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PANAMA CANAL SHIP MANNED MODEL TRAINING CENTER

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ABSTRACT

The Panama Canal Ship Manned Model Training Center, features a ship handling training center using manned model ships at a 1:25 scale. This training center arrived hand in hand with the Third Set of Locks to address the need to safely handle Neo-Panamax ships through the expanded Canal. This is a physical, to-scale representation of bodies of water and several structures, providing pilots with essential training in order to improve acquired responsiveness and maneuverability skills for Neo Panamax ships. At the center, real effects are replicated at a reduced scale without the risk of damaging full sized, working vessels. Panama's training facility has a true, to scale reproduction of Locks, docks and channels of the Canal. This facility consists of two artificial lakes connected by a channel that was designed and constructed to exactly represent the actual Culebra Cut, including its alignment and the lengths, widths, depths and headings of each of its reaches. The implementation of the center was completely executed by a multi-disciplinary team of Panama Canal's finest professionals. The physics of applied forces and hydrodynamics are factors that affect ship handling maneuvers. The hydrodynamic effects experienced during flow interaction and the physical phenomenon perceived during specific maneuvers over non-uniform and vorticial effects provided by currents generated in a navigation tunnel, and different analysis in narrow spaces, are simulated in the center. The training facility is part of the pilot's training program at the Canal, as it provides support and training to other professionals outside the Panama Canal.

Keywords: manned model, training, ship handling

1 INTRODUCTION

This publication aims to highlight the importance of the design and construction at a particular scale of a Ship Manned Model Training Center in Panama City, as part of the training for the Panama Canal Authority. In the following document it can be seen in detail the purpose and importance of this project's construction, both for the Panama Canal pilots and for the good development of the operations of the Canal. The project site chosen for its development, the design criteria, the importance in the simulations of hydrodynamic phenomena and the lessons learned from the execution of the project are also highlighted in this document.

A comprehensive training covers three types of training: (a) training on-board real vessels, where limited operations are carried out at tolerable risks, (b) training in numerical simulators, where the scenarios derive from mathematical equations and where visual and maneuverability capacities are recreated in order to develop crisis management skills, and (c) training in manned scale models, where the operations to be carried out may exceed normal safety limits and at the same time allow navigation in a real environment under true hydrodynamic effects. This type of model is limited in terms of wind effects.

When starting this project, the Panama Canal had real vessel training and various numerical simulation models, so the new manned scale model allowed complementing the overall practical training. This publication is intended to highlight the importance of the Ship Manned Model Training Center in Panama City, as part of the Panama Canal Authority´s training facilities.

2 PURPOSE OF THE PROJECT

With the beginning of the Expansion Program, the Panama Canal acquires a series of commitments in order to offer its new services, the transport of NeoPanamax ships through the Isthmus of Panama. This entails the need for expert training, inherent in the transport of ships with larger dimensions, cargo capacities and increased draft. Personnel training had to be carried out at the same time as the Centennial Locks continued its non-stop operations, so personnel availability for specialized training abroad was reduced. Thus, the Panama Canal Authority analyzed available training opportunities in the market for the handling of this type of ships, especially in terms of practical training in scaled manned ships models, which for some time it was considered to be acquired by the Canal.

It is important to mention that the Panama Canal already had a training center based on numerical simulators, which is kept updated through the most recent technological advances. The addition of a new training center that allowed training in manned models would fully complement the Center for Simulation, Research and Maritime Development of the Panama Canal Authority (SIDMAR), which offers training programs for captains, practitioners, port personnel and cadets, national and international.

The Panama Canal choose to build its own ship Manned Model training center instead of mobilizing its staff to existing training centers, and thus maximizing the investment in this type of training, further expanding its offer of specialized training service. This would be the first center of its kind in the region, which would allow the Panama Canal to take its pilots' training to the next level. A series of visits and research were conducted on training centers worldwide. Port Revel training center was visited in France, with whom the Canal signed a Memorandum of Understanding to assist in the implementation of the new training center in Panama. The Research and Training Center on Ship Management - Ilawa in Poland and the Warsash Maritime Academy in the United Kingdom were also visited. Other centers such as the Maritime Pilots Institute of Louisiana in the United States of America, the Chemstar Bangkok Nautical School in Thailand, the Ash Harbor in Australia and the Maritime Academy of Massachuetts in the United States of America were investigated. All these, allow to physically simulate the interactions of ships with tugs and other vessels, dock, climb, stop, accelerate, turn, anchor, among others.

