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MINIMIZING BED SCOUR INDUCED BY SHIP BOW-THRUSTERS BY USING QUAY WALL FLOW DEFLECTOR

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Abstract

Recently, the combination of larger bow-thrusters installed with vessels have created higher levels of bed scour action affecting the berthing structure and its overall stability. Therefore, the bed near a quay wall structure must have sufficient strength by placing a bed protection which may cause the cost of the project to rise. This research is carried out to investigate experimentally the effect of modifying the geometry of the quay wall surface on minimizing bed scour. This is done by inserting flow deflectors within the longitudinal direction of the wall surface in order to deflect/minimize the water jet affecting the bed near the quay wall. Experimental tests had been carried out for single and triple deflectors. The results showed that the use of flow deflectors achieved a reduction in bed eroded area in front of quay wall face by about 63%, and causes the start point of erosion to move far away from it; this may improve the stability of quay walls. Therefore, the importance of the present study is testing a new possible measure to improve the stability of quay walls by minimizing the scour in front of the wall and to decrease the cost of bottom protection.

Keywords: **:** Quay wall; bow-thruster; bed scour; flow deflector

1.0 INTRODUCTION

As the shipping industry is increasing rapidly, there is a highly concern about the effect of the use of large bow-thrusters in order to make ships more maneuverable. Bow-thrusters during the berthing/de-berthing process introduce flow, which is obstructed and redirected in all directions generating complicated flow patterns. In addition to the flow velocities in lateral directions, a strong jet flow is directed towards the bottom. When the forces of the jet load exceed the strength of the bed, the soil will erode and lead to the appearance of scour holes. It is obvious that the bow-thrusters can erode the soil at the foot of the quay structure.

Regarding the damage problems allocated in front of quay wall structures induced by propeller wash, a number of case studies had been reported. Bergh and Cederwall (1981), and Bergh and Magnusson (1987) reported a survey of the serious damage of 25 quay structures at Swedish ports. Chait (1987) reported cases of severe damage induced by the use of bow-thrusters for maneuvering at a number of South African ports, especially at berth No. 12 at Port Elizabeth. A study of erosion problems at quay structures at French ports was undertaken by Longe et al. (1987). Qurrain (1994) reported that 42% of the major British ports had encountered propeller-induced bed scour, which of those, 29% classified as being of a serious nature that needed remedial action.

On the other hand side, numerous of experimental and numerical research studies have been done to categorize the problems of bed erosion in front of the quay wall structures induced by the ship's propeller wash. Stewart (1992), Hashmi (1993), Qurrain (1994), Hamill et al. (1999) and Ryan (2002) studied the scouring action by a confined propeller jet in the presence of such quay wall configurations as perpendicular quay wall, parallel quay wall or combined quay walls in the closed type quay. Series of equations were proposed to determine the additional scour depth induced by the presence of the quay walls. Ryan et al. (2013) used the Artificial Neural Networks (ANNs) to provide an accurate and easily implemented tool to predict the scour depth in the presence of a quay wall configuration parallel to the harbor wall structure.

While, Blaauw and Van de Kaa (1978), Bergh and Cederwall (1981), Hamill et al. (1993), Hamill et al. (1999), Schokking et al. (2003), Nielsen (2005), Van Blaaderen (2006), Lam et al. (2011), Van Doorn (2012), and Hong et al. (2013) had been investigated the scours induced by propeller experimentally using physical models. More concentration about the potential damage made by the propeller jet and its action to the seabed scouring was highlighted by Whitehouse (1998), and Sumer and Fredsøe (2002).

Nowadays, some researches give more concern about how to reduce/minimize the scour action in front of the quay walls. Tolba and Balah (2008) suggested a system consists of vertical filter screen used for protecting slopes under open piled structures against ship propeller action. The system used to interrupt the propeller jet and deviate it away from the under slope. The results proved that the location and volume of erosion on the slope due to propeller jet action could be controlled and minimized by using a specific configuration of the filter screen. PIANC (2015) suggested a possible measure to reduce the scour depth in front of a solid quay wall using a jet deflector slab as illustrated in Figure 1.

