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EFFECT OF CROSS WATER CURRENTS ON A REPRESENTATIVE NAVIGATIONAL SHIP IN EGYPT

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ABSTRACT

For studying the effect of cross water currents on navigational ships, a representative design ship was chosen based on statistical analysis of the available data for ship units along the River Nile within Egypt. In this study, a distorted scale model of 1:80 in the horizontal direction and 1:20 in the vertical direction was designed. A wooden ship, which is specified as the geometrical model of a design representative prototype ship was tested in a rectangular flume inside the north experimental hall of the Hydraulics Research Institute (HRI).

The aim of this study is to develop a set of dimensionless curves, as shown in Appendix (B). The main benefit of these curves is to produce the transverse movement of the representative design ship. This movement should be utilized to check that the navigational ship doesn't go out of its permitted maneuvering lane, according to the specifications given by (PIANC & IAPH, 1997). Hence, this result can be used to accomplish suitable designs of outfall structures, the proper design of guide pier downstream barrage components, or to verify the safe navigable path through bends. This is all to provide operational traffic safety for passing ships along the River Nile within Egypt.

Key words: Safe inland navigation; cross water currents; transverse flow velocity; representative ship; ship transverse movement

1. INTRODUCTION

The subjected ship area under the water surface level, which is mainly called the draught, can be considered as the most effective factor for ship stability against the transverse velocity components from any field of cross water currents. These cross currents can be encountered at river crossings, stream bends, intake and outlet structures of water plants, inlets of branched canals, and in the approach zones to navigation locks. This instability in ship navigation while passing through these previously mentioned fields is because of the generated hydrodynamic forces due to acting transverse flow velocity components. Such velocity components could affect ship navigation by complete lateral drift across its course which may reach two times the ship width and/or rotation in the vertical ship axis, (Ross, G., 1984). As a result of this shift in the ship's course, collision hazards with other nearby passing ships may arise. For this reason the permissible cross velocity on the ship is limited to 0.3 m/s (Novak 1996; Romisch 1998; Linke & Zimmermann, 2001). Therefore, the studies in Egypt, (HRI 1997; HRI 1999; and HRI 2001), took this value as a reference without proper studies taking into consideration the River Nile's circumstances.

The present study deduced that the lateral transverse movement of the navigational unit and its rotation doesn't depend on the above mentioned value, but other different factors should be taken into consideration to ensure safety for navigational ships along the River Nile in Egypt such as: the ship's parameters (mass, width, length, draught, and speed), the fairway's characteristics (depth, width, and velocity), and the cross water current field conditions, such as distance to the ship, width, inclination, and magnitude. Consequently, a total of 135 experimental tests were carried out to develop a set of dimensionless curves. These curves involved representative ship parameters (width, draught and speed), fairway specifications (depth and width), and the magnitude of the transverse flow velocity component and its inclination to the flow direction. However, it was very difficult to study and simulate both the rudder angle effect and the behavior of the ship model while moving against stream. This simulation also wasn't easy (PIANC, 1992; Anthony F. Molland, 2011) due to the following reasons: the effects of time-scale distortion due to Froude scaling between velocity and distance ratios, human judgment, and available tools and equipments through this study. Nonetheless, the negligible effect of the rudder angle will produce the maximum deviation of the ship which of course becomes its critical deviation value. This is all to produce the transverse movement of the representative ship and make sure that the navigational ship doesn't leave its maneuvering lane.

2. HYDRAULIC MODEL

A fixed bed model was mainly constructed for this purpose inside the Hydraulics Research Institute (HRI). The dimensions of the model are 18.5 m long, 2.73 m wide, and 0.7 m deep. The model also is provided with three sumps; the first is the main one at the model inlet, the second is located at the model outlet and connected with the first sump by a side channel at the left of the model with 1 m width to make a closed circuit model, and the third is fixed at the right of the model beside it. The details of the model are shown in Figure (1) and Photos (1, 2, and 3) in Appendix (A).

Water is pumped to the main sump by an 8-inch diameter pipe, and the valve feeding is closed until the water reaches a suitable level in the sump. Then the water is pumped again from the sump to the model intake by a centrifugal pump with a total capacity of 100 l/s through a 6-inch diameter pipeline. There is also another pump with a capacity of 45 l/s which pumped water from the main sump to another sump beside the model approximately at its mid length. This sump allows the water to enter the model from its side, as shown in Figure (1) and Photos (5, 6, 7, and 8) in Appendix (A). The model is provided by a control gate at its outlet to adjust the water level in the model and release the water to the outlet sump which is connected to the main sump by a side channel to circulate the system [see Photo (4) in Appendix (A)].