The Panama Canal chooses to conceptualize the new facilities with a multidisciplinary team composed by its best professionals, who successfully started the design in November 2014, completed its construction in February 2016, and currently manage its operations since March 2, 2016, providing its services nationally and internationally.

This innovation project required special design parameters and the accommodation of design and construction standards appropriate to the desired scale. As part of the design, the Port Revel facilities and the recommendations emanating from the technical staff that provided advice throughout the project were taken as a reference. Likewise, parameters of the Panama Canal were incorporated in terms of the configuration of its facilities and the exercises to be simulated. Therefore, a series of sites available for the implementation of the project were analyzed, the marine structures to be built were considered and the hydrodynamic effects applied to navigation in the simulations were evaluated.

3 PROJECT SITE

The Ship Manned Model Training Center was built on a disposal site of unclassified material which came from dry excavation and dredging activities carried out in the extension and deepening of the Access and Navigation Channel of the Panama Canal during the Expansion Program. This site is located in the Summit area in alongside the Panama Canal.

The available area was a the disposal site that corresponds to approximately 15.5 hectares, of which 3.6 hectares were used for the implementation of the training center. The operational area comprises approximately 36,000 cubic meters of raw water, outlined in two artificial lakes, North Lake and South Lake, and a navigation channel that interconnects them. Hydraulic structures, docks and reaches were established throughout the area using a reduced geometric scale of 1:25.

3.1 Location and Access

The facility is located at an approximate elevation of 90.00 meters PLD in the area of Polygon E-2, owned by the Panama Canal Authority, located between the Radisson Sumitt Resort Hotel and the Culebra Cut (Gaillard Cut). The center has a two-lane access from Avenida Omar Torrijos Herrera. This avenue consists of asphalt pavement and presents abundant traffic during peak hours. The direct access to the installation is composed of a compacted dirt road which allows safe vehicular passage all year long.

3.2 Services

Site selection was based on its proximity to an 8-inch diameter raw water pipe, which transports raw water from the Gatun Lake, at the Chagres River in Gamboa, to the Raw Water Pumping Station in Paraiso Town. This existing infrastructure favored the possible interconnection through a new pumping station that would allow the system to be filled.

Likewise, the selected site had facilities for handling water discharge required when fully or partially emptying the lakes with the safe operation of a continuous and controlled discharge during the rainy season in Panama. At the same time, the high position of the installation favored gravity, presenting potential savings in the initial investment of the discharge system.

3.3 Soils

Considering the chosen site was composed by unclassified material resulting from dry excavation and dredging activities, the soil that remains in the area is muddy and highly permeable, which did not provide a good basis for the construction of any structure. That is why the soil was improved and carefully excavated in order to guarantee its stability, for the the bulk of these excavation activities were carried out during the dry season in order to ensure the best performance of the excavation equipment.

3.4 Water

Water used to fill the center came directly from the Gatun Lake, so it had the characteristics of the mentioned lake, been suitable for the conservation of the equipment used in the center. Thus, aquatic species emerged almost immediately after the completion of the filling works. This center with its navigation channel and its two artificial lakes has become a micro habitat for countless local species that could not have taking advantage of the area prior to this project.

3.5 Winds

The center is located between the Balboa and Gamboa hydrometeorological stations, so the values of each one were used to estimate wind characteristics in the area. The average wind speed in the area is between 2.1 and 3.6 m/s, with maximum values reaching historically from 3.6 through 5.7 m/s. The winds direction annually prevails from North to West. In the area there are no tall trees nor abundant vegetation that could create a wind barrier that could have an effect on reducing winds intensity for the regular operation of the maneuvers to be simulated.

4 ENGINEERING - COMPONENTS

The distribution of the facilities at the project site was directly influenced by the characteristics of the existing Culebra Cut, which is basically the navigation channel that connects the Pedro Miguel and Cocoli locks with the Gatun Lake, crossing the central mountains of Panama. It is a narrow and winding channel, which was intended to be emulated in its entirety as part of the hydraulic structures to be considered in the simulations, given the complications that could occur in particular exercises.

