NAVIGATION EFFECTS DUE TO OUT FLOW WATER EXITS

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ABSTRACT

The discharge of flows into a waterway, e.g. from industrial, power plants, and storm water collectors, may affect passing ships depending on the induced transverse momentum acting on a ship in front of an outfall structure. In this study, the effect of the angle of inclination of the outlet was investigated along with its opening angle, depth of water, and the magnitude of the velocity in a rectangular flume. Cross current velocities at the outlet of the introduction construction were measured and then compared by the designer, in which the maximum cross current velocities of the water introduction construction were estimated specially a state-of-the-art theoretical approach, to determine if that design was safe or not. The results are presented by curves and equations which can be used for the design of the water intruded construction to provide operational traffic safety for the passing ships in inland waterways.

KEYWORDS: Navigable channels, Inland Navigation, Cross Currents, Inland Waterways, River Outlets, Water Collectors, Power Plants.

1. INTRODUCTION

The lateral drift of the ship and/or rotation in the vertical ship axis, may cause collision hazards to other passing or incoming ships. Both effects depend on the ship parameters; mass, width, length, draught and speed, fairway parameters; depth and width, and hydraulic parameters water head, discharge and distribution of outfall velocities. Several researchers have been studying the mentioned parameters effect on the lateral drift of the ship and/or rotation in the vertical ship axis.

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The main objective of this study is to modify the available design equation, proposed by Pulina [4], to include the outlet characteristics which would effect the value of the maximum allowable cross current velocity induced by lateral water due to intruded construction to provide operational traffic safety for the passing ships in the inland waterways**.** It was found that the maximum allowable cross current velocity is directly related to the ship parameters, fairway parameters, and hydraulic parameters [3]. A full set of curves and the modified Pulina's formula [4] are presented to show these relationships.

2. EXPERIMENTAL SETUP

A flume was constructed mainly for this purpose in the west experimental hall of the Hydraulics Research Institute (HRI), Ministry of Water Resources & Irrigation, Egypt. The flume was constructed, from bricks, cement, sand and mortar. The flume dimensions are 11.00 m long, 3.00 m width, and 0.5 m depth. It has three sumps, the first is the main one at the inlet, the second is at the outlet and connected with the first sump by a side channel at the left of the flume with 1.00 m width to form a closed circuit flume, and the third is outside the flume on the right side of it. Sketches of the flume are shown in Fig.1 .

First, the water is pumped to the main sump via a pipe of 4.0 inch diameter and the feeding valve is closed until the water reaches to a reasonable level in the sump. Then the water is pumped again from that sump to the flume intake by a centrifugal pump with a total capacity of 40.0 l/s through a pipe line of 4.0 inch diameter. A second pump with the same capacity is pumping water from the main sump to another sump outside the flume at its middle length which allows the water to enter the flume from its side. The flume is provided with a control gate at its outlet to adjust the water level in the channel and releases the water to the outlet sump which is connected to the main sump by a side channel to circulate the system. The velocity of the flow in the model was measured using an Electro-Magnetic Current-meter type E.M.S., manufactured by Delft Hydraulics Laboratory, The Netherlands.

