MANEUVERABILITY in LOCK ACCESS CHANNELS

M. Vantorre
Naval Architect, Full Senior Professor, Head of Maritime Technology Division, Ghent University, Belgium
Knowledge Centre 'Maneuvering in Shallow & Confined Water', Flanders Hydraulics Research, Antwerp, Belgium

J. Richter
Naval Architect, Researcher, Flanders Hydraulics Research, Antwerp, Belgium

ABSTRACT: An overview is given of hydrodynamic effects acting on a ship approaching a lock, including approach channel and approach structure layout, density currents, translation waves, return flow, cushion effects, and retardation forces. Most of these effects have a non-stationary nature, which is challenging from the point of view of maneuvering simulation. Lock approaches are illustrated by practical examples.

1 INTRODUCTION

Most sea-going ships are not particularly designed or equipped for approaching locks. Their main means of control, mostly propeller(s) and rudder(s), are optimized for navigation at service speed, but during harbor approach (and, particularly, lock approach), ship behavior drastically changes due to speed reduction, shallow water effects, interaction with banks and other shipping traffic, etc. Frequently, sea-going vessels are equipped with bow (and, more rarely, stern) thrusters to improve the lateral controllability during low speed harbor maneuvers, but even these vessels often require tugs to assist them during (un)berthing, turning maneuvers, and lock approach. Inland waterway vessels, on the other hand, often need to perform such maneuvers on a more than daily base, so that they are mostly equipped with powerful bow thrusters and high performance rudders to guarantee high controllability at low speed.

All phases of a ship's voyage, including access to a lock, must be performed in a safe way, i.e. with an acceptable risk, but also in an efficient way, i.e. within an acceptable timeframe and making use of a reasonable amount of resources. The success of lock approaches depends on the interaction between the ship, the channel and lock characteristics, the meteorological and hydrological conditions, the assisting tugs, aids to navigation, and all human controls involved: the pilot or captain, the wheelman and the tug captain(s). Real-time simulation techniques are commonly applied for design of new infrastructure, assessment of accessibility of existing harbors/locks for new shipping traffic, and training purposes. However, simulations are only reliable if all relevant forces acting on a vessel during the considered maneuver are taken into account in the mathematical model of the simulator program. Some of the effects should be integrated in any simulator used for harbor maneuvers, but during lock approach and entry the ship's hydrodynamics are dominated by specific effects which are often a challenge for the developers of mathematical models.

2 HYDRODYNAMICS OF LOCK ACCESS

Simulations of maneuvers in lock access channels can only be realistic if the effect of shallow water on the hydrodynamic forces and moments acting on the ship is taken into account. Furthermore, bank effects should be included to account for eccentric approach and a ship-ship interaction force module is required if encountering or overtaking maneuvers frequently take place in the approach. All these phenomena, as well as the forces induced by tugs, can be considered as standard effects for harbor maneuver simulations.

Besides these effects, interaction with the specific geometry of the ***approach channel and approach structures*** induces forces and moments that are to some extent comparable to bank effects, but may be quite different due to their transient character and the permeability of the approach structures. Figure 1 displays the effect of different approach structures on the lateral force acting on a ship entering a lock along its centerline. While a solid structure causes an effect similar to a bank or quay wall – attraction to the wall combined with a bow-out moment – the effect of a permeable wall is completely different. Moreover, flow asymmetry clearly still affects the ship after the latter has entered completely into the lock or, during an exit maneuver, even before the ship has left the lock. Lock approaches are often asymmetric, and it is difficult to predict the occurring hydrodynamic effects; this is illustrated in Figure 2, showing the oscillatory character of the forces acting on an approaching ship.

Although locks are mostly planned in a protected location with respect to ***currents***, approaching ships are quite sensitive to even moderate flow patterns because of their limited approach speed. Moreover, lock operations may cause additional currents due to discharge and opening of the lock gate; especially with sea locks, density differences between the approach channel and the lock chamber induce flow patterns which not only cause important forces and moments on the approaching vessel, but may also affect the assisting tugs. Figure 3 gives examples of ***density flow*** patterns around a ship waiting to enter a lock, showing the effect of the approach structure geometry. Density currents due to lock gate opening may affect approaching vessels for a considerable time, e.g. 20 minutes and more for a large sea lock.

Especially in the case of a large blockage factor – i.e. when the limits of the dimensions of the entering ship are (nearly) reached – the entry of a ship into a lock can be compared with the motion of a piston in a cylinder. When entering the lock, a ***translation wave*** will be generated that reflects on the closed lock gate. This transient wave system depends very much on the hull shape, and will be more pronounced in case of full form ships (tankers, bulk carriers, barges). In the gap between the ship's keel and sides, and the lock's floor and walls, a ***return flow*** will occur, increasing the frictional resistance. The wave system and the return flow considerably increase the ship's resistance, cause vertical motions and affect the inflow to propeller and rudder.