The training center has a 25 times smaller replica of the Culebra Court, including its orientation, alignment, north direction, courses, reaches and banks. Since the soil found on the project site did not have the same characteristics found throughout the Culebra Cut, the design of the banks that are located there required a meticulous design through the application of soil-cement and a strict control in terms of transition points between one slope and the other, both during the design and then during the construction works. Based on the topographic and hydrographic information of the current navigation channel, the Culebra Cut at the training center is a real accurate replica of the original.

From this navigation channel, two artificial lakes, the North Lake and the South Lake, were conceptualized. Both the Culebra Cut and the South Lake have a shallow water level between 60 and 70 centimeters, which at scale represents the draft that is handled along the Panama Canal, allowing, through a regulatory structure, the simulation of the maximum and minimum operating levels of the interoceanic route. Meanwhile, the North Lake manages two water levels, the same shallow water level between 60 and 70 centimeters and a deep water level set at 200 centimeters. The latter simulates open sea depths, specifically towards the north entrance of the Canal on the Atlantic side.

Along the training center, between the North Lake and the South Lake, numerous hydraulic structures emerge such as the Atlantic Entrance to the Panama Canal, Balboa Port, Rodman Pier, Las Cruces, Sherman, Tigre current generator, mooring stations of Cucaracha and Cartagena, Agua Clara, Gatun and Cocoli locks, accompanied by their respective approach walls, a series of landing docks and common deep-water ports. All these structures are a partial or total replica of the actual facilities at a scale 25 times smaller. As part of the project, a replica of the Centennial Bridge was also designed, which is projected for a future expansion of the center.

The structures that simulate the Gatun and Agua Clara locks each have a single chamber, while the Cocoli locks have two chambers. These cameras simulate real levels under which ships would be driven at their entry and exit. Particularly the structure that simulates the Cocoli locks, has a piping system that represents the existing sewers used during the filling and emptying of the chambers. The Cocolí and Agua Clara scenarios are equipped with rolling type gates and their respective niches, similar to the existing locks. On the other hand, Gatun locks handle guillotine gates. The considerations of the gate type and sewer system support the effects produced by the entry and exit of ships, and the piston effect generated in one or other scenario. While the approach walls support the exercises or bending maneuvers that are normally practiced when entering the locks. The center is equipped with common navigation signs, buoys, lights, routing signs and signposts.

The design considered dimensions, weight and speed of vessels that would eventually operate in the center, in order to establish the minimum resistance parameters for different structures. For this purpose, all structures are reinforced concrete. The characteristics of these vessels should correspond to those defined in their manufacturing orders, since at the same time that the facilities were designed and constructed, such vessels were also constructed. The hulls of the ships were made at the H2X Shipyard in Marseille, France and the tugs in Vancouver, Canada by Master Modeler Ulrich Briner. For these activities there was full support of the owners of the vessels that were intended to be replicated, providing detailed plans and specifications of each of the vessels. Particularly the tugboat manufacturer, in addition to sending the plans and detailed information, sent the design of the hull model at a scale 25 times smaller, which contributed to its factory acceleration. Once the construction of the helmets was completed, they were sent to Port Revel, France for total instrumentation and calibration. As the ships and tugs were finished, they were sent to the center.

The training center currently has a 25 times smaller replica of the NORD DELPHINUS bulk carrier (DWT 8.8 ton), another of the container ship, MAERSK EDINBURGH (DWT 11.8 ton), one of the Liquefied Natural Gas vessel, STREAM LNG (DWT 6.2 ton), and another of the oil tanker, AEGEAN UNITY (DWT 7.3 ton). It also has four models of tugboats of the Cerro, Cerro Punta, Cerro Ancon, Cerro Picacho and Cerro Campana (DWT 54 kg) class.

The Tigre current tunnel or current generator was equipped with current generating motors, which simulate various currents that occur along the Panama Canal route, as well as the currents that can be experienced in certain maneuvers or exercises of failure. The selection of the equipment was made taking into account its versatility and high performance in very shallow waters.