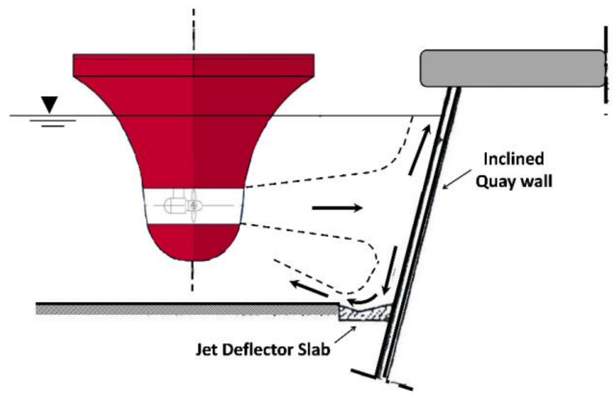

Figure 1 Jet Deflector Slab suggested for inclined closed quay wall by PIANC (2015)

Recently, in relation to minimize the scouring, Galal et al. (2016) studied experimentally the effect of sea side quay wall roughness and inclination on bed scour and the results indicated that the eroded area induced by ship bow-thrusters has been decreased by the increase of the sea side wall roughness and inclination.

Despite all of the case studies detailing these problems, limited literature had been found dealing with the change of the quay surface geometry to reduce/minimize the scour effect of the introduction of a quay wall perpendicular to the axis of the propeller. The present research is an attempt to examine experimentally a solution for minimizing the bed scour happened nearby the solid quay wall face, induced by ship bow-thruster, by using flow deflectors as shown in Figure 2. The basic idea of the examined system is to interrupt, divert and dissipate the energy of the jet produced by the thruster away from the quay wall face. The efficiency of the examined system will be evaluated by comparing between the bed eroded volumes before and after using the flow deflector. Furthermore, additional evaluation of the examined system will be taken into consideration by determining the distance Y_S which represents the starting position of bed scour measured from the solid quay wall face as shown in Figure 2.

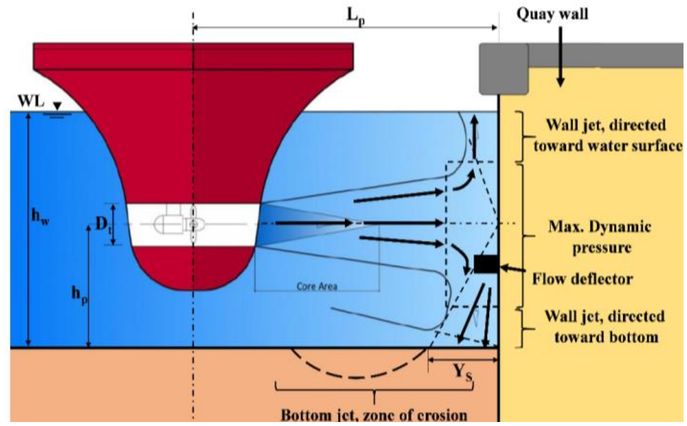

Figure 2 A schematic diagram to explain the effect of flow deflector on jet spreading at a solid quay wall.

1.1 Propeller Efflux Velocity

The maximum axial velocity at the initial plane of a propeller is named efflux velocity V_o. Many theories have been established to determine the velocity field behind a propeller; the most well-known researches are done by Fuehrer and Römisch (1977), Blaauw and Van de Kaa (1978), and Verhey (1983). The propeller jet can be characterized by quantities such as efflux velocity, decay of the maximum axial velocity, and the flow field distribution. The efflux velocity V_o is regarded as the mean axial flow velocity at the face of the propeller (Albertson et al. (1950), and Fuehrer and Römisch (1977)), which is

$$V_o = 1.59.n.D_P\sqrt{C_t} \quad (1)$$

where n is the rotational speed of the propeller in revolution per second, D_P is the propeller diameter in meters, and C_t is the thrust coefficient of the propeller. However, in many situations no values are available for the number of revolutions n and/or the thrust coefficient C_t. Therefore, empirical relationships have been derived; Blaauw and Van de Kaa (1978), and Verhey (1983) give a method to predict the efflux velocity for ducted propeller based on the engine power as:

$$V_o = C_1\left(\frac{P}{\rho_w.D_P^2}\right)^{\frac{1}{3}} \quad (2)$$

where P is the maximum installed engine power in watts, and values for the coefficient C_1 are equal to 1.17 for ducted propellers and equal to 1.48 for free propellers.

Once the efflux velocity is known, certain decay in maximum velocity occurs as the distance from the propeller plane increases. For the decay in maximum velocity, commonly a separation is made between the so-called zone of flow establishment and the zone of established flow. The German method based on Fuehrer et al. (1981), and Schmidt (1998) stated that when a bow-thruster (assumed to be a ducted propeller) is directed onto a vertical quay wall, the axial velocity field is dependent on the ratio between the distance y from the propeller outflow and the diameter D_P as:

$$\frac{V_{y,max}}{V_o} = 1.9.\left(\frac{y}{D_P}\right)^{-1.0} \quad for\ \frac{y}{D_P} > 1.9 \tag{3}$$

$$\frac{V_{y,max}}{V_o} = 1.0 \quad for\ \frac{y}{D_P} < 1.9 \tag{4}$$

2.0 EXPERIMENTAL SET-UP

Experiments are conducted in the wide flume located in the Coastal Engineering Laboratory, Faculty of Engineering, Port Said University. The dimensions of the flume are 46.0 m long, 2.0 m wide and 1.2 m deep.

Both sides of the flume are made of glass as shown in Figure 3. The floor of the flume is made of concrete covered by a 20.0 cm sandy bed with median sediment grain size of D_{50} = 0.3 mm. This size signify that the particle size distribution of sediments was fairly uniform. The length of the basin is sufficient to avoid a large influence of the recirculation flow, while the basin width considers enough for the placement of the ship based on Nielsen (2005), and Van Blaaderen (2006).

The model tests are focused on sea-going vessels which moored to a vertical solid face quay wall. The model of the ship is a simplified version of the ship "Pride of Rotterdam". This prototype ship which has comparable relative dimensions to real-life situations is used by Nielsen (2005), and Van Blaaderen (2006). The prototype ship used in the present research has a length of 215.0 m, width of 30.0 m, a draught of 14.25 m, and a 2 bow-thruster of diameter 2.5 m. The ship dimensions are shown in Table 1.

In the prototype situation, we consider a situation in which the ship is lying parallel to the quay wall with the duct of the bow-thruster perpendicular to the quay wall. In this research a static situation is considered. Even though the bow-thruster is in use, we assume that the ship stays in its original position. It is also assumed that the vessel will be at the moored location in contact with the fender, the closest point of the bow-thruster. According to PIANC (1997), the keel clearance h_k must be at least 1.0 m. Because of the foreseen limitations of the measurement apparatus, this value is chosen at 1.50 m. The term L_P here does not refer to the distance of the ship from the quay wall, but to the distance between the centerline of the bow-thruster to the quay wall. Because specific dimensions of the model of the ship are not given, the length of the bow-thruster duct B_T is estimated using guidelines given by PIANC (1997), which say that the length of the duct of a bow-thruster is 29% of the maximum breadth of the ship. The maximum installed power P of one of the bow-thrusters is 2000 kW operating at a speed of rotation n of 166 rpm.

Table 1 Prototype and model dimensions

Variable	Symbol	Prototype dimensions	Model dimensions
Vessel Length	L_V [m]	215.00	8.60
Maximum vessel beam Length	B_V [m]	30.00	1.20
Vessel Draught	h_V [m]	14.25	0.57
Length of the tunnel thruster	B_T [m]	8.70	0.40
Height of propeller axis above bed	h_p [m]	5.25	0.21
Distance from propeller axis to quay wall face	L_p [m]	21.00	0.84
Diameter of propeller (bow)	D_p [m]	2.50	0.10
Water depth	h_w [m]	15.75	0.63
Keel clearance	h_k [m]	1.50	0.06

2.1 Scaling of Experimental Model

A scale of 1:25 is chosen for the scale model, because the values of the parameters with this scale are practically manageable in the physical model. A scale model propeller of 100 mm in diameter fitted to a stainless steel tunnel as shown in Figure 4. The characteristics of the propeller used in the present research are shown in Table 2. In this study a typical ship's propeller having a diameter of 2.5 m and a thrust coefficient C_t = 0.53 operating at a rotational speed of 166 rpm was used as a prototype for the 100 mm diameter propeller. The initial efflux V_o calculated from Eq. (1) is 8.0 m/s.

The Froude number and the Reynolds number are considered the main criteria in fluid motions combined with a flow around a structure. The Froude number is defined as the ratio between inertia and gravity:

$$F_r = \frac{V_o^2}{g.L} \tag{5}$$

Therefore, this scaling relationship leads to

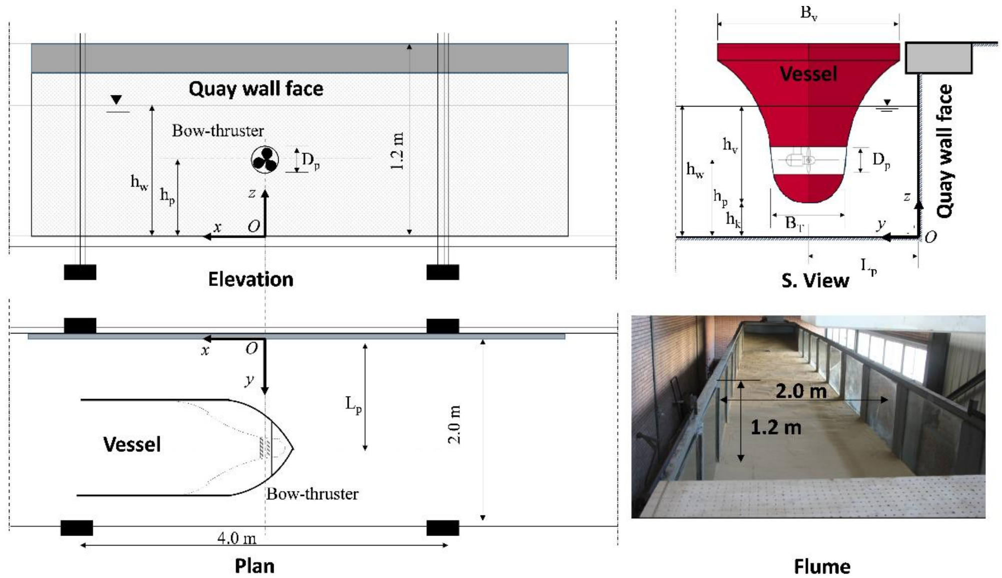

Figure 3 General layout of the flume used in Experiments.

$$V_{o(model)} = V_{o(prototype)} \cdot \sqrt{\frac{D_{P(model)}}{D_{P(prototype)}}} \tag{6}$$

Verhey (1983) found that when the Reynolds Number for a propeller (Re_{prop}) exceeds 7x10^3, and the Reynolds Number for the propeller flow (Re_{flow}) exceeds 3x10^3, the scale effects due to viscosity are negligible. Verhey (1983) calculated the Reynolds number of the propeller (Re_{prop}) and the Reynolds number of the flow (Re_{flow}) using *Eq. (7)* and *(8)*, respectively as:

$$Re_{flow} = \frac{V_o . D_P}{\nu} \tag{7}$$

$$Re_{prop} = \frac{n . D_P . L_m}{\nu} \tag{8}$$

where ν is the kinematic viscosity of the fluid (kinematic viscosity of water at 15 C^o is 1.141x10^6 m^2/s), n is the number of revolutions per second, and L_m is a length term dependent on the blade area ratio β, number of blades of the propeller N, diameter of hub D_h and propeller diameter D_P. The L_m term defined by Blaauw and Van de Kaa (1978) is

$$\mathrm{L_m} = \beta . \mathrm{D_p} . \pi \left(2\mathrm{N} \left(1 - \frac{\mathrm{D_h}}{\mathrm{D_p}} \right) \right)^{-1} \tag{9}$$

The Reynolds Number for a propeller (Re_{prop}) was found to be 2.3x10^4, and for the propeller flow (Re_{flow}) 14.0x10^4. Therefore, scale effects could be ignored satisfying the criteria of Froudian scaling.

Table 2 Propeller model characteristics.

Variable	Value
Propeller diameter, D_P	100 mm
Hub diameter, D_h	19.5 mm
Blade number, N	4
Pitch ratio, P'	1.4
Blade area ratio, β	0.4
Thrust coefficient, C_t	0.529

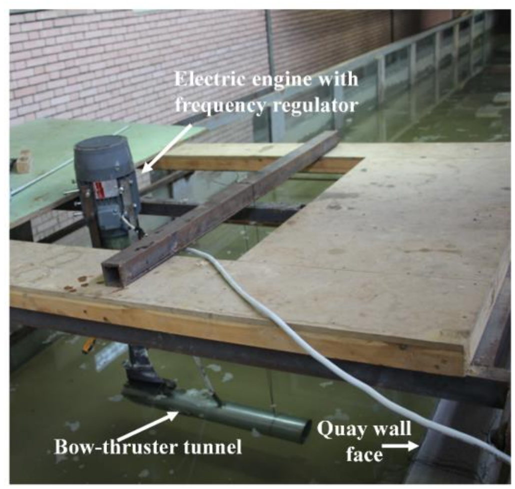

Figure 4 The modeled bow-thruster used in experiments.

2.2 Measuring Procedure

In order to verify the propeller model scale, a series of axial flow measurements were conducted using a flow velocity meter type which is able to measure one-dimensional flow up to 4.5 m/s. The velocity meter was placed along the axis of the propeller at several locations with different y/D_P values. As long as the flow velocity meter sensor is in the water flow, one reading is taken per second. Once the reading becomes steady, the true average water velocity is obtained. Figure 5 shows the scatter diagram between the measured axial flow V_{im} and calculated the axial flow V_{ic} by using Eqs. (3) and (4). The results show high agreement between the measured and calculated velocities with high correlation coefficients (R^2) especially in the established flow.

Since the experiments were performed in still water without channel flow and sediment supply, one may safely assume that the turning off and on of the propeller will not affect the overall development of the scour profile, as was suggested by Hamill (1987).

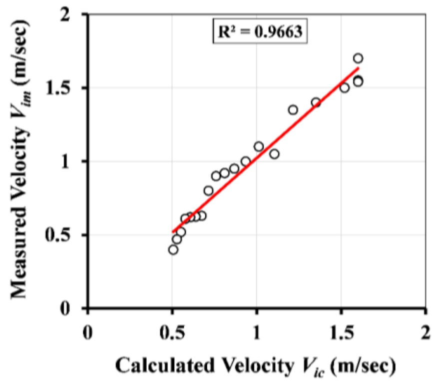

Figure 5 Comparison between measured and calculated propeller axial flow.

Therefore, preliminary experiments have been conducted to examine the temporal development of the scour profile; measurements were taken at predetermined time intervals until the asymptotic state was reached. The eroded area reached to its equilibrium profile after an hour which was obtained.

Before each experiment, the water depth h_w was maintained constant equal to 0.63 m and the sandy bed was leveled to be nearly a horizontal flat bed, divided into a grid. Then, a graduated pointing device on a (40 mm x 40 mm) grid was used to survey the bed by determining *x*, *y*, and *z* for each grid node with respect to the origin point *O* as shown in Figure 3. The flume was then slowly filled with water to avoid disturbing the leveled sandy bed. Once the predetermined water depth was reached, the bow-thruster was turned on. After the experiment, the same process of bed surveying was repeated and the differences between *z* values at the nodes express the depth of scour/accretion happened to the sandy bed. Determinations of the deposited and eroded volumes together with the distance Y_S, were determined using Surfer 11.0 software after knowing the measured bed levels before and after each test. Figure 6 shows the present experimental setup of the modeled concrete quay wall face and flow deflector. A set of experiments had been carried out to investigate the effect of using flow deflectors fixed to the quay wall surface on bed scour. These were conducted by fixing a flow deflector of width b_d and height y_d to the wall surface, as shown in Figure 6, in order to deflect/minimize the water jet that affect the bed nearby the quay wall structure. The height of the deflector, measured from its center line to the bed surface, is expressed as h_d. The center of the bow-thruster is located at a constant height above the bed (h_p = 21 cm) and constant clearance distance between the center of bow-thruster centerline to the quay wall face (L_p = 84 cm). The quay wall face is made of a concrete material, while the flow deflector is made of wood. The experimental work was divided into six model sets (Base Model, A, B, C, D, and E) with a constant bow-thruster relative height h_p/h_w = 1/3 as shown in Table 3. The first model set in the present study was used here as a basic/reference model without any flow deflectors attached to the quay wall surface. While, a single flow deflector was tested in models (A, B, C, and D) are taking into consideration the change of its dimensions and its position with respect to the centerline of the bow-thruster. A (2.5 cm x 2.5 cm) single deflector with a relative height (y_d/h_p = 0.12) and relative width (b_d/L_p = 0.03) has been used in model sets (A and B).

The model sets A and B have different relative elevations, (h_d/h_p = 0.68 and 0.36), respectively. The other model sets (C and D) used a (2.5 cm x 5.0 cm) single wide deflector with relative dimensions (y_d/h_p = 0.12 and b_d/L_p = 0.06) and relative elevations (h_d/h_p = 0.68 and 0.36), respectively. The final model set (E) consisted of triple deflectors which were distributed within the lower half of the cone shape of the water jet at three relative heights hd1/hp = 0.67, h_{d2}/h_p = 0.45 and h_{d3}/h_p = 0.23, respectively. The deflector's cross-section is set as (2.5 cm x 2.5 cm) with a relative height (y_d/h_p = 0.12) and relative width (b_d/L_p = 0.03).

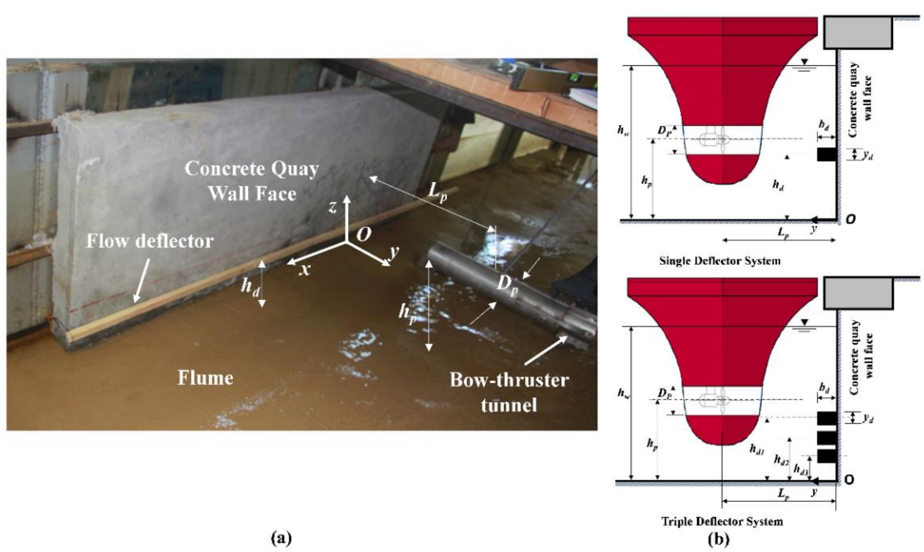

Figure 6 (a) Experimental setup of the modeled concrete quay wall face and flow deflector, and (b) Schematic views of the model sets.

Table 3 Experimental model sets characteristics.

Model Name	Deflectors Dimensions
Base Model	• No. of deflectors = 0 • $h_p/h_w = 1/3$
Model A	• No. of deflectors = 1 • $h_p/h_w = 1/3$ • $y_d =$ 2.5 cm, $y_d/h_p = 0.12$ • $b_d =$ 2.5 cm , $b_d/L_p = 0.03$ • $h_d/h_p = 0.68$
Model B	• No. of deflectors = 1 • $h_p/h_w = 1/3$ • $y_d =$ 2.5 cm, $y_d/h_p = 0.12$ • $b_d =$ 2.5 cm , $b_d/L_p = 0.03$ • $h_d/h_p = 0.36$
Model C	• No. of deflectors = 1 • $h_p/h_w = 1/3$ • $y_d =$ 2.5 cm, $y_d/h_p = 0.12$ • $b_d =$ 5.0 cm , $b_d/L_p = 0.06$ • $h_d/h_p = 0.68$
Model D	• No. of deflectors = 1 • $h_p/h_w = 1/3$ • $y_d =$ 2.5 cm, $y_d/h_p = 0.12$ • $b_d =$ 5.0 cm , $b_d/L_p = 0.06$ • $h_d/h_p = 0.36$
Model E	• No. of deflectors = 3 • $h_p/h_w = 1/3$ • $y_d =$ 2.5 cm, $y_d/h_p = 0.12$ • $b_d =$ 2.5 cm , $b_d/L_p = 0.03$ • $h_{d1}/h_p = 0.67$, $h_{d2}/h_p = 0.45$, $h_{d3}/h_p = 0.23$

3.0 RESULTS AND DISCUSSION

For each of the experiments conducted during the present investigation, the results of the bed scour measurements were collected and analyzed. In the following sections, the effect of using single and triple flow deflectors was displayed.

3.1 The Effect of Using A Single Flow Deflector On Minimizing The Bed Scour

In this section, we displayed the influence of using a single deflector on minimizing the bed scour. The left panel of Figure 7 shows the results of the contour plots of the bed scour measurements of models A and B compared with the basic model. While, on the other hand, the left panel of Figure 8 shows the results of models C and D compared with the basic model. In general, the main distinguishing feature observed is that the volume of bed scour in case of using flow deflector decreased as compared with the basic model.

In fact, the development of scouring processes in front the quay wall is governed by the quay structure obstruction and jet diffusion mechanisms. Therefore, in case of the presence of flow deflector within the lower half of the water jet cone induced by the bow-thruster, it causes a flow vortex. The combined effect of the incoming jet flow and vortex induced by the flow deflector acts to dissipate rather than concentrate the jet energy, weakening the jet scouring capability by jet diffusion. In the same way, the sediments particles move away from the quay wall.

In order to clarify the results, Figure 9 shows the typical scour profiles of the bed surface parallel to the quay wall at y = 0 cm (y/L_p = 0), and y = 12 cm (y/L_p = 0.143).