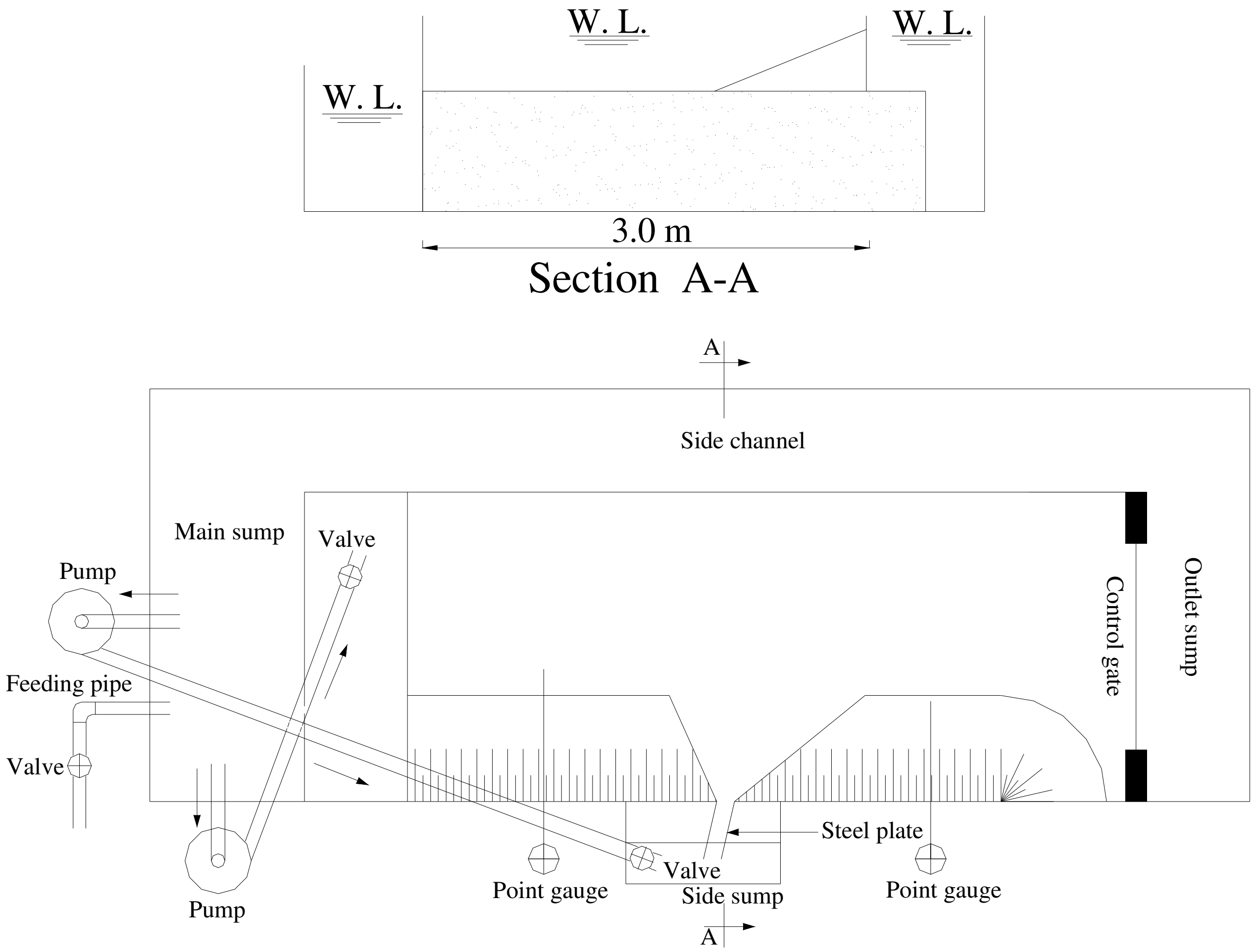

Fig.1. Longitudinal profile of the flume

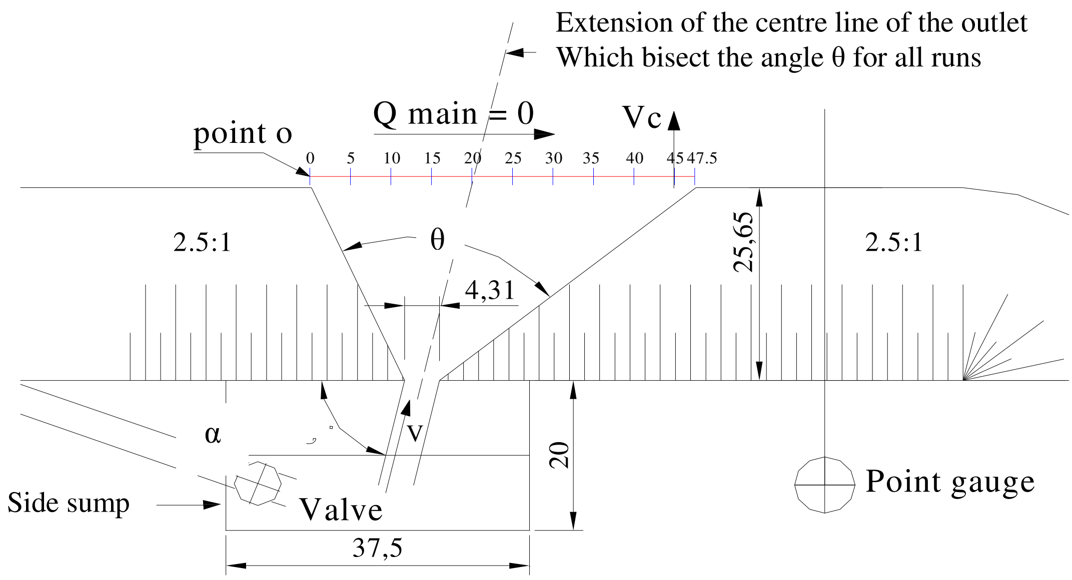

Fig.2. The velocity distribution in the model

3. MODELING

3.1. Similarity Of The Model – Prototype

A model was set up for the rain water collection system to protect the city of Bamberg, Germany from the effect of the floods by draining the flood water into the Main Danube Canal, Tobias [7]. Due to the space facilities, and instrumentation at HRI 's hall, the length scale was selected to be 1:25. As the model is operated according to Froude similarity. The scale ratios of the model were:

Length Scale	Velocity Scale	Discharge Scale	Time Scale
1:25	1:5	1:3125	1:5

The selected model scale was checked to ensure model turbulence. The minimum Reynolds number of different model sections shows that the model flow is fully turbulent which was required . Fig.2 presents the velocity distribution in the model, which has been scaled down in HRI's formula .

3.2. Model Calibration

For the model calibration, one velocity distribution section was taken in the model, as shown in Fig. (3) The main discharge = zero, the water depth = 3.1 m, the discharge of the outlet is 10 m^3/sec, the inner angle of the outlet between its two sides

