TANK TEST OF VESSEL ENTRY AND EXIT FOR THIRD SET OF PANAMA LOCKS

Delefortrie G
Ghent University
Belgium
Guillaume.Delefortrie@UGent.be

Willems M
Flanders Hydraulics Research
Belgium
Marc.Willems@mow.vlaanderen.be

Laforce E
Flanders Hydraulics Research
Belgium
Erik.Laforce@mow.vlaanderen.be

Vantorre M
Ghent University
Belgium
Marc.Vantorre@UGent.be

De Mulder T
Flanders Hydraulics Research
Belgium
Tom.Demulder@mow.vlaanderen.be

De Regge J
Technum – Consorcio Pos Panamax
Belgium
JDR@Technum.be

Wong J
Panama Canal Authority
Panama
JWong@pancanal.com

ABSTRACT

The Panama Canal Authority (ACP) plans to extend the capacity of and allow larger ships to the Canal by building a so-called third lane, consisting of a new set of locks parallel to the existing ones. The design ship is a so-called Post-Panamax 12000 TEU container carrier. In order to optimise the approach to and the manoeuvres within the locks, in 2007-2008 experimental research has been conducted at Flanders Hydraulics Research, Antwerp, Belgium on a 1/80 scale model of the approach lane, the lock and the design vessel. With the ship model moving along a guiding rail, lateral forces acting on the ship and movements of the vessel can be recorded during a selection of entrance and exit manoeuvres. During a number of tests, the effect of density exchange current was examined. The present article offers an overview of the test-setup with a discussion of a few interesting results of the test runs.

INTRODUCTION

The Third Set of Locks and the new approach lane the Panama Canal Authority (ACP) plans to build, will allow the acceptance of larger post-panamax size vessels and increase the throughput of the canal significantly. Triple lift type locks with rolling gates have been designed. Each new lock chamber will have a length varying between 427m and 488m, depending on the opening of the double inner gates. The width of each chamber will be 55m. The design ship is a so-called Post-Panamax 12000 TEU container carrier (length over all 366m, beam 48.8m, draft 15.2m; block coefficient 0.65).

One of the task orders of ACP contract no. CMC-159475 entitled *Engineering Services for Additional Studies and Technical Assistance for New Locks* consists of the execution of tank test model studies for the vessels manoeuvring in the future Third Set of Locks in the Pacific and Atlantic sides of the Panama Canal to determine design and operational criteria, such as the need and the configuration of lock approach walls, design criteria for fenders inside lock chambers, and required tug assistance. The task was assigned to the Consorcio Pos Panamax (CPP), which contracted Flanders Hydraulics Research (FHR) to perform the model testing. Scientific support is provided by the Maritime Technology Division of Ghent University, Belgium.

EXPERIMENTAL SETUP

A 1/80 scale model of the new lock with the approach channel has been built at Flanders Hydraulics Research. A scale model of the 12000 TEU container vessel is allowed to move on a straight line parallel to the locks' centreline, while the lateral motions are restrained by a guiding rail to which the ship model is connected at the bow and at the stern. The lateral forces in each connection point are measured by dynamometers, while the ship is free to move in vertical direction. The ship's velocity is controlled by changing the propulsion of the ship, which is provided by its propeller or by tug assistance. As in practice it is not feasible to apply small scale tug models, tug assistance was simulated by small model scale airplane propellers mounted on the ship that only exert forces in the longitudinal direction. With the measured lateral forces the necessary tug assistance in any direction can be determined. The rudder of the ship model is not controlled during the tests.

Additional measurements are the thrust and torque of the propeller, the absolute vertical position of bow and stern, the water level in front of bow with respect to ship (wave gauge), and the roll angle of the ship. Wave gauges were provided to measure the water level at the closed end of the lock within the lock model, and on the front wall of the lock entrance. The distance of the ship along the axis is measured, which also allows the ship's speed to be controlled.

To sail along the beam with different eccentricity (or at an angle) with respect to the lock axis, the frame with the wheels can be positioned eccentrically regarding the ship's axis. The experimental setup does not allow contact of the ship with the wall or lateral motion in the lock. Therefore no cushion effects are activated or measured and no lateral approach velocity can be determined.

Before the entrance to the lock chamber four different approach wall configurations have been tested: none, a closed wall, a permeable wall with inclined rectangular partitions, and a series of piles (see Figure 1). An approach wall offers the advantage of a structure where the ship can moor before the opening of the gates or helps the pilots to align the vessel with the longitudinal axis of the lock. The drawback is that its asymmetry likely induces more lateral forces on the ship.

