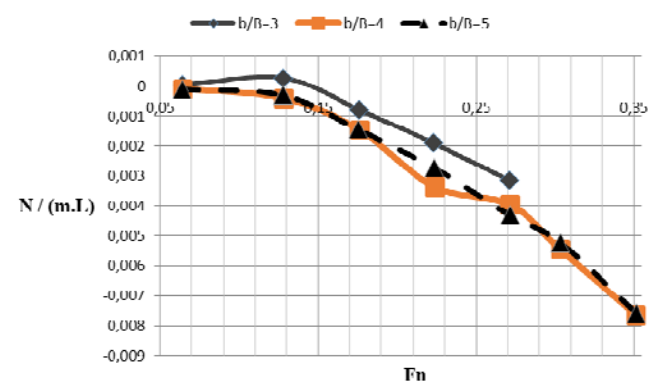


Figure 8. The yawing moment exerted on the tanker ship model in the vicinity of vertical wall

The hydrodynamic forces increase by Froude number significantly according to diagrams. This

behavior is expected logically. The negative sway force is towards the bank and the negative yawing moment tends to increase the distance of ship bow from the bank according to force measuring unit conventions.

In smaller distances to bank the sway force is towards the bank and its direction changes as the ship speed and distance to vertical bank increases. The sway force sign changes approximately in a Froude number equal to 0.15. The test results demonstrate that this point is delayed as ship distance to bank increases. In other words the sway force is towards the bank in narrow distances and its direction is reversed as the distance increases.

If we neglect the once positive yawing moment measured, in all the ranges of speed and distance to bank that is tested in this research, the yawing moment tends to further the ship bow from the vertical bank.

The sway force is considerable for tanker ship model too. In intermediate forward speed ranges, the sway force increases as the distance to bank increase. This behavior is completely not expected. In the first sight one may think that the bank effect decreases as the ship distance to bank increase. It is compliant with our knowledge of common fluid dynamics. This fact is through until ship wave making in vicinity of the bank is not considered. It should be mentioned that bank effect strongly depends on the interaction of the ship and the reflected waves from the bank. So the wave making pattern and its reflection from nearer bank and ship-reflecting wave interaction is an influential parameter to the forces exerted on the vessel. Assume that the ship distance to bank is large enough. When the ship moves forward it makes a wave pattern that propagates oblique towards the bank. The waves incise the bank and reflect. According to model tests when the ship distance to bank is large these reflecting waves damp before they reach the vessel. When the ship distance to bank is small the waves do not generate in the gap between ship and bank and the forces exerted on the vessel are mainly due to pressure changes and viscous effect. The model tests demonstrate that when the model is so close to the bank no considerable wave system generates.

The critical condition occurs in the case that the ship is in an intermediate distance to the bank. In the model tests held in the towing tank for tanker ship model this distance is about 4 times ship breadth. In this case the ship waves reflect from the bank and coincide with the ship. If the ship speed is large enough the vessel moves faster than the reflected wave and this wave pattern cannot affect the vessel so much. If the ship speed is low when the waves reflects from the bank and come back towards of the vessel the vessel is not present on that location. Finally the most critical case happens when the ship speed is medium. In this case the reflecting wave system affects the hull completely and the amount of induced sway force and yawing moment is considerable.

The model tests are repeated for the dhow model and sway force and yawing moment measured in the tests are plotted in the figure 9 and 10.

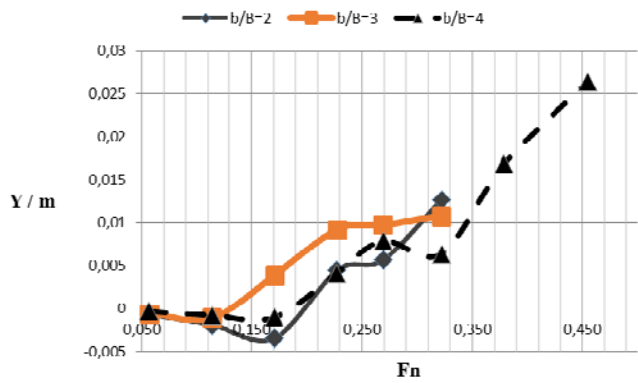


Figure 9. The sway force exerted on the Dhow model in the vicinity of vertical wall

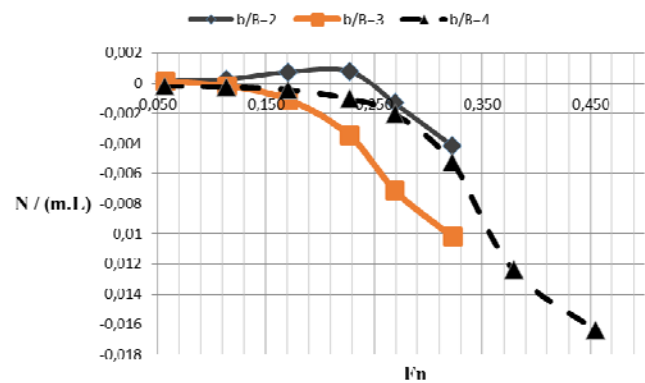


Figure 10. The yawing moment exerted on the Dhow model in the vicinity of vertical wall

The point that sway force direction changes is important in this case too. For the dhow model this point is about Froude number 0.1. The sway force exerted on the tanker ship and dhow model is compared in figure 11 for bank ratio 4.