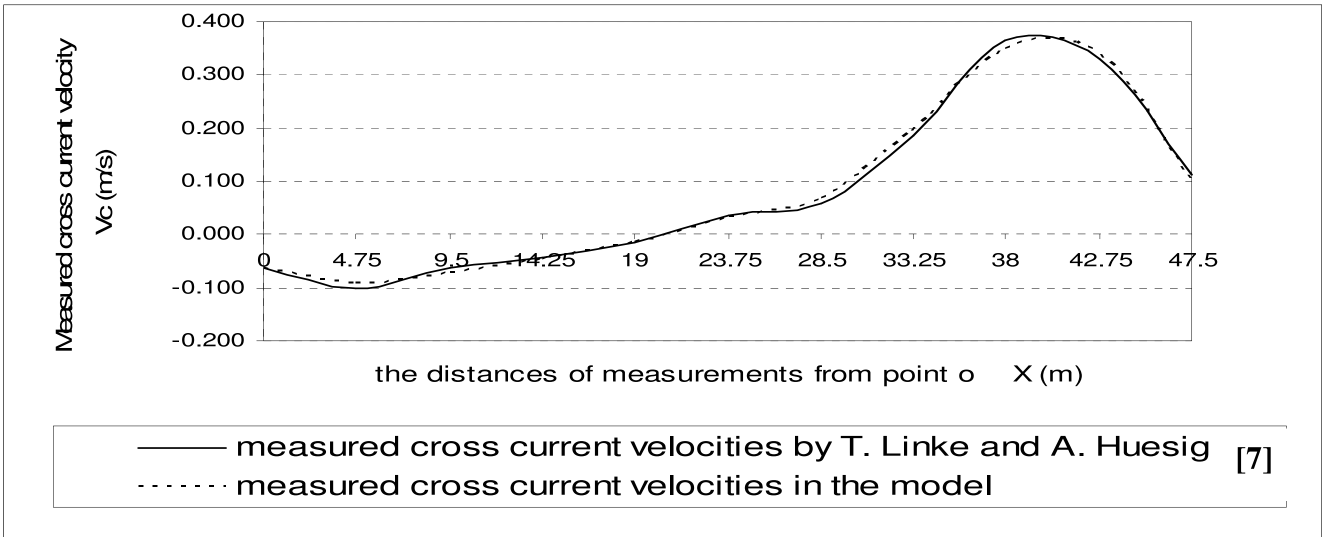

Fig.3. Comparison of measured cross current velocities at the outlet by Tobias [7], and by the author in HRI's flume

(θ) = 75°, the angle of the water exit (α) = 77° and the opening width of the outlet is 4.31m. Fig. (3) shows a comparison between the measured cross current velocities at the half of the water depth at the outlet by Tobias [7] and that measured in the model. The difference between the two measurements did not exceed 12.5 % .

4. EXPERIMENTAL PROGRAM

Seventy two runs were carried out, the current meter reading was taken after certain time to ensure that the flow in the flume was fully developed to a steady state condition, also the side sump was designed to achieve the uniformity of the velocity, V entering the flume. This program was divided into fifteen groups, shown in table 1.

Table 1. The Experimental Program

Group No.	α	θ	h (m)	V (m/sec)
1	90	75	6	0.5, 0.75, 1.0, 1.5, and 2.0
2	90	60	6	0.5, 0.75, 1.0, 1.5, and 2.0
3	90	45	6	0.5, 0.75, 1.0, 1.5, and 2.0
4	90	30	6	0.5, 0.75, 1.0, 1.5, and 2.0
5	75	75	6	0.5, 0.75, 1.0, 1.5, and 2.0
6	75	60	6	0.5, 0.75, 1.0, 1.5, and 2.0
7	75	45	6	0.5, 0.75, 1.0, 1.5, and 2.0
8	75	30	6	0.5, 0.75, 1.0, 1.5, and 2.0
9	60	75	6	0.5, 0.75, 1.0, 1.5, and 2.0
10	60	60	6	0.5, 0.75, 1.0, 1.5, and 2.0
11	60	45	6	0.5, 0.75, 1.0, 1.5, and 2.0
12	60	30	6	0.5, 0.75, 1.0, 1.5, and 2.0
13	75	75	3 and 8	0.5 and 2.0
14	90	30	3 and 8	0.5 and 2.0
15	60	60	3 and 8	0.5 and 2.0

5. RESULTS AND DISSCUSION

Pulina [4] studied the effect of cross current velocity induced by lateral water intruded constructions which is considered as a main factor for the ship characteristics. On the other hand, it does not consider all the characteristics of the outlet. The present study modified the Pulina equation to be:

$$\text{Vc max.} = 0.81 \cdot \frac{Vs}{L} \cdot \left[\frac{Zq \cdot \text{mg}}{0.6 \cdot Z^{0.5} \cdot t_a \cdot \text{b} \cdot \text{Cz} \cdot \frac{\rho}{2}} \right]^{0.5} \qquad \text{.............................. (1)}$$

Where: b (m) is the width of the intruded construction at the location of the still water surface in the bank, mg is the entire accelerating mass of ship, t_a (m) is the draught of ship, Vc (m/s) max. is the maximum allowed cross current velocities at the outlet, Z (m) is the distance between outlet of the intruded construction and the location of the still water surface in the bank, Vs (m/s) is the ship speed, Zq (m) is the transverse movement of ship, Cz is the resistance parameter of ship right-angled to longitudinal axis, L (m) is the ship length, and ρ (kg/m³) is the density of water.

The entire accelerating mass of ship in this equation yields from the addition of the mass of ship and the supplementary hydrodynamic mass.

mg = m · (l+m_w/m), where:

$$m_w = 2.2 \cdot m \cdot \frac{1.9^{t_a/h}}{(B/t_a)^{0.84}} \qquad \text{For } t_a/h < 0.47 \qquad \text{.....................(2)}$$

$$m_w = 0.814 \cdot m \cdot \frac{16^{t_a/h}}{(B/t_a)^{0.84}} \qquad \text{For } t_a/h > 0.47 \qquad \text{..................... (3)}$$

In which, h (m) is the water depth, m (kg) is the ship mass, m_w (kg) is the supplementary hydrodynamic mass, and B (m) is the ship width. Additionally, the resistance parameter of ship right-angled to longitudinal axis yields from the following function:

$$Cz = (17.6 \cdot \frac{3.2}{V_s} - 13.4) \cdot (0.16)^{h/t_a} \geq 0.3 \qquad \text{..................... (4)}$$

The data in the present study was analyzed to obtain an empirical formula which can be added to the above described formula for determining the safe characteristics of the outlets for the passing ships in inland waterways, and based on the regression analysis of all observed results. Vc, the cross current velocity at the middle of the water depth in the direction perpendicular to the line of measurements at the end of the outlet, was measured for different values of the average velocity induced by the outlet, V.