The lock chamber was built in glass to take account of the roughness scale. Moreover it offers the advantage to record the flow underneath and alongside the vessel. Recordings were possible with 3 DSLR cameras and a dynamic webcam placed on top of the model. The reflection in inclined mirrors placed next to the model permitted to capture the effects underneath the vessel.

Due to the difference in density between the water in the lock chamber and in the approach channel, density exchange currents are generated during spilling operations and during the opening of the lock gate. In order to investigate both effects, the model scale lock was equipped with a gate that could be opened according to a realistic opening law, and spilling outlets were constructed in front of the lock gate. While brackish water was used in the approach channel (density: 1012 kg/m³) during the entire experimental program, the lock was filled with fresh water during density exchange current tests. The fresh water was dyed so that its flow is visible during recording. During these tests the ship could be waiting along the approach wall (static test) or already be approaching the lock (dynamic test). In static tests the ship was connected to the guiding rail with a dynamometer which disabled the longitudinal acceleration of the vessel, while measuring the longitudinal force acting on the vessel. During dynamic tests the waiting time between the opening of the gates and the entrance of the vessel was a significant parameter. Reflecting floats were present on the water allowing to assess the magnitude and direction of the surface flow velocity.

TEST SCENARIOS

The largest tidal difference occurs at the Pacific side of the canal. The Pacific side was therefore selected as the critical condition. Most tests where conducted at a water depth over the lock sill of 18.30m, which corresponds with a low tide and leads to an under keel clearance of 20%. Some runs were conducted at a critical under keel clearance of 10% and a more comfortable under keel clearance of 30%. The ship sails in the following six conditions:

- Ocean – Lock: from the Pacific side to the first lock chamber (to the Gatún Lake);
- Lock – Lock: from one lock chamber to the next shallow lock chamber (towards Gatún Lake);
- Lock – Lake: from the last lock chamber to the Gatún Lake;
- Lake – Lock: from the Gatún Lake to the first lock chamber;
- Lock – Lock: from one lock chamber to the next deep lock chamber (towards the Pacific Ocean);
- Lock – Ocean: from the last lock chamber to the Pacific Ocean.

The lock chamber had a removable bottom to allow a difference in depth. At the end of the lock model a turning circle was provided so that the ship can be disconnected from the guiding rail and turned. For lock-lock operations the closed approach wall was extended to simulate a second lock. In this way the six conditions can be experimented without major efforts.

Dynamic tests were conducted at three speeds, corresponding with speeds of 1, 2 and 3 knots. The speed can be reached using both (moderate) propeller action and tugs, or tugs only. As the typical speed of large container carriers at dead slow is 7 knots, braking assistance of the tugs may be needed. The ship model enters the lock at three different eccentricities: centric, 1.50 m out of the longitudinal lock axis and 0.60 m between the ship's hull and the lock walls. When starting in the approach lane, the ship will always accelerate with propeller action until a speed of 4 knots. Before the start of the approach wall condition the speed is regulated with the fans (tugs), whenever possible. If a density exchange process is involved, the ship enters the lock 1, 2, 5 or 10 min after the complete opening of the gates.

Note: all data (speeds, times, distances) are expressed in prototype values, unless specified. A Froude scale law (scale 1/80) is used for reducing prototype data to model data.

RESULTS

The results in this paragraph focus on the Pacific-lock entrance at a desired speed of 2 knots with propeller assistance (dead slow). Sign conventions are shown on Figure 2. Results are shown in function of the longitudinal position of the ship's fore perpendicular.

Runs without density exchange current

When the ship enters the lock centrically along its longitudinal axis, a closed approach wall causes a lateral force towards the wall and a bow-out yawing moment. A permeable approach wall not only results into significantly smaller hydrodynamic forces, but also causes a sign change of the lateral force, see Figure 3a. The effect of an approach wall appears to be maximal when half of the ship's length is within the narrow section.

An eccentric entrance of the lock, Figure 3b, yields larger forces acting on the ship due to the asymmetric condition, which exists both with and without an approach wall. The increase of moment is rather small for a permeable approach wall compared with the no wall condition, but the closed approach wall yields a large bow out moment, which is anyhow not larger compared to the centric condition. For the closed approach wall, the eccentricity even causes a reduction of the lateral force, although the magnitude remain significantly larger compared to the other approach configurations.