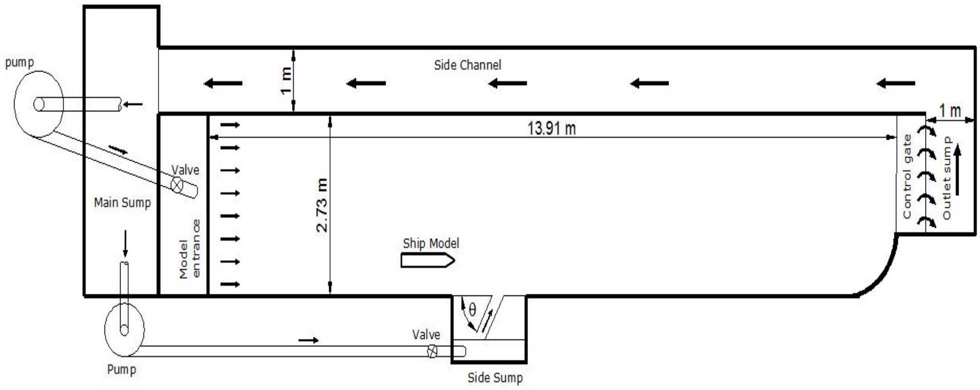

Fig. 1. *Close circuit model*

2.1. Tested Ship Model

At a convenient location beside the model, the tested ship was steered by an operator who controlled the ship model by a long electrical cable which connected the ship to both a power supply and a speed controller. This electrical cable was held and released at the same time by a technician who walked slowly behind the ship model during its motion during all the tests. Because of the effects of time-scale distortion due to Froude scaling between velocity and distance ratios, human judgment, and the availability of tools and equipment, it was very difficult to study and simulate both the rudder angle effect and the behavior of the ship model while moving against stream. Therefore, the ship model was tested provided that it was moving with the stream in a straight path for one meter at least before crossing the field of cross water currents. This condition was very important to ensure that any influence of ship model course wasn't for any reason but the effect of cross currents. The ship model was manufactured of wood weighing a total of 14.62 kg and has dimensions of 0.94 m in length and 0.19 m in width which is specified as a model of a representative design prototype ship along the River Nile in Egypt (Ahmed, A. F., 2004; Sabit, A. S., 2006), with a geometric scale of 1:80; moreover, the ship model is covered with a sheet of plastic to prevent the leakage of water inside it [see Photo (9) in Appendix (A)].

Photo 9. *The modeled ship*

For studying the effect of the cross water currents on the navigational ship, there is some equipment that should be used on the model to achieve this purpose, which are as follows:

- AC induction electrical motor: Which is supported at the top rear of the ship, as shown in Photo (10) in Appendix (A), to provide its motion inside the model.

- Ship propeller: A type of fan that transmits power by converting rotational motion into thrust and is fixed behind the ship below the water's surface. In addition, there is a steel frame which combines the AC motor with the propeller, as shown in Photos (11 & 12) in Appendix (A). The propeller has three blades welded upon a hollow aluminum cylinder which is grooved in such a way that allows it to be driven by the v-belt pulley with a rubber steering cable, as shown in Photos (13 & 14) in Appendix (A). The cylindrical aluminum hollow has a smaller diameter than the v-belt pulley to get a required speed of the model.

- Speed controller: A device used to control the rpm of the shaft of the AC induction electrical motor, as shown in Photo (15) in Appendix (A).

2.2. Instrumentation and Equipment

- Flowmeter: An electronic flowmeter was installed on the feeding pipe to measure the passing discharge into the model [see Photo (16) in Appendix (A)].

- Electro-Magnetic Current-meter: Flow velocity in the model was measured using an Electro-Magnetic Current-meter [see Photos (17 & 18) in Appendix (A)].

- Digital camera and tripod: The motion of the ship model is documented in video films during its movement before, during, and after the influence zone of cross water currents. A sixteen-megapixel digital camera was used for that purpose and supported on its tripod in a fixed location during all model tests, as shown in Photo (19) in Appendix (A).

- Balance bubble: A balance bubble is used during all the tests to ensure that the ship model has no inclination along two different axes upon that model, in other words, to ensure that the ship model is completely horizontal in the model before the beginning of any test, as shown in Photos (20 & 21) in Appendix (A).

- Stopwatch: The ship model speed is one of the most important factors affecting the maximum transverse movement during its path inside the influence zone of cross water currents. It must be adjusted just before the beginning of any test by using a stopwatch [see Photo (22) in Appendix (A)] during the motion of the ship model between two specified locations with a known distance.

2.3. Model-Prototype Similarity

In such a model with free surface flow, the inertial and gravitational forces are predominant; therefore, the model is based on the Froude Similarity law. The scale in vertical and horizontal direction will be distorted, i.e. LrV = (1:20) and LrH = (1:80). The advantage of this distortion provides a suitable modeling for the representative ship design and other parameters in the model, such as water depth, ship draught, and velocities based on the available tools, equipment, and the available space in the experimental hall. The Froude number (F) which represents the square root of the ratio of inertial forces to gravitational forces is given by: F = $V / \sqrt{gd}$

Froude similarity requires that the Froude numbers in both model and prototype (nature) are equal. From this condition, the following scales arc derived for both horizontal and vertical scales, (Steven A. Hughes, 1993):

Scale	Vertical	Horizontal
Velocity (V_r)	$L_{rv}^{1/2}$	$L_{rv}^{1/2}$
Time (T_r) = L_r / V_r	$L_{rv}^{1/2}$	$L_{rH} / L_{rv}^{1/2}$
Discharge (Q_r) = V_r. A_r	$L_{rv}^{1/2.}\ L_{rH}^{2}$	$L_{rv}^{3/2.}\ L_{rH}$

3. CALIBRATION OF BOTH DRAUGHT AND SPEED OF THE SHIP MODEL

The ship model draught (t) is adjusted in the model water to the required value by applying the buoyancy law which is illustrated as follows: Mg = ρgV, where M = the total weight of the ship model (kg), g = the gravity acceleration (m/s^2), ρ = the water density (1000 kg/m^3), and Vs (the submerged volume of the ship model) = the plan's cross sectional area of the ship model (m^2) × the ship model draught t (m).