It was found that the peak values of the measured cross current velocities occurred at the extension of the centre line of the outlet and have a symmetrical distribution for all values of V for the first four groups, shown in table 1, and did not have a symmetrical distribution for the rest of the groups.

This is because the angle of the water exit (α) has been taken 90° for the first four groups and less than 90° for the rest of the groups . For example, group no. 1, it was found that the current velocity Vc increases as the outlet velocity V increases, increasing V from 0.5 to 2.0 m/sec increased the maximum measured cross current velocity from 0.311 to 1.053 m/sec. This means that 300 % increase in V leads to 238.5% increase in Vc max.

Similar results are also concluded for the other groups as shown in Figs 4 to 7.

It was also concluded that, the value of the measured cross current velocity Vc max. increases with the decrease of the inner angle of the outlet between its two sides θ, this is due to reduction of the cross sectional area of the passing flow, while Vc max increases with the increase of the water exit angle α , Figs 8 to 10. It was also found that the water depth, h had a minimum effect on the value of the measured cross current velocity Vc max.

The data in the present study was analyzed to obtain an empirical formula which can be added to Pulina's formula [4] to determine the safe characteristics of the outlets for the passing ships in inland waterways, and based on the regression analysis of all observed results, as shown in Fig. 11. The general formula which represents the line of best fit was developed as Vc max./V = $0.46(\alpha / \theta)^{0.58}$ & $R^2 = 0.7379$ and Equation (1) may be re-written as follows:

$$0.46 \cdot V \cdot (\boldsymbol{\alpha/\theta})^{0.58} = 0.81 \cdot \frac{Vs}{L} \cdot \left[\frac{Zq \cdot \mathrm{mg}}{0.6 \cdot \mathbf{Z}^{0.5} \cdot t_a \cdot \mathrm{b} \cdot \mathrm{Cz} \cdot \frac{\rho}{2}} \right]^{0.5} \qquad \text{………..…} \quad (5)$$

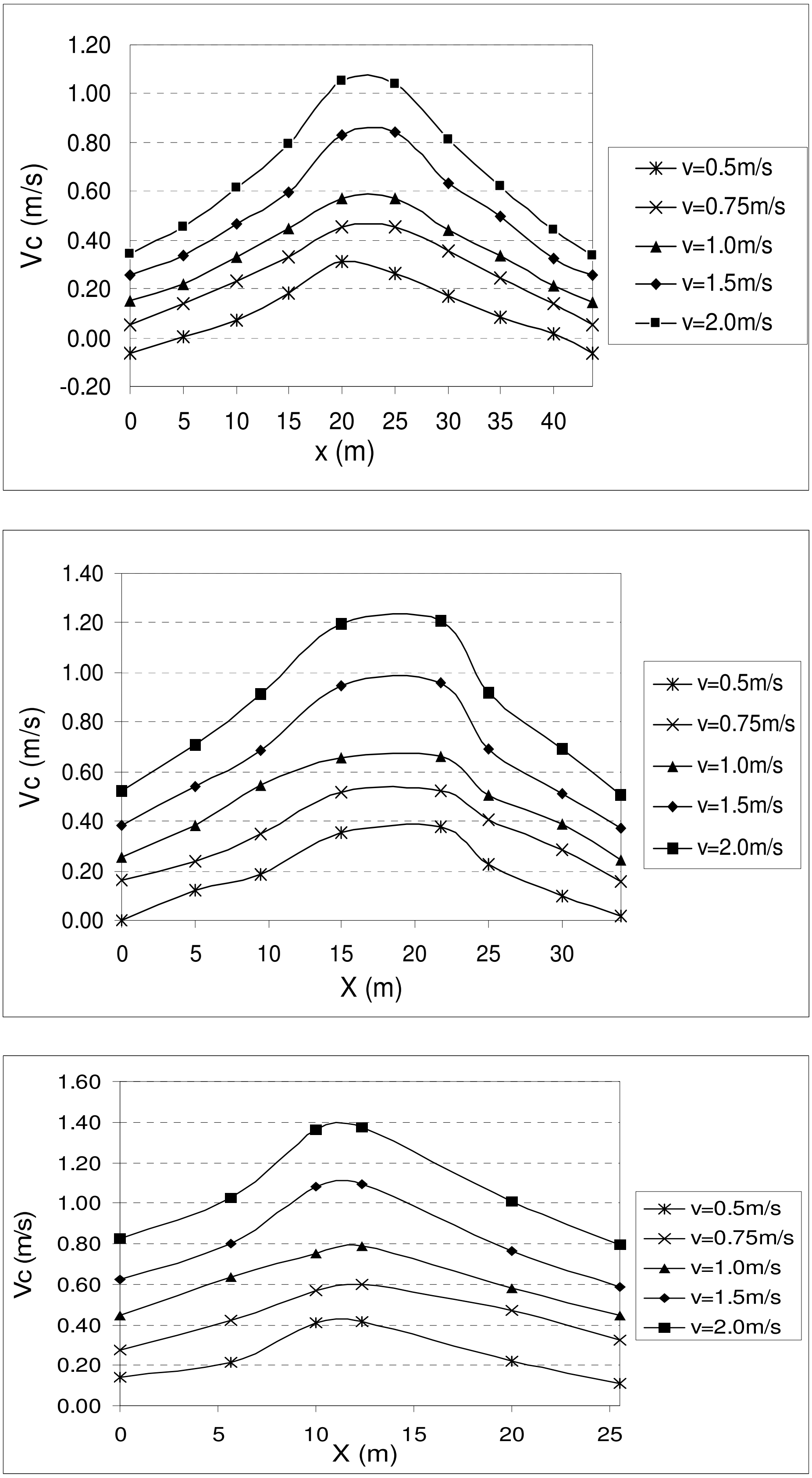

Fig.4. The measured cross current velocities at the outlet of the intruded construction, groups No. 1, 2, and 3