When the margins between the lock walls and the ship sides are small, contact with lock structures (approach structures, fenders) is almost inevitable. Lateral motions of the ship that has partially or fully entered the lock chamber are affected by so-called ***cushion effects*** due to the piling-up of water; moreover, sudden accelerations or decelerations, occurring as a result of contact, cause ***retardation forces*** due to the inertia of the water mass between wall and ship. These memory effects are very dependent on ship and lock geometry.

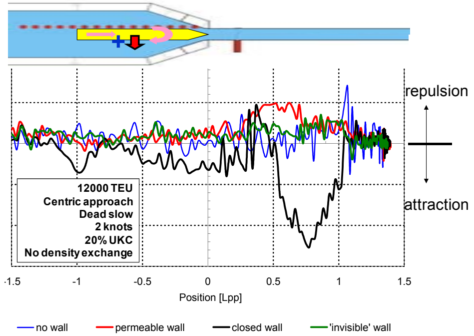

Figure 1. Lateral force on a self-propelled guided ship model during lock approach: effect of approach wall layout. Zero position is sketched above. Source: Flanders Hydraulics Research commissioned by Consorcio Pos Panamax on behalf of Panama Canal Authorities, [1], [2].

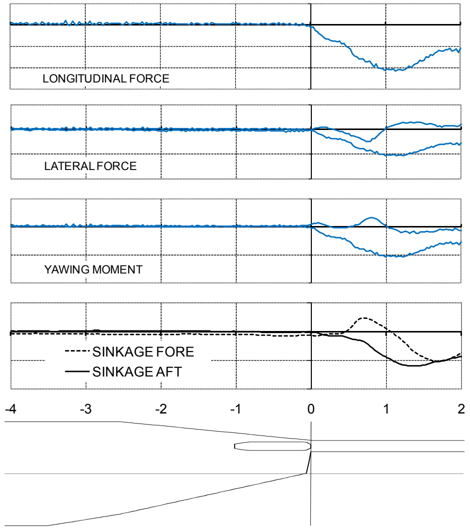

Figure 2. Captive model test with a bulk carrier entering the Pierre Vandamme Lock (Zeebrugge, Belgium) with asymmetric approach at constant speed. Longitudinal position convention: see Figure 1. Towing tank for maneuvers in shallow water (co-operation Flanders Hydraulics Research – Ghent University), Antwerp.

Besides all these phenomena that are typical for lock maneuvers, the ship is also subject to other environmental effects, such as ***wind***. In some cases, the ship's windage area is reduced due to partial coverage by the lock construction, which decreases the wind forces and moments, but also induces time-dependent wind actions.

Depending on their relative importance, it must be decided so as not to include these effects into the mathematical model of a simulator suited for lock maneuvers.

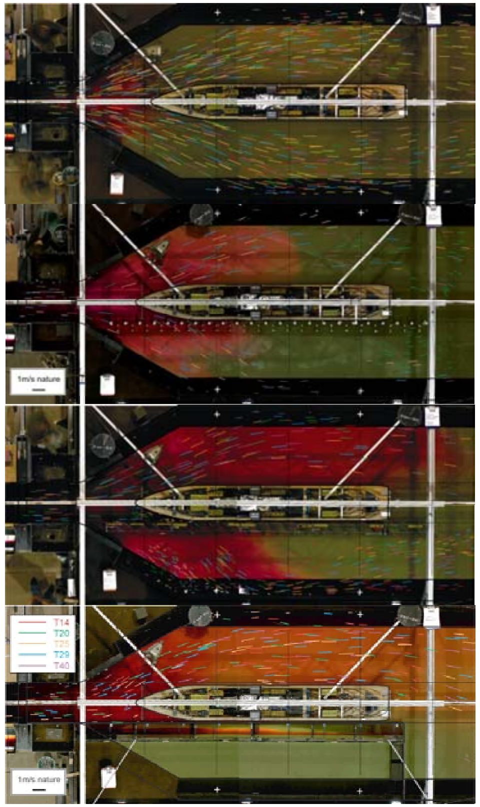

Figure 3. Effect of approach structure configuration on surface current pattern due to density exchange flow: no wall – 'invisible' wall (series of piles) – permeable wall – closed wall. Source: see Figure 1; [1], [2].

3 PRACTICE OF LOCK APPROACH

The procedure followed during approach of large sea-going vessels to locks depends very much on the local situation. Three examples will be given: the Panama Canal Locks, the Terneuzen West Lock and the Berendrecht Lock.

Ships approaching the present Panama Canal Locks get aligned with the lock centerline by means of tugs pushing them to the approach walls, where locomotives are attached to assist them through the lock(s), see Figure 4. This way of operation allows an efficient use of the lock capacity. The procedure for the Third Set of Locks, planned to be operational in 2014, will be different as the new locks will not be equipped with locomotives.

Figure 4. Bulk carrier pushed by tugs to the approach wall before entering Gatún Locks, Panama Canal.