Accordingly, one can get the desired value of the ship model draught (t) by calculating the corresponding total ship model weight from the above mentioned relationship; hence, by subtracting the empty weight of that model we can get the gravel weight which will achieve the required ship model draught, as shown in Photo (20) in Appendix (A).

In addition, the ship model speed should be calibrated before the beginning of any test. At first, the ship model is adjusted at the middle of the model width and also at a distance equal to 1.0 m from section (A), as shown in Figure (2); secondly, the small gravel inside the ship model is redistributed by using the balance bubble to ensure that the ship model is completely horizontal; thirdly, the tachometer of the speed control is adjusted to a certain value, then the AC motor is turned on; fourthly, the stopwatch is started just as the ship model moves across section (A) and then stopped just as the ship model crosses section (B), as shown in Figure (2). By knowing the distance from section (A) to section (B), which is equal to 7.0 m, and by knowing the time it takes the ship model to move between the two sections, one can calculate the corresponding speed. Finally, the above mentioned steps should be repeated to get the required relative ship model speed (Vsr) which represents the ship velocity (Vs) with respect to the stream velocity (Vstr.), i.e. Vsr = Vs + Vstr as the ship model is calibrated through the main stream flow.

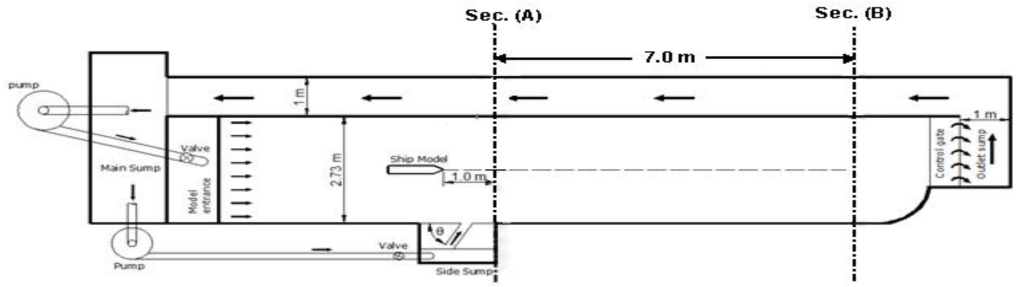

Fig. 2. *Calibration distance between section (A) & (B)*

4. EXPERIMENTAL PROCEDURE

Using the ultrasonic flow-meter which was installed at the inlet pipe of the main pump, the discharge was adjusted to the required value, and the water level was then adjusted to the desired value by both tailgates which were installed at the end of the model and at the reading of the point gage. Each test was carried out after a certain time to ensure that the flow in the model was fully developed to a steady state condition. The current meter reading of the probe was taken to obtain the model discharge and was compared with the ultrasonic flow-meter value. The opening width between the two steel plates (b) and the inclination (θ) were adjusted to the desired values, as shown in Figure (3) and Photo (6).

The digital camera -- which is the main output device -- was calibrated, enabling it to be set on the same marked signs on the tripod for every test, as shown in Photo (19).

Then a wooden ruler was prepared, having the same model width of 2.73 m, and was divided into thirteen equal divisions of 0.2 m, except the last right part which had a width of 0.13 m, as shown in Photo (25). Later on, the camera was used to take several images of that wooden ruler at the water's surface at different positions along the longitudinal direction of the model every 0.5 m, as shown in Photo (25).

Afterwards, these images were processed by the AutoCAD program, and a perspective grid mesh was subsequently obtained along the model by drawing lines across the model represented by each wooden ruler position - of 0.5m - at its contact surface with the water's surface. Then, longitudinal lines were drawn along the model which joins the marked signs of the division points along the ruler every 0.2m, as shown in Photo (25). Finally, we installed a grid mesh with a cell dimension equal to (0.5m x 0.2m) for the model at its water level, as shown in Figure (4).

Photo 25. *The contact line between both the wooden ruler and the water's surface along the longitudinal direction of the model every 1.0 m*

After determining the required values of the ship model's draught and speed, the required discharge value into the side pump was adjusted. Before the second step, one should take time to achieve uniformity of velocity during the water's entrance to the model from the side sump. Afterwards, the ship model was adjusted at a distance (x) from the right side of the model which is a distance equal to 1.0 m from section (1), as shown in Figure (3). Then, the tachometer of the speed control was adjusted to the desired value after which both the AC motor and the digital camera were switched on. [The camera is used to record the complete path of the ship model in a video until it crosses section (2)]. Finally, both the AC motor and the camera were switched off. By using the Topaz Moment software program, the recorded video would be cut into several images, under the same condition in which the ship model was for the whole path it traveled.