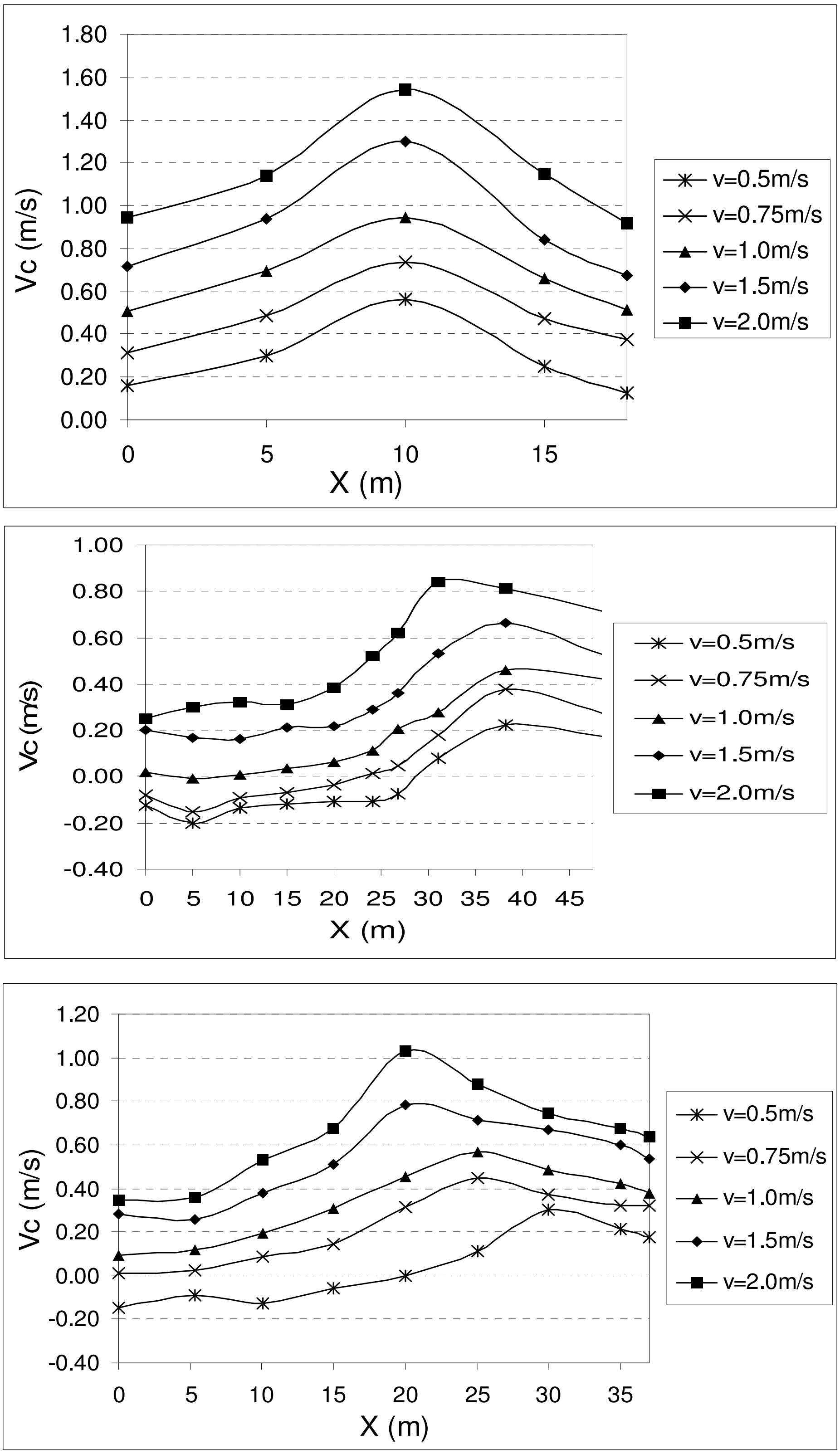

Fig.5. The measured cross current velocities at the outlet of the intruded construction, groups No. 4, 5, and 6