An increase of under keel clearance to 30% has only a minor effect on the forces, but a decrease to 10% has a severe effect when a closed approach wall is fitted, see Figure 3c. The effect on the speed of the vessel is more significant. Due to the resistance increase when entering the lock, a desired speed of 2 knots is impossible to maintain within the lock. The average speeds the vessel reaches decreases with the under keel clearance. Squat and roll are never critical.

<u>Runs with density exchange current</u>

During static tests, the discharge of fresh water causes a sway force tending to move the waiting ship away from the approach wall. The opening of the gate causes a second, smaller peak. The lateral force increases with decreasing permeability of the approach wall; in case of a closed structure this force can take extremely high values, see Figure 4. Similar conclusions can be drawn for the yawing moment. The ship is also subject to oscillating longitudinal forces with an amplitude depending on the type of approach wall.

Figure 5 gives an example of the forces measured during dynamic runs. Compared to the condition without density exchange current the lateral force does not vary much in case no approach wall or a permeable approach wall is fitted. On the other hand the repulsive lateral force increases significantly with a closed approach wall. The effect of density exchange current is less pronounced for the yawing moment. Unlike the condition without exchange currents squat and roll become critical with a closed approach wall.

CONCLUDING REMARKS

The entrance to the lock seems to be dominated by the approach wall configuration. A closed approach configuration does not appear to be an option, especially when density exchange currents are involved realistic tug and lateral thruster assistance can unlikely counteract the large lateral force with a closed approach wall.

Additional test runs with smaller vessel types are planned. Further analysis of the results will focus on the following:

- Determine whether the hydrodynamic forces can be counteracted by lateral thrusters, rudder and/or tug assistance. Also sinkage and roll must be restricted to safe values;
- Analysis of the effect of the wind;
- Optimisation of procedures: it may for instance be useful to increase tug assistance to support the throughput of the locks;
- Development of real time simulation modules for training purposes.

FIGURES

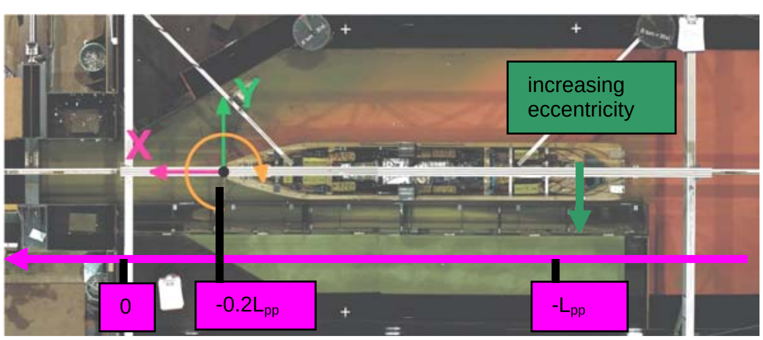
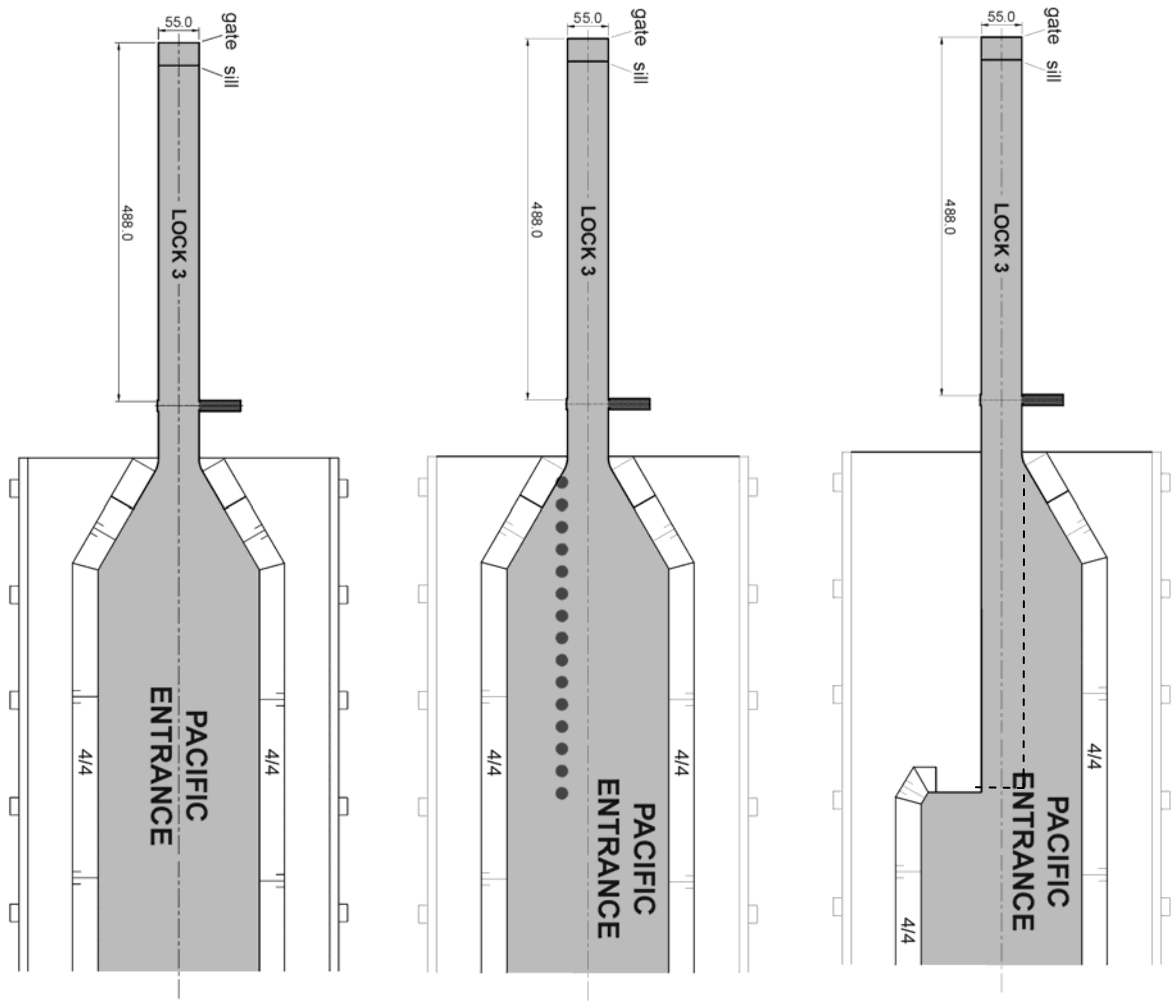