The images were inserted inside AutoCAD, followed by coinciding each with the prepared grid mesh for the model. Afterward, by using zoom view for precise determination, a suitable sign was marked at the side of the ship model for each image, followed by a joining between these signs to make a line, which represents the ship model's path influenced by the cross water currents field, as shown in Photo (26) and Figure (4). Finally, the transverse movement of the ship model would be obtained by subtracting the initial course location of the ship model from its final course location.

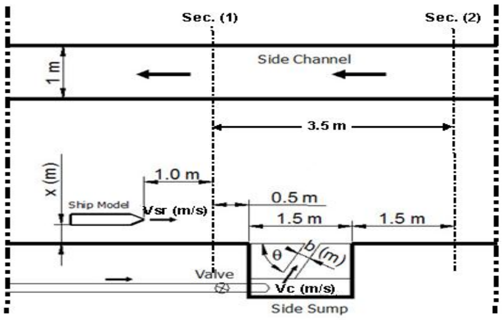

Fig. 3. *Considered variables during tests and testing distance*

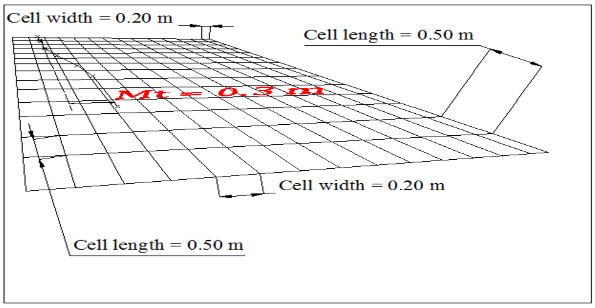

Fig. 4. *The ship's transverse movement (Mt)*

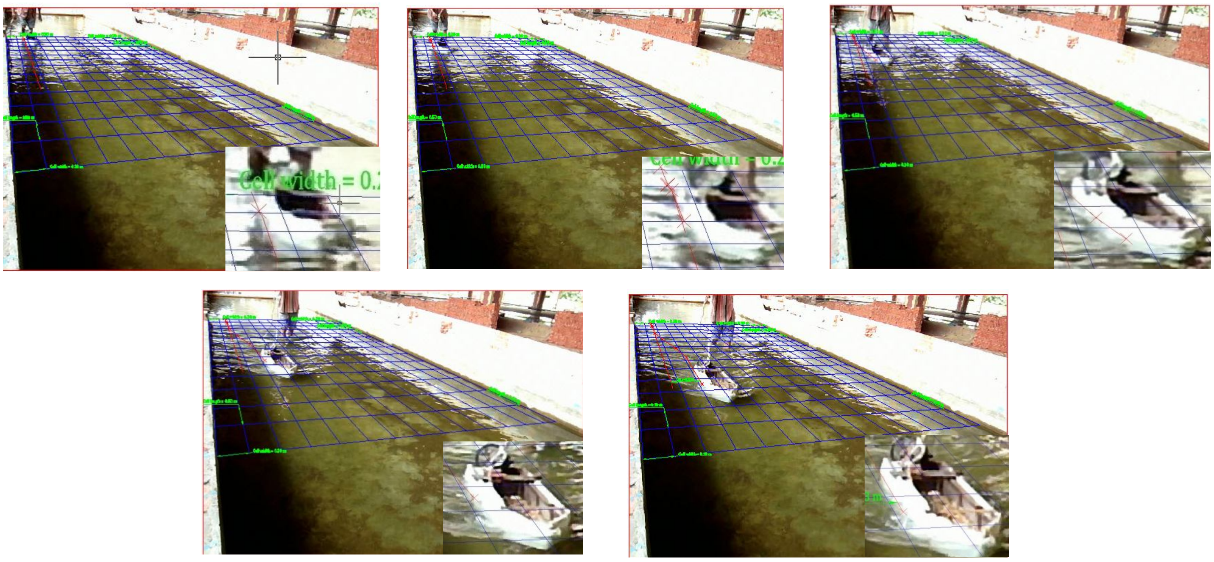

Photo 26. *The sign (x) at the side of the ship model along its path*

5. RESULTS AND ANALYSIS

The main attained result of this study was to get the ratio of the ship transverse movement to its width (Mt/B_S), as shown in Figures (3 and 4). These results were attained provided that two conditions existed; the first one being that the ship was moving with the stream, and the second one being that the rudder angle of the ship was not changed.

5.1. Effect of Dimensionless Distance (X/b) on (Mt/Bs)

For a specified value of the width of the field of cross water current (b) corresponding to the distance of the ship (x) from it, the transverse movement (Mt) was measured. The variation of the ratio of ship transverse movement to its width Mt/Bs with the dimensionless distance (b/x) was studied experimentally under the following boundaries: Vc/Vsr = 0.1, 0.5, 0.9 & θ = 30°, 60°, 90° & h/t = 2, 3, 4.