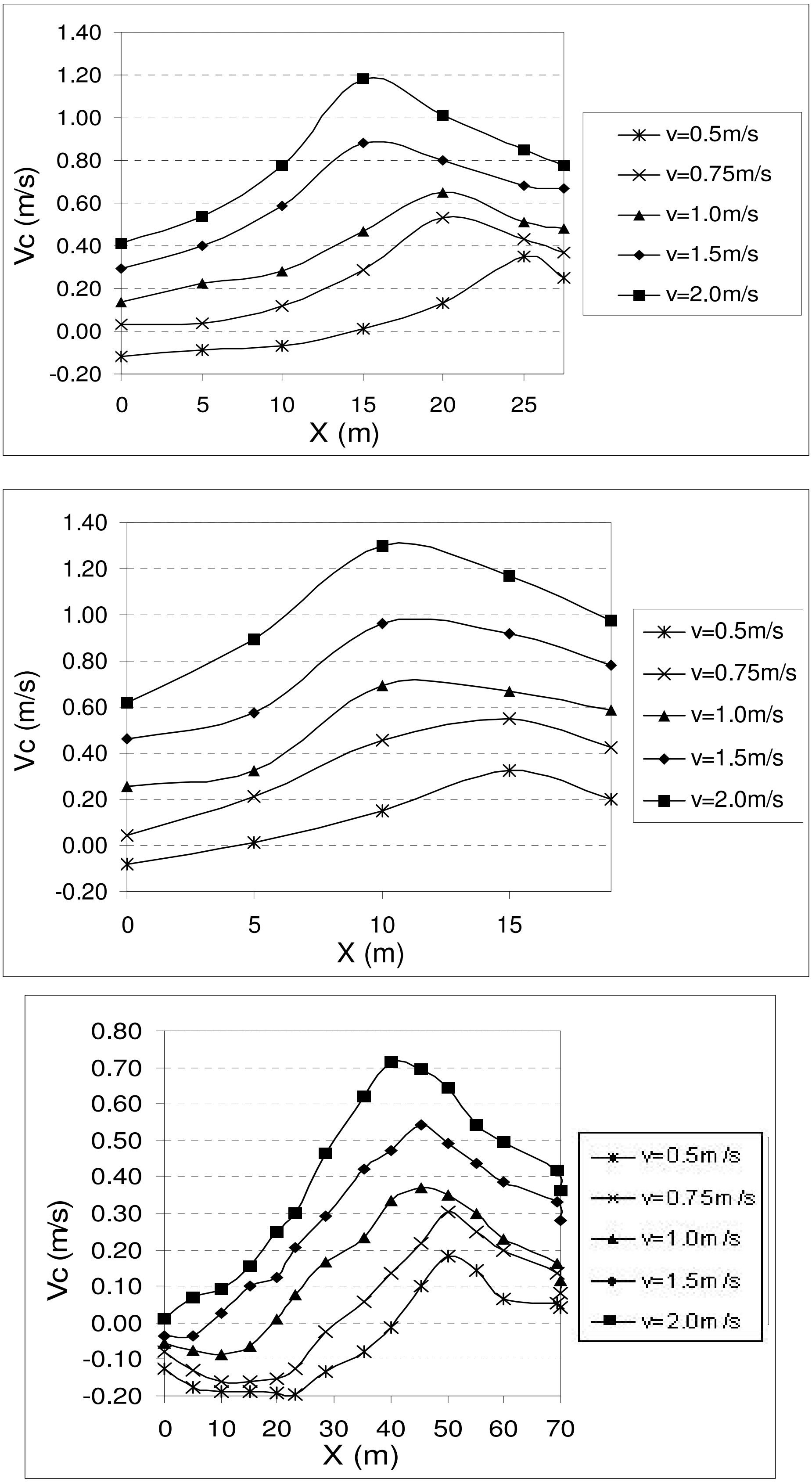

Fig.6. The measured cross current velocities at the outlet of the intruded construction, groups No. 7, 8, and 9