Figure 2. Ship entering in lock with positive direction of forces, moment and positions. The current position of the ship is at x = $-0.2L_{PP}$.

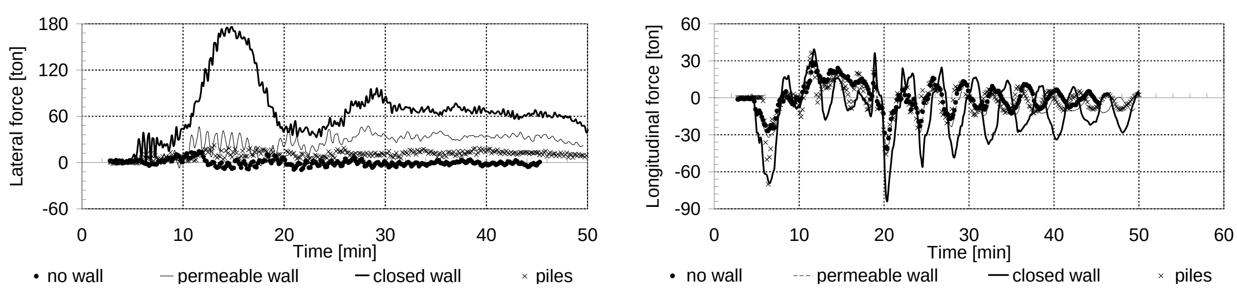


a. No approach wall.

b. Permeable approach wall or series of piles

c. Closed approach wall. Closing the dashed line allows Lock-Lock tests.

Figure 1. Different approach wall configurations on the Pacific entrance.



a. Sway force

b. Longitudinal force

Figure 4. Static density exchange current, influence of wall configuration, 12000 TEU container carrier, ship’s bow 80 m before narrow section, 20% under keel clearance. Spilling starts at 5 min and is finished at 16 min, gate completely open at 21 min.