The value of b/x was changed from 0.2 to 2.5 in all experiments. This range was selected as follows: the values of (b) were chosen based on the data presented by (Romisch, 1998). The values of (x) were chosen in such a way that the ship would move in different paths: through, inside, and outside the zone of cross water currents.

Some typical results on the variation of Mt/Bs with b/x are shown in Fig. (5) for two tests which represent the high and low boundaries of the data envelope. The values of the dimensionless parameters for the two experiments were equal to: (Vc/Vsr = 0.9; θ = 90°; h/t = 4) & (Vc/Vsr = 0.1; θ = 30°; h/t = 2).

In the first test, it was found that the value of Mt/Bs at b/x = 0.2 was equal 0.83, while at b/x = 1.5, the value increased to 3.69, then was reduced to 3.25 at b/x = 2.5. This means that the ratio of ship transverse movement to its width (Mt/Bs) increased by 345% due to the change of the b/x value from 0.2 to 1.5 which then decreased by 12 % due to the change of the b/x value from 1.5 to 2.5. Following the same procedure, the value of Mt/Bs in the second test increased from 0.0 to 0.67 due to the change of the b/x value from 0.2 to 1.5which was then reduced by 31% due to the change of the b/x value from 1.5 to 2.5.

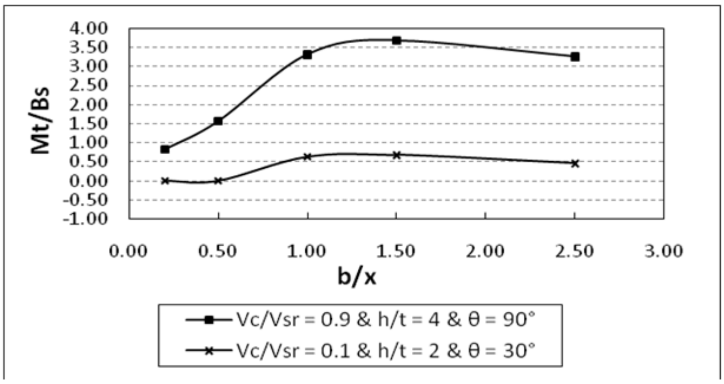

Fig. 5. *Variation of Mt/Bs with b/x (Cases of tests represent the high and the low boundary of the data envelope)*

From these results, it can be concluded that the dimensionless distance (b/x) has a great effect on the ratio of ship transverse movement to its width (Mt/Bs). As b/x increases, Mt/Bs tends to increase until its peak value at b/x = 1.5, then it decreases at b/x = 2.5. That means that Mt/Bs is directly proportional to b/x, until b/x is equal to 1.5, then it is inversely proportional in the range of one and a half to two and a half. This is in reference to the ship's passing far away from the cross water current, while in the meantime the cross water current field width (b) is small, i.e. the distance (x) is much greater with respect to (b), so the ship passes without any change of its course. This is because the ship navigates far from the zone of the cross water current. Conversely, if the ship approaches from the field of the cross water current, i.e. the distance (x) is decreased and at the same time the width of that cross current (b) is increased, then Mt/Bs is gradually increased. That is to say, the force generated from the cross water current pushes the extreme front submerged volume of the ship and makes it rotate in a counter-clockwise direction about its vertical axis; therefore, the ship starts to change from its original course. Afterwards, the same force pushes the middle submerged volume of the ship so that the deviation of the ship is continuously increased. Similarly, while the rear submerged volume of the ship enters that field, the cross current force pushes it again and makes it rotate in a clockwise direction. Afterwards, the same force pushes the extreme rear submerged volume of the ship until the ship navigates to its final course. The difference between the final and initial courses, which is called the transverse movement, can then be attained.

With respect to the decrease of (Mt/Bs) in case b/x > 1.5, it can be explained as such: while the distance between the ship and the field of the current (x) is decreased and at the same time the current width (b) is increased, both the front and rear submerged volumes of the ship are subjected at the same time to the same cross current force. Therefore, while the force pushes the front submerged volume of the ship and makes it rotate in a counter-clockwise direction, it also, in the meantime, pushes the rear submerged volume and makes it rotate in a clockwise direction, so that the ability of the ship to change its original course to another one in the case where b/x >1.5 is less than its ability in the case of b/x < 1.5. In other words, the deviation of the ship is less in the case of b/x >1.5 than in the case of b/x < 1.5. Accordingly, Mt/Bs is decreased in case b/x>1.5.

5.2. Effect of the Ratio of Cross Water Current Velocity to Relative Ship Speed (Vc/Vsr) on (Mt/Bs)

Both the cross water current and the relative ship velocity dominate and affect the passing of the ship, and as a result they play a decisive role in determining the transverse movement of it. The variation of Mt/Bs with the ratio of cross water current to relative ship velocity (Vc/Vsr) was studied experimentally under the following boundaries:

b/x = 0.2, 0.5, 1.0, 1.5, 2.5 & θ = 30°, 60°, 90° & h/t = 2, 3, 4.