The navigation channel and lakes are initially fed by raw water from Gatun Lake and its maintenance during the rainy season is essentially due to rainfall in the area. A raw water line 4 inches in diameter and 1,500 meters in length was driven to the site, which was derived from a main line located next to the Panama Canal railroad track. This required the installation of a pumping station to be controlled from the training center. Through a hydraulic spillway and overflow structure, the center manages to maintain its optimum levels during the rainy season. The excess water returns to Gatun Lake through a discharge channel, which eventually flows into the Culebra Cut.

Given the high permeability of the soil, the center's design included a waterproofing solution based on a bentonite mantle, in order to avoid the waste of water due to high infiltration rates. The mantle was carefully placed on the bottom and banks of the excavations, to later be covered with select material in order to guarantee the anchoring maneuvers without this being compromised. On the other hand, cut and fill slopes were protected with an erosion control blanket, which contributed to the revegetation of the site.

Next to the North Lake is the ships gallery, offices, meeting room, bathrooms and workshop. These facilities are equipped with electricity, drinking water and wastewater management. A drinking water line of 4 inches in diameter and 1,500 meters in length was driven to the site, which was derived from a main line also located next to the Panama Canal railway track, generating a crossing below the mentioned track. Power supply was obtained from the line located next to the access road and the new facilities were equipped with a new wastewater treatment system.

Due to the importance of controlling excavation levels and the scale representation of the hydraulic structures with unusual dimensions and tolerances, during the construction an unusual and detailed site accompaniment was sought, which finally fulfilled its mission.

5 NAVIGATION AND HYDRODYNAMICS

In the context of the safe operation of a ship, human performance depends on the skills of the operator, training and understanding the physical phenomena that govern the movement of a vessel at sea. Many accidents occur in confined areas such as ports, approach to ports, and canals because maneuvers are complicated based on external factors. This is why sailors must be well trained, since hydrodynamic interactions are extremely powerful and influential in maneuverability.

The maneuverability of a ship is understood as a set of characteristics that represent the inherent capacity of a vessel to perform various required maneuvers, safely and efficiently. The required maneuvers include basic actions carried out in unrestricted waters, such as turning, maintaining the course, stopping, moving or turning on an axis. Additionally, maneuvers must be carried out when docking and undoing in different situations, using rudder, engine, propellers and tugs if necessary, navigation in shallow water, canals and other restricted areas, often in the proximity of other objects and under the influence of Winds and currents.

The successful performance of all required maneuvers depends on the operator's knowledge of the characteristics inherent to the handling of the ship, as well as the knowledge of the physical phenomena that affect the maneuverability of a ship and the ways in which these phenomena modify the movement of the ship. Forces are created as the result of flow patterns and the distribution of pressure that builds up around the body of the ship. In a straight line movement, these pressure controlled forces are balanced. When a ship performs maneuvers, the pressure distribution around the hull is modified, creating forces that cause the ship to begin moving in a curvilinear trajectory.

In simple maneuvers, such as turning in a circle, turning on the axis, decreasing or accelerating, it is possible to predict that the forces were generated due to the change in pressure distribution. These forces controlled by the pressure field also affect the trajectory of the vessel. However, more complex maneuvers create non-stationary and extremely complex flow patterns around the helmet. In fact, it is almost impossible to calculate the flow dependent pressure distribution caused by such maneuvers, and therefore it is almost impossible to simulate the forces that result from changes in the pressure distribution or its impact particularly on the movement of the vessel.

An example is the docking maneuver performed by a ship approaching a dock, decelerating, reversing its propeller, using the rudder, and then accelerating forward again, using tugboats to push or tugboats pulling the bow. All these actions create extremely complex non-stationary flow patterns around the ship's body, and these flow patterns can be affected later due to the proximity of the berthing structures and the short free distance below the keel. These flow patterns are strongly influenced by the type of construction present in the berthing structures, and specifically if it is a solid wall spring or a pile spring, for example. In addition, the flow pattern at any time in time is affected by the memory effects of previous patterns.

Another example of an extremely complex flow pattern is that created by ship interaction between vessels. Two ships approaching each other in a narrow channel, affect each other and are also affected by the banks (bank interaction) of the channel. The instantaneous flow pattern is associated with its pressure and force distribution, and must be counteracted by the pilot in use of the rudder and the vessels engine.