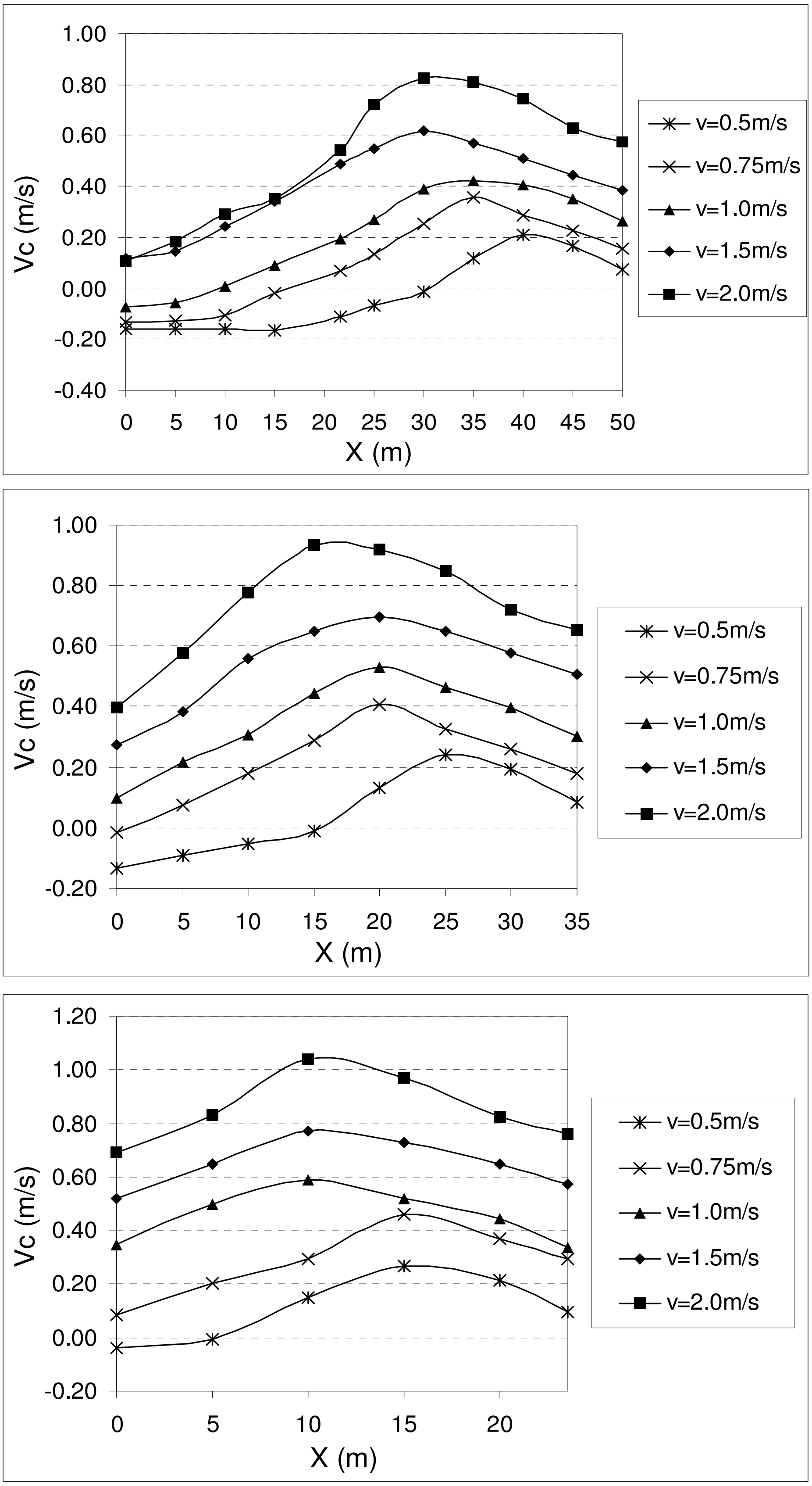

Fig.7. The measured cross current velocities at the outlet of the intruded construction, groups No. 10, 11, and 12