The value of Vc/Vsr was changed from 0.1 to 0.9 in all experiments. This range was found to cover and exceed the practical ranges of Vc/Vsr in the prototype as illustrated: the chosen values of (Vc) are based upon when the ranges of cross water current velocities are from 0.5m/s to 1.5m/s in the prototype. In addition, the selection values of (Vsr) are from (3 knots = 5.5 Km/s) to (10 Knots = 16 Km/s) which are based on the specifications given by (PIANC & IAPH, 1997).Some typical results on the variation of Mt with b/x under the different values of Vc/Vsr are shown in Figures (6, 7) for two tests which represent the high and low boundaries of the data envelope. The values of the dimensionless parameters for the two experiments were equal to: θ = 90°; h/t = 4 & θ = 30°; h/t = 2. In the above tests, the variation of Mt/Bs with b/x was found to be affected by the variation of the values of Vc/Vsr. In the first group of tests [Figure (6)], the values of Mt/Bs decreased by about 96%, 70%, 49%, 54%, and 55% when b/x was equal to 0.2, 0.5, 1.0, 1.5, and 2.5 respectively due to the change of the Vc/Vsr value from 0.9 to 0.1. In the second group of tests [Figure (7)], the decrease of the Mt/Bs values was found to be equal to 0.0%, 96%, 51%, 54%, and 64% when b/x was equal to 0.2, 0.5, 1.0, 1.5, and 2.5 respectively due to the same changes of the Vc/Vsr value.

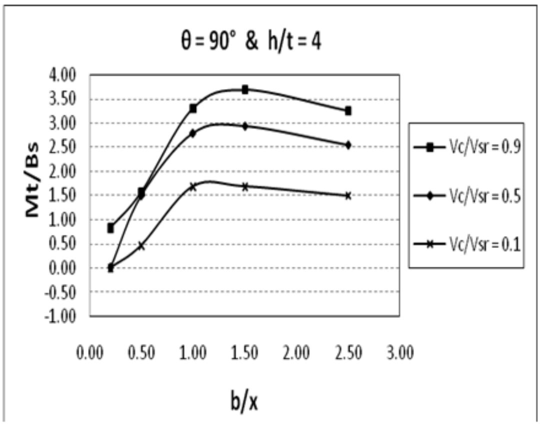

Fig. 6. *Variation of Mt/Bs with b/x – under different values of Vc/Vsr, (Cases of tests represent the high boundary of the data envelope)*

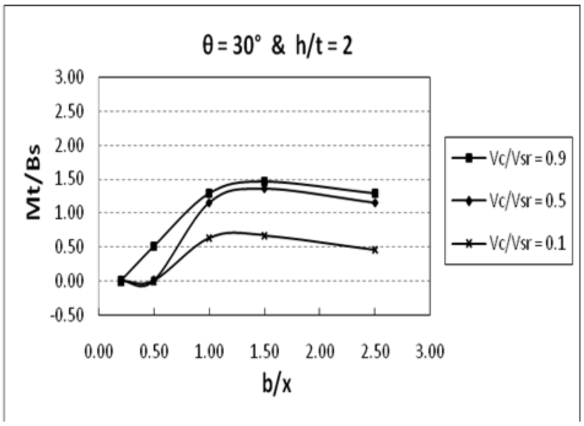

Fig. 7. *Variation of Mt/Bs with b/x – under different values of Vc/Vsr, (Cases of tests represent the low boundary of the data envelope)*

In general, it is concluded that the ratio of cross water current velocity to relative ship velocity (Vc/Vsr) has a great effect on the ratio of ship transverse movement to its width (Mt/Bs). The results indicated that Mt/Bs is directly proportional with Vc/Vsr. In other words, Mt increases with the increase of Vc/Vsr values.

At the higher values of Vc/Vsr, the force which generated from the cross water current is much greater than the force which generated at the lower values of Vc/Vsr; besides, the incurrence time of the submerged volume of the ship while crossing the field of the cross water current, at the higher values of Vc/Vsr, is higher than that incurrence time at the lower values of Vc/Vsr. Because of the two mentioned reasons, the ship transverse movement is increased at the higher values of Vc/Vsr than that transverse movement in the case of the lower values of Vc/Vsr.

5.3. Effect of the Horizontal Angle Between the Cross Water Current Field and the Stream Direction θ on (Mt/Bs)

The variation of Mt/Bs with the horizontal angle between the cross water current field and the stream direction (θ) was studied under the following boundaries: Vc/Vsr = 0.1, 0.5, 0.9 & b/x = 0.2, 0.5, 1.0, 1.5, 2.5 & h/t = 2, 3, 4.

The values of θ are equal to (30°), (60°), and (90°). These values were found to cover the practical ranges of θ in the prototype.

Some typical results on the variation of Mt with b/x under the different values of θ are shown in Figures (8 and 9). These experiments represent the high and low boundaries of the data envelope. The values of the dimensionless parameters for the experiments were equal to: Vc/Vsr = 0.9; h/t = 4 & Vc/Vsr = 0.1; h/t = 2. In the above experiments, the variation of Mt/Bs with b/x was found to be affected by the variation of θ. In the first group of tests [Figure (8)], the values of Mt/Bs decreased by about 96%, 60%, 63%, 62%, and 64% when b/x was equal to 0.2, 0.5, 1.0, 1.5, and 2.5 respectively due to the change of the θ value from 90° to 30°. In the second group of tests [Figure (9)], the decrease of Mt/Bs values was found equal to 0.0%, 0.0%, 48%, 47%, and 56% when b/x was equal to 0.2, 0.5, 1.0, 1.5, and 2.5 respectively due to the same changes of the θ value.