Similar conditions arise when the vessel performs complex maneuvers with currents, especially between non-uniform currents that are typically found in shallow water or in restricted waterways. Such conditions greatly complicate the proper flow and pressure modeling, causing the accuracy of the results to be uncertain. However, it is essential that pilots who have completed training courses in mathematical simulators understand the physical phenomena that govern each movement of a ship, and especially the proximity effects that affect its maneuverability. They should realize how different hydrodynamic forces are created in close maneuvers, and how these forces affect the behavior of a ship.

As indicated, proximity effects are not always accurately simulated in FMB (Full Mission Bridge) simulators which provide training in an operations center to carry out ship control practices, navigation, collision prevention, communications and identification of ships, which are very useful due to the approximate nature of simulation methods. In MM (Manned Models) simulators forces are correctly represented, therefore the situation is properly simulated. However, although both types of simulators can recreate appropriate hydrodynamic forces, neither provide an explanation of the flow phenomena that causes such forces.

Maneuver simulation present complex problems given the diversity of responses that a ship shows with respect to another, related to the variables that intervene and, conditions all maneuver, such as draft, deadweight, distances to surroundings, available water under the keel, atmospheric state and sea, course and speed, among others.

Scale models allow, in a practical way, the demonstration of the maneuvers fundamental principles, familiarization with the boundary conditions of the ship and those of the pilot´s, docking and undocking maneuvers, with and without current, turning maneuvers without waves, channel navigation, anchoring and anchor maneuvers, traffic situations, among many more. These models are conceptualized based on the similarity theory of a prototype model that allows simulating real hydrodynamic effects on a reduced scale.

5.1 Similarity of Model – Prototype

The theory of physical models is based on the fact that from fundamental quantities - length (L), time (t) and mass (M), the remaining quantities involved in fluid mechanics are predetermined (derived quantities), and in which in this system (LtM) the hydrodynamic equations of the fluid are dimensionless, and therefore remain invariant in the face of a transformation.

$$L_p = \lambda\ L_m\ ; \quad t_p = \lambda_t\ t_m\ ; \quad M_p = \lambda_M\ M_m\ ; \qquad \text{[m: modelo, p: prototipo]} \qquad [1]$$

In this way, if the behavior in the model (Lm-tm-Mm system) of a given phenomenon is known, it is theoretically possible to deduce the factor of said phenomenon in the prototype (Lp-tp-Mp system), without using for each magnitude the change of scale according to the values of the parameters λ, λt, λM adopted in the previous transformation.

In this transformation each equation represents what in the theory of physical models is known as "model-prototype similarities". The first one is the "geometric similarity", the second one the "kinematic similarity" and the third the "dynamic similarity".

The “geometric similarity” determines that the relation of homologous model-prototype dimensions is constant, denominating said relation “geometric scale” or simply “scale” (l). In this similarity only form aspects have any influence, highlighting the geometric details and surface roughness, which represent a first challenge for the model-prototype similarity to be complete.|

The "kinematic similarity" implies the similarity of model-prototype movements, which together with the "geometric similarity" determines that the trajectories of homologous model-prototype particles are similar. In this case, the similarity relationship is known as the "time scale" (lt).

The "dynamic similarity" between two geometrically and kinematically similar systems implies the constancy of the relation of masses and, therefore, of forces in homologous elements. The relationship between masses is called "mass scale" (lM).

As indicated, the equations of hydrodynamics remain invariant in the model-prototype transformation, but the same does not happen with the fluid, which cannot be reproduced to scale. Its physical characteristics, density, viscosity, among others, for the purposes of the model, change with respect to those in the prototype according to the chosen scales (l, lt, lM).

Achieving a complete geometric resemblance is complicated due to the difficulty of fully reproducing form and roughness. With the dynamic similarity this problem increases, given that the relationship between the forces acting in the prototype such as gravity, viscosity, surface tension and pressure, against the forces acting in the model, does not remain constant or its importance in both systems it's the same. However, in practice, a “partial dynamic similarity”, based on the predominant forces in each case, is sufficient for the model to facilitate the solution of the problem sought by the trial. In this "partial similarity" two of its scales, time and mass (lt, lM), are preset when determining the predominant force in the phenomenon and the fluid to be used, so the only scale to choose is the geometric one (l). This is done in such a way that the model assumes the necessary dimensions so that the maneuvers are representative of reality. Therefore, once the geometric scale (l) and partial similarity have been chosen, using the dimensional analysis, the other two scales (lt, lM) as well as the derived quantities can be determined.