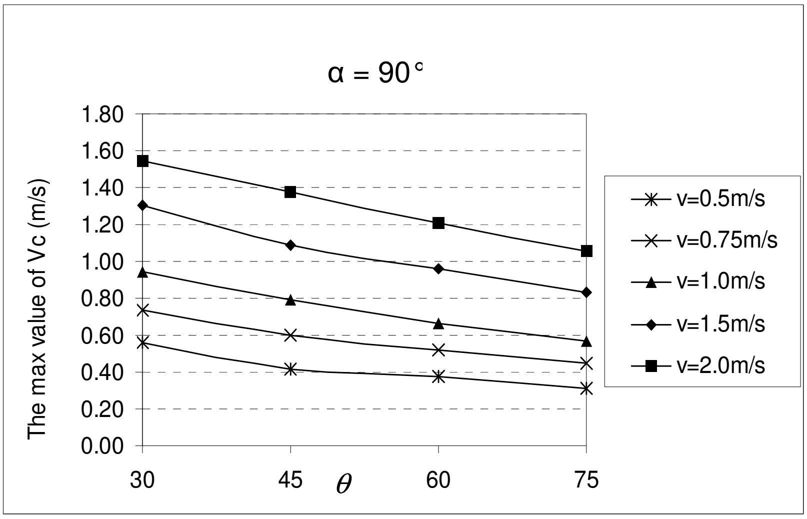

Fig.8. Variation of (θ) with (Vc max.) for different values of (V) for α = 90°

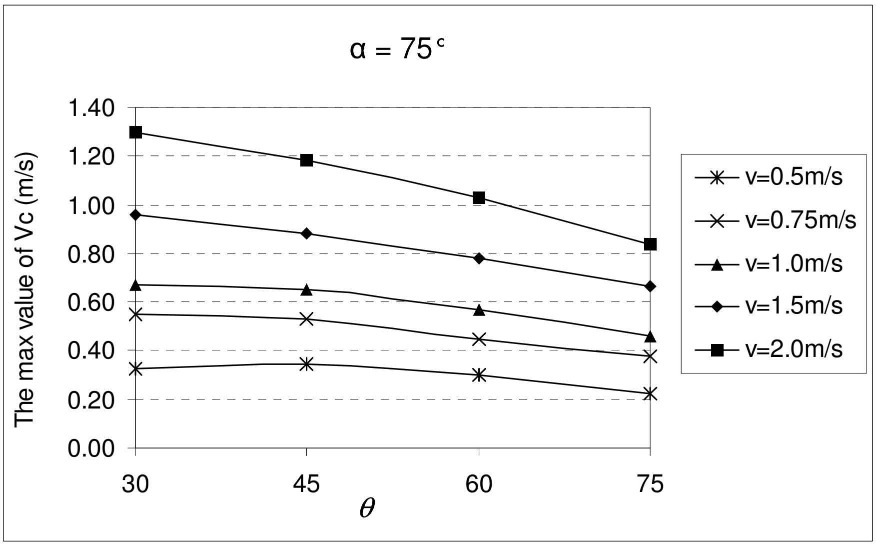

Fig.9. Variation of (θ) with (Vc max.) for different values of (V) for α = 75°

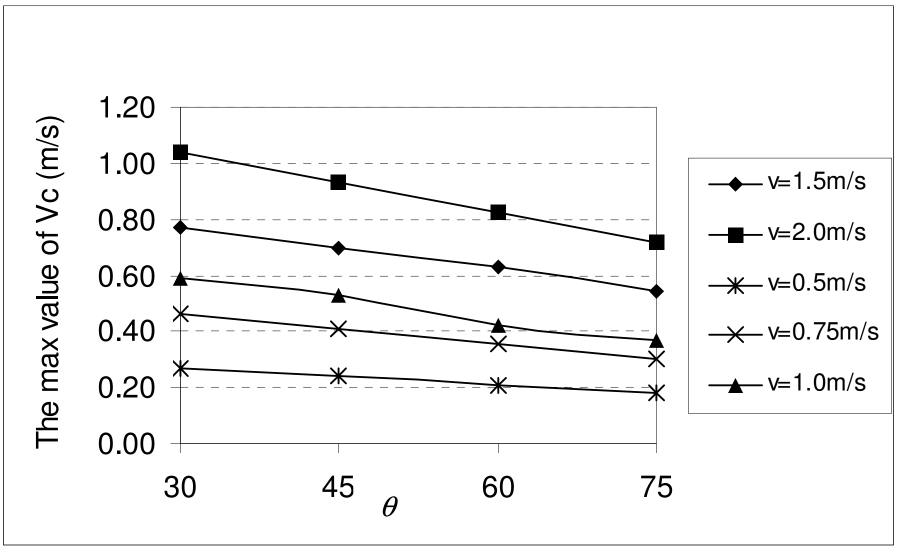

Fig.10. Variation of (θ) with (Vc max.) for different values of (V) for α = 60°

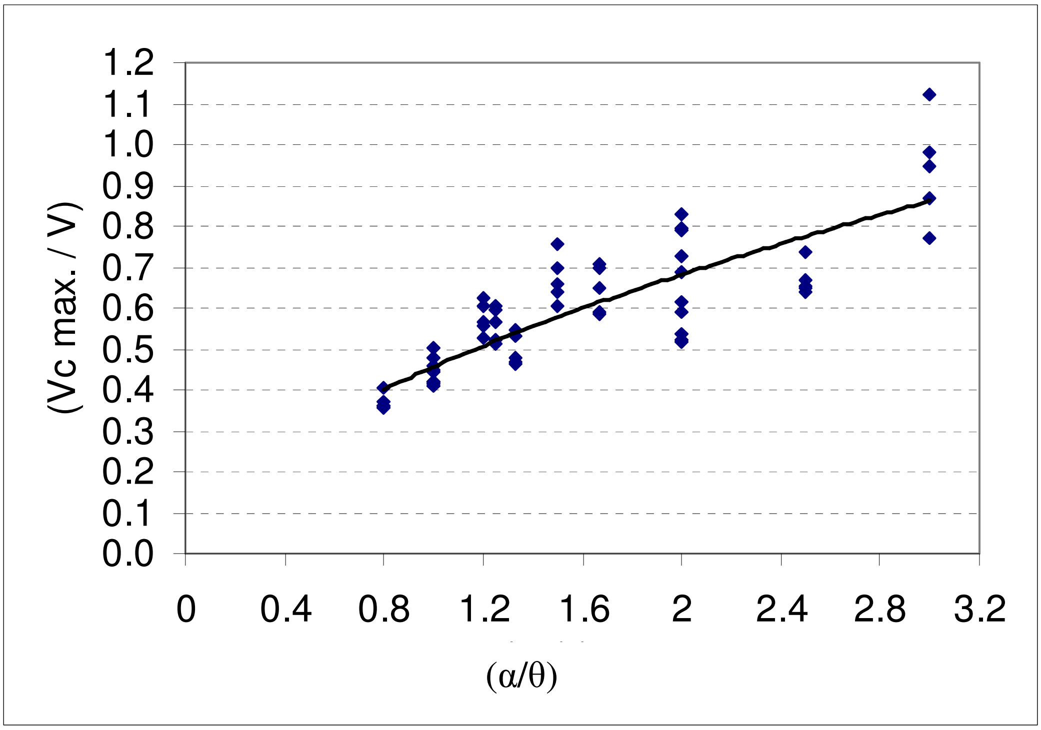

Fig.11. Variation of (α /θ) with (Vc max./V)

From equation (4), the ultimate value of the outlet velocity V for safety of the passing ships in the inland waterways, may be calculated from the ship parameters, fairway parameters and hydraulic parameters. Below this value the navigation motion will not be affected.

6. CONCLUSIONS

From this study, the following were concluded:

1. The value of the measured maximum cross current velocity Vc max. increases by the increase of velocity V which is induced by the outlet.
2. The value of the measured maximum cross current velocity Vc max. increases by the increase of the angle of the water exit α.
3. The value of the measured maximum cross current velocity Vc max. increases by the decrease of the inner angle of the outlet between its two sides θ.
4. It was found that the water depth, h had a minimum effect on the value of the measured maximum cross current velocity Vc max.
5. Based on the regression analysis a modified Pulina's formula, represented by

equation (5) was developed. The ultimate value of outlet velocity V for safety of passing ships in the inland waterways may be calculated from the ship parameters, fairway parameters, and hydraulic parameters. Below this value the navigation motion is not affected.

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تأثير مخارج المياه الجانبية على الملاحة

يعد صرف المياه من المخارج الجانبية للمجارى الملاحية كالصرف الصناعى أو صرف مياه الأمطار أو صرف مياه محطات الكهرباء المستخدمة فى عمليات التبريد من أهم العوامل المؤثرة على حركة السفن الملاحية عند مرورها بجانب أو بالقرب من هذه المخارج والتى قد تؤدى إلى إنحراف هذه السفن الملاحية فى الإتجاه العرضى، وهذا قد يؤدى إلى أخطار تصادمية مع سفن مجاورة.

فى هذا البحث قد تم التوصل إلى أن القيمة العظمى للسرعة العرضية الناتجة عند المخرج تزداد بزيادة كل من سرعة المياه فى بداية المخرج والزاوية الخارجية للمخرج وتقل بزيادة الزاوية الداخلية للمخرج.

كما أوضحت الدراسة أن زيادة عمق المياه له تأثير ضعيف على القيمة العظمى للسرعة العرضية الناتجة عند المخرج. وكذلك تم إستنباط معادلة تعبر عن أهم الخصائص الهندسية والهيدروليكية للمخرج والتى من شأنها التأثير على القيمة العظمى للسرعة العرضية الناتجة.