The results indicated that the angle between the cross water current field and the stream direction (θ), is directly proportional to the ratio of the ship transverse movement to its width (Mt/Bs). That is to say that the perpendicular force which is acting upon the submerged volume of the ship and causing the transverse movement is equal to the inclined cross current force multiplied by sin(θ), so that, as the angle θ increases the perpendicular force increases too, and consequently, the ship transverse movement is increased.

From this analysis of measurements, it can be concluded that the angle between the cross water current field and the stream direction (θ), has a considerable effect on Mt/Bs. In other words, Mt/Bs is larger in the case where the cross water current field is perpendicular to the stream direction as compared with another one inclined with the stream.

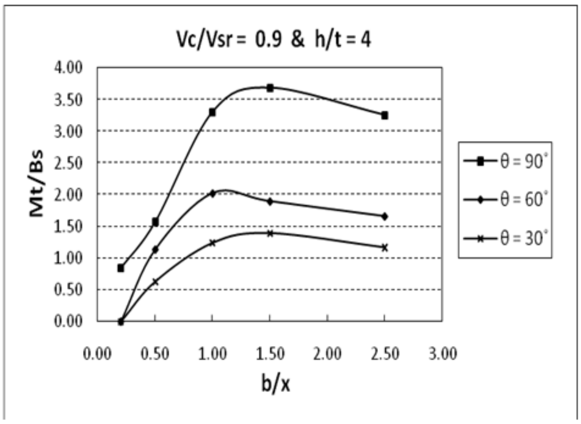

Fig. 8. *Variation of Mt/Bs with b/x – under different values of θ, (Cases of tests represent the high boundary of the data envelope)*

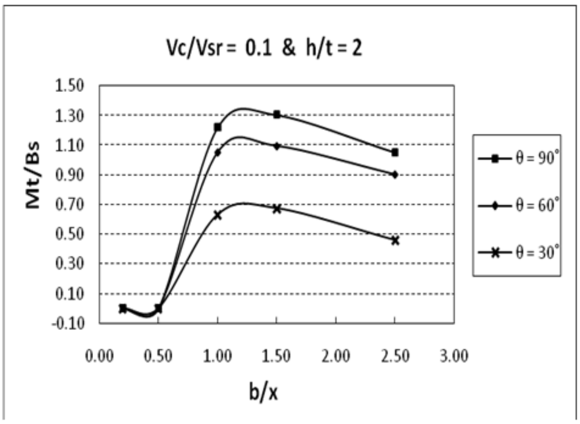

Fig. 9. *Variation of Mt/Bs with b/x – under different values of θ, (Cases of tests represent the low boundary of the data envelope)*

5.4. Effect of the Ratio of The Water Depth to the Ship Draught (h/t) on (Mt/Bs)

The variation of Mt/Bs with the ratio of the water depth to the draught of the ship (h/t) was studied under the following boundaries: b/x = 0.2, 0.5, 1.0, 1.5, 2.5 & Vc/Vsr = 0.1, 0.5, 0.9 & θ = 30°, 60°, 90°.

The values of h/t equal 2, 3, and 4. These values were found to cover the practical ranges of h/t in the prototype as follows: the chosen values of (h) are based on the maximum and minimum water depth which could be achieved in the model according to the available tools and equipment. These values are from 5 m to 8 m in the prototype. In addition, the selection values of (t) which represent the loaded and the unloaded ship draught are from 1.4 m to 2.4 m (Ahmed, A. F., 2004; Sabit, A. S., 2006). This range is giving an average approximate value of 1.8 m which equivalent to the representative design ship draught.

Some typical results on the variation of Mt/Bs with b/x under the different values of h/t are shown in Figures (10 and 11). These experiments represent the high and low boundaries of the data envelope. The values of the dimensionless parameters for the experiments were equal to: Vc/Vsr = 0.9; θ = 90° & Vc/Vsr = 0.1; θ = 30°. In the above experiments, the variation of Mt/Bs with b/x was found to be affected by the variation of h/t. In the first group of tests [Figure (10)], the values of Mt/Bs increased by about 20%, 9%, 12%, 12%, and 18% when the b/x was equal to 0.2, 0.5, 1.0, 1.5, and 2.5 respectively due to the change of the h/t value from 2 to 4. In the second group of tests [Figure (11)], the increase of Mt values was found to be equal to 0.0%, 0.0%, 39%, 31%, and 13% when the b/x was equal to 0.2, 0.5, 1.0, 1.5, and 2.5 respectively due to the same changes of the h/t value.

The results indicated that the ratio of the water depth to the ship draught (h/t) is directly proportional with Mt/Bs. As the water depth (h) is increased with respect to the ship draught (t), the small submerged volume of the ship was found. This result leads to a weak resistance of the ship against the force which generated from the cross water current field; therefore, the deviation of the ship is increased. That is to say, the ship transverse movement is increased in the case in which the water depth (h) is increased with respect to the ship draught (t).