Partial similarities, as indicated, are established by analyzing the dominant force in the phenomenon to be studied, in order to have the best representation in the model. Based on this, the rest of the forces will present deviations with the prototype, known as the “scale effects”, which, in each case, must be analyzed to ensure the validity of test results. For this it is convenient that the scale be as large as possible.

In most hydraulic tests, surface tension forces are small, so they can be ignored without significant errors. On the other hand, gravity and viscosity forces prevail, mainly gravity forces, which is why this force its adopted as the main one - “Froude's similarity” - with the greatest application in hydraulics.

5.2 Hydrodynamics Effects

The hydrodynamic effects play an important role in confined and shallow waters, since new modern ships with large sizes and capable of developing high speeds are considered for designs of ports, mooring stations, navigation channels, among others, mainly because these parameters represent an indispensable safety factor for maneuvers.

The presence of another vessel added to the effects of shallow water causes an increase in the interaction effects of these vessels with one another and the surrounding hydraulic structures. At the moment a ship moves in the water, there is a region with high pressure in the stern and bow; however, the stern region has a smaller magnitude due to friction losses. This is because water displaced by the ship in the bow flows around and below the hull towards the stern, creating a Venturi effect under the hull which causes a negative pressure in the central region of the ship. In shallow water the Venturi effect is increased which causes a reduction in the water level line at the central region of the vessel that moves with the ship, and a wave spice rises in the stern and bow. This depression causes a reduction in the water-free height below the keel of the vessel.

The reduction in the water-free height under the keel of a ship is the result of a hydrodynamic interaction between the ship and the bottom. The more restricted the operation areas are, the cited free height will be increasingly affected and if it is additionally combined with the interaction of banks or coastline effects, the affectation will be even greater.

In a uniform channel, a ship sailing in the central line could suffer a reduction in free height under the keel and cause a sinking effect, but without any effect of interaction with the coastline. On the other hand, if the vessel deviates from the center of the uniform channel, a low-pressure region will be generated between the vessel and the nearby bank. As the vessel increases speed it will reach a limit where a wave that interacts with the vessel will be generated in a region between the ship and the bank, generating a high pressure region. In the same way, the interaction between the bank and the ship increases as the distance between them decreases. Which means that the force of attraction to the bank is affected by the speed of the ship, the depth of the water and the proximity to the referred bank.

5.2.1. Ships Crossing

Similarly, the interaction between two vessels that pass close to each other is of paramount importance. Hydrodynamic interaction can affect ship's direction and cause collisions. The interaction occurs at any depth, but in the same way as the other type of interactions, it is amplified in shallow waters. The separation distance between two ships is a critical parameter in the development of operations. Usually the lateral distance between decks should not be less than two times the largest width between both vessels, and the effects are more influential on smaller ships. In the case of two ships that cross each other from opposite directions, they have an interaction where both ships are pushed to starboard. In the case in which a ship tries to overtake another ship, thrust forces are initially produced to starboard and then to port, but additionally there is a rotation (yaw moment) and a suction force that generates an approach between the ships. This interaction will also be affected by the size of the various types of hulks involved and the various drafts.

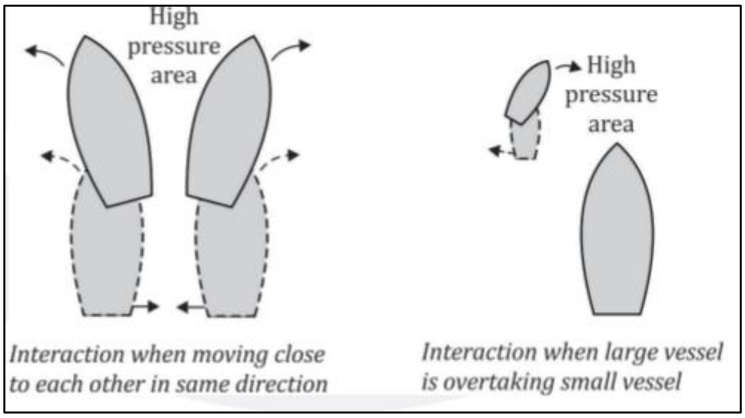

Figure 1. Interaction effect between ships in motion. [A]
Source: http://shipofficer.com/so/wp-content/uploads/2015/02/8.-Ship-Handling-Principles.pdf