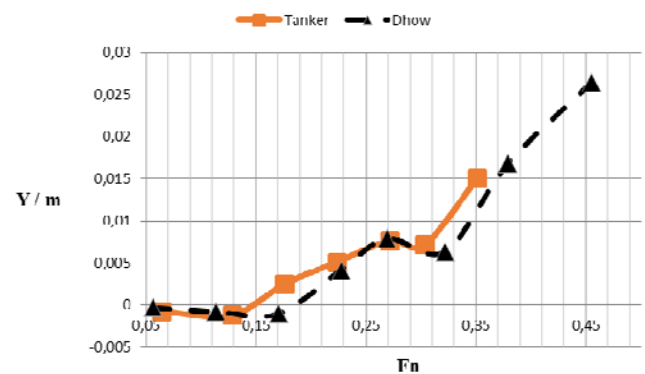


Figure 11. comparison of non-dimensional sway force exerted on tanker and dhow model in bank ratio of 4

The tanker model bottom is so flat but the dhow model has deadrise angle. Therefore it would be some flow suction in the dhow bottom and hydrodynamic loads would be smaller compared to tanker ship model.

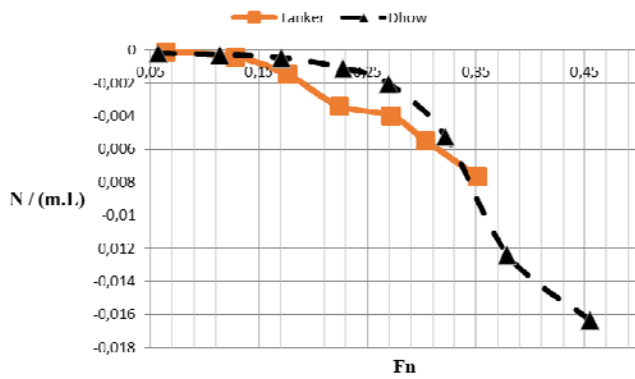


Figure 12. comparison of non-dimensional yawing moment exerted on tanker and dhow model in bank ratio of 4

4 CONCLUSION

Determination of forces exerted on the ships is so important from the maneuvering estimation point of view. Ships experience directional dynamic instability during moving forward alongside banks and quay walls. In order to analyze these phenomena it is essential to obtain suitable formulae for the forces exerted on the ship hull. These forces are applied in the ship maneuvering equations of motion and dynamic stability of the equations are examined. In this paper the model test and experimental fluid dynamic method is recognized as a powerful tool to

derive the forces induced on the hull during entering restricted waterways. The results of model tests depend on the models used to study the problem. The data measured during the tests are applicable only if the ship hull form is close to hulls tested in this study.

REFERENCES

- Fujino ,M. , 1968, "Experimental studies of ship manoeuvrability in restricted waters" , International Ship Building Progress, Vol. 15, No. 168, pp 279-301
- Gronaz A, Investigation of the influence of a vertical wall on a ship moving with drift angle
- Eda , H., 1971, " Directional Stability & Control of Ships in Restricted Channels", Transactions SNAME, pp 71-116
- Lee C, Lee S, 2008, Investigation of ship maneuvering with hydrodynamic effects between ship and bank, Journal of Mechanical Science and Technology 22, 1230-1236
- Norrbin , N., 1974, " Bank effects on a ship moving through a short dredged channel", 10th ONR Symposium on Naval Hydrodynamics, Cambridge, Mass
- Norrbin , N., 1985, "Bank clearance & optimal section shape for ship canals", 26th PIANC International Navigation Congress, Brussels, Section 2, Subject 1, pp 167-178
- Wang H, Zou Z, Xie Y, Kong W, 2020, Numerical Study of Viscous Hydrodynamic Forces on a Ship Navigating near Bank in Shallow Water, Twentieth International Offshore and Polar Engineering Conference, Beijing, China
- Zhou X, Sutulo S, Soares C, 2012, Computation of Ship Hydrodynamic Interaction Forces in Restricted Waters using Potential Theory, Journal of Marine Science and Application, 11:265-275.