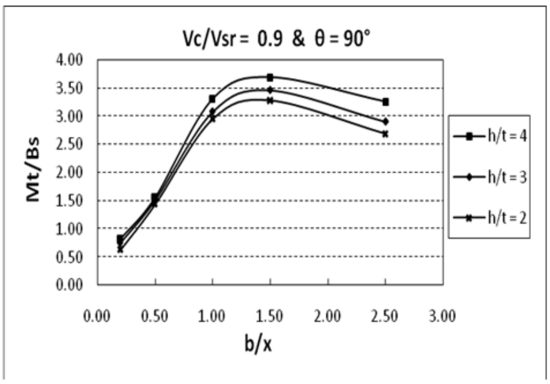

Fig. 10. *Variation of Mt/Bs with b/x – under different values of h/t, (Cases of tests represent the high boundary of the data envelope)*

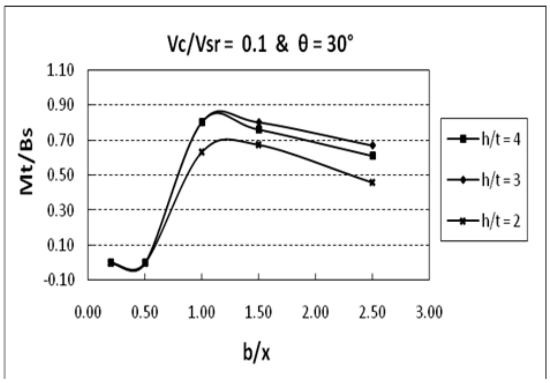

Fig. 11. *Variation of Mt/Bs with b/x – under different values of h/t, (Cases of tests represent the low boundary of the data envelope)*

From this analysis of measurements, it can be concluded that the ratio of the water depth to the ship draught (h/t) has a considerable effect on the ship's transverse movement. It was found that Mt/Bs is larger in the case of the higher value of the ratio h/t. This means that the higher the percentage of h/t, the higher Mt/Bs is.

6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Generally, it is concluded that the developed curves in this study, shown in appendix (B), took into consideration the effect of most parameters on the transverse movement of the representative design ship along the River Nile in Egypt unlike the other formulas which are concerned with the evaluation of cross water current velocities but didn't consider more than one parameter. The transverse movement values resulting from these curves should be utilized to check that the ship doesn't leave its manoeuvring lane, according to the specifications given by (PIANC and IAPH, 1997). Accordingly, this result may be used for the optimum design of the different types of outlets on the river, or for the best design of guide pier length upstream or downstream barrages, or to determine the safe navigable ranges when the ship is passing through bends to prevent its contact with banks.

Recommendations for the Future Studies

- Further experiments need to be carried out to study the effect of cross water currents on the transverse movement of ships navigating against the stream.
- More intensive experimental studies need to be carried out to develop an empirical equation taking into consideration the effect of both ship lengths and widths on the transverse movement value, as they were kept constant in this study.
- It is recommended to carry out intensive studies to get a technique for studying the effect of the ship's rudder angle on the transverse movement value.

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APPENDIX (A): PHOTOS OF HYDRAULIC MODEL AND THE USED EQUIPMENT

Photo 1. *Details of the model (Rear view)*

Photo 2. *The main sump and the feeding system of the model intake (Front view)*

Photo 3. *The model intake (Rear view)*

Photo 4. *The side channel of the model (Rear view)*

Photo 5. *The outlet sump and the control gate of the model (Side view)*

Photo 6. *Details of the side sump of the model*

Photo 7. *Side sump of the model (Rear view)*

Photo 8. *Feeding system of the side sump of the model (Front view)*

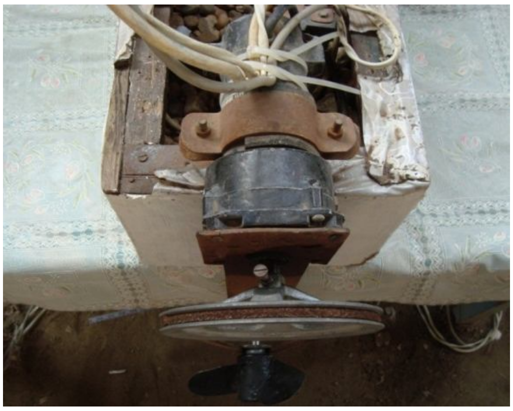

Photo 10. *AC induction electrical motor*

Photos 11., 12. *Different views of steel frame which combines the AC motor with the propeller*

Photos 13., 14. *Hollow aluminum cylinder propeller and its blades*

Photo 15. *Speed controller*

Photo 16. *Ultrasonic flowmeter*

Photo 17. *Electro-magnetic current-meter (The reader)*

Photo 18. *Electro-magnetic current-meter (The prop)*

Photo 19. *Supported digital camera*

Photo 20. *The Balance bubble along an axis of the ship model*

Photo 21. *Stopwatch clock*

APPENDIX (B): (Mt/Bs) VERSUS (b/x), UNDER DIFFERENT VALUES OF Vc/Vsr