5.2.1. Moored Ships

A mooring ship will initially feel the effect of a passing ship, where the moored ship will feel a repulsive force forward, which will cause it to rise forward and the stern move away from the dock, in the same way it will also be pushed towards the dock later. As the ship advances and approaches three quarters of the length of the moored ship, a suction force is produced that generates attraction, it increases as the moving ship approaches, and as the ship continues its movement. The opposite effect happens until it has finished. Usually the moving ship does not carry a significantly high speed that could cause waves. The main parameters to evaluate the interaction between a moving ship and a moored ship are the speed of the passing ship and the lateral separation distance between both vessels. There are also other factors that include the water-free distance under the keel, such as water density, tides, ship movements, among others. The magnitude estimation of the forces that interact is required for the proper structural design of the mooring structures.

5.2.1. Piston Effect

During the maneuver required to enter a ship into a sluice, a mass of water is produced. This mass of water pushes towards the sluice due to a reduction in the cross section of the entrance, and therefore a pseudo blockage of the entrance. Due to this reduction, the speed of the return flow increases, the loss of energy increases and the discharge of the return flow is too small to evacuate the water in front of the ship. This causes the formation of a translation wave in front of the ship, the reduction in the return flow produces a negative translation wave from the entrance of the sluice towards the channel. The reduction of the return flow causes a slight sinking of the ship and produces an increase in its resistance. The first wave formed in front of the ship is reflected several times against the hulk and in the sluice.

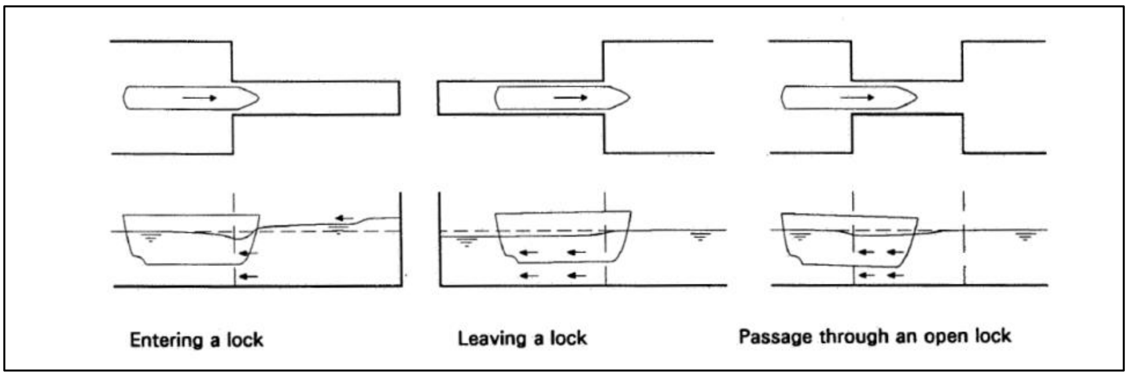

Figure 2. Waves in Piston effect. [B]
Source: https://lib.ugent.be/fulltxt/RUG01/001/887/173/RUG01-001887173_2012_0001_AC.pdf

6 CONCLUSIONS

The Ship Manned Model Training Center allows continuous training of Panama Canal pilots in relation to navigation maneuvers in deep and shallow waters, narrow and restricted areas, dock and docking stations, crossing ships and a number of maneuvers performed in daily operations throughout the Panama Canal.

The facility has allowed complementing the pilots training program, offering experience in ship manned models more attached to reality, which alongside with other types of training, provide a comprehensive program.

The center has allowed training personnel outside the Panama Canal Authority, thus making the facility provide additional income to the organization.

The installation showed the capacity of Panama Canal staff to plan and manage this project, as well as their design and construction capabilities to build a complete system of lakes and artificial channel, a variety of hydraulic structures, including Panamax and NeoPanamax locks at a reduced geometric scale of 1:25.

The detail level and fine precision required in the making of this training center required a thorough and very professional work by survey staff during earthworks and construction activities.

This project required a comprehensive commitment of many professionals responsible for the design and construction of a system as particular and special as the one used in the Panama Canal.

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