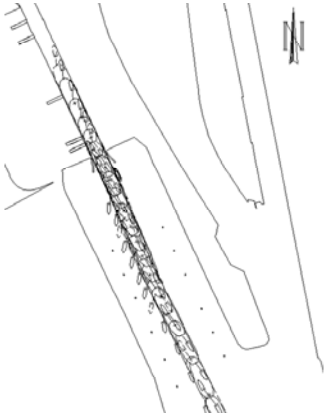

Figure 5. Real-time simulation of lock entry of a bulk carrier with 37 m beam to the Terneuzen West Lock. Source: Flanders Hydraulics Research, [3].

The Panama Canal Authorities presently allow ships with a beam up to 32.2 m in their 33.5 m wide locks. The Terneuzen West Lock (The Netherlands), giving access to the port of Ghent (Belgium), has a width of 40.0 m, but is equipped with floating fenders of 1.0 m width each at the lock walls; since 2008, ships with a beam of 37.0 m are allowed, after a simulation study at Flanders Hydraulics Research (Antwerp, Belgium), see Figure 5, and a number of test voyages. Alignment of the ship in the centerline of the lock is very important, and is realized by two tugs at the bow and one or two tugs at the stern. The bollard pull of the stern tugs depends on the wind conditions, but also on the speed of the vessel at dead slow ahead, as speed control is one of the main functions of the stern tugs. An increase of the allowable beam to 38 m is presently being studied.

For ships entering the Berendrecht Lock in the port of Antwerp (Belgium), the alignment might look less critical, taking account of the lock width of 69 m and the typical maximum width of the ships making use of it (about 55 m). However, due to the geometry of the access channel, it is not possible to align the ship far ahead of the lock entrance; moreover, assisting tugs have a limited free space to operate, see Figure 6. This situation requires a completely different strategy. In order to assess the accessibility of the lock for container carriers with length up to 381 m, real-time simulations have played an important role, [4].

For facilitating the access to the locks in Terneuzen and Antwerp, the Flemish and Dutch pilots make use of a portable system SNMS (Scheldt Navigator for Marginal Ships), that allows to determine the ship's position within centimeters accuracy. In lock mode, the pilot can determine the position of the ship with respect to the lock walls.

4 CONCLUSIONS

The safe and efficient use of locks requires an approach strategy that depends on the ship characteristics, the geometry of lock chamber and lock approach, available (tug) assistance, aids to navigation, and environmental conditions.

As human control and co-ordination between pilot/captain, wheelmen, tug masters, and lock operators play a crucial role, maneuvering simulation offer useful tools for optimizing lock design, assessing the accessibility of existing locks for new shipping traffic, and training. However, it is of great importance that all phenomena affecting and even dominating the behavior of a ship entering a lock are represented in a reliable and realistic way in the mathematical simulation model.

5 REFERENCES

[1] Delefortrie, G., Willems, M., Vantorre, M. & Laforce, E. (2009). Behavior of post panamax vessels in the Third Set of Panama locks. *International Conference on Marine Simulation and Ship Maneuverability (MARSIM '09)*, Panama City, Panama. Panama Canal Authority; International Marine Simulator Forum.

[2] Delefortrie, G., Willems, M., Laforce, E., Vantorre, M., De Mulder, T., De Regge, J. & Wong, J. (2008). Tank test of vessel entry and exit for third set of Panama locks. 517-523. *Proceedings of the International Navigation Seminar following PIANC AGA 2008*, Beijing, China. Communications Press.

[3] Vander Donckt, S., Vantorre, M., Laforce, E. (2007). Canal Ghent-Terneuzen: Maximum ship dimensions for the West Lock (in Dutch). Mod. 803-2. Flanders Hydraulics Research, Antwerp.

[4] Eloot, K., Verwilligen, J., Vantorre, M. (2010). Synergy between theory and practice for ultra large container ships. *PIANC MMX Congress*, Liverpool.

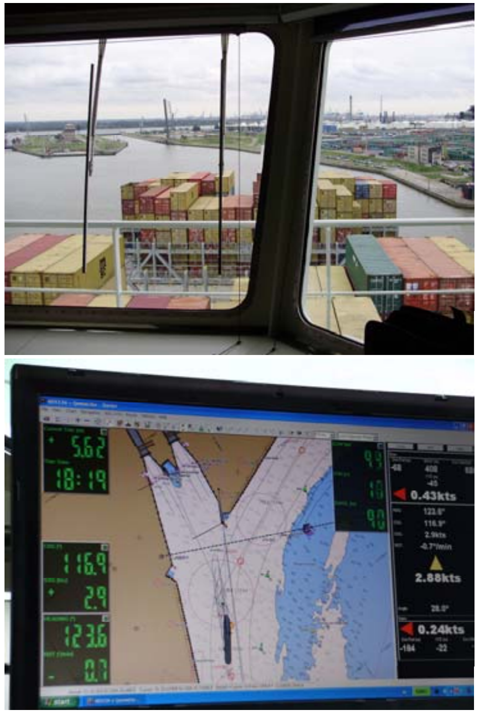

Figure 6. ULCC approaching the Berendrecht Lock, Port of Antwerp, Belgium, assisted by a portable pilot assistance system.