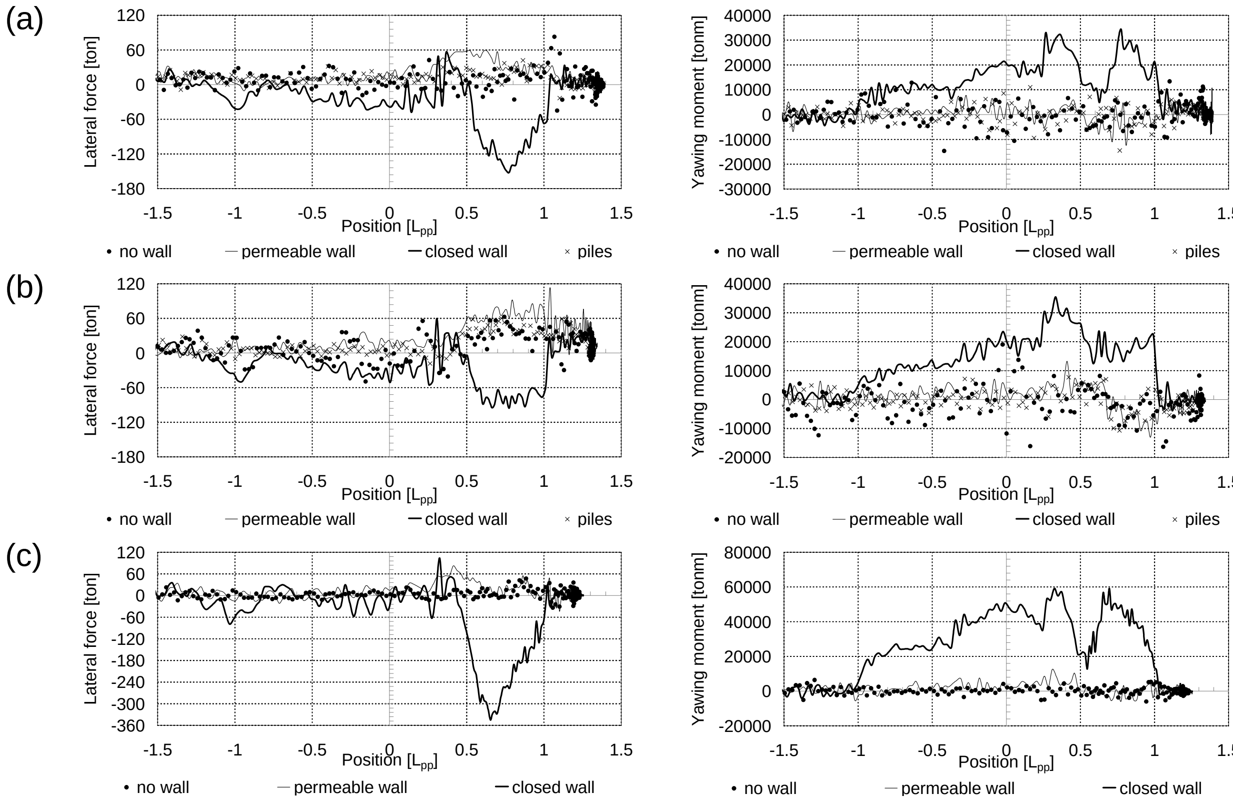
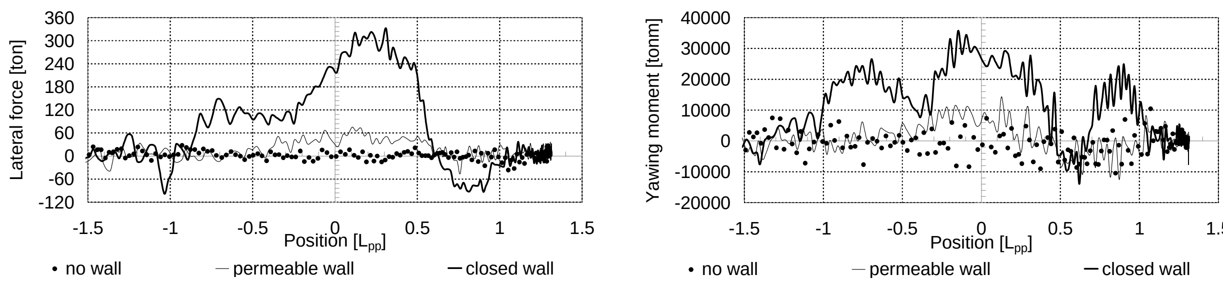


Figure 3. Ocean-Lock test without density exchange: influence of wall configuration on lateral force and yawing moment,12000 TEU container carrier, desired velocity 2 knots, dead slow ahead. (a) centric entrance, 20% UKC; (b) eccentric entrance (1.5 m out of the axis), 20% UKC; (c) centric entrance, 10% UKC.



a. Sway force
b. Yawing moment

Figure 5. Dynamic density exchange current, influence of wall configuration, 12000 TEU container carrier, desired velocity 2 knots, dead slow ahead, 20% under keel clearance. The ship passes the narrow section 5 min after opening the gate, the latter taking place at -0.9L_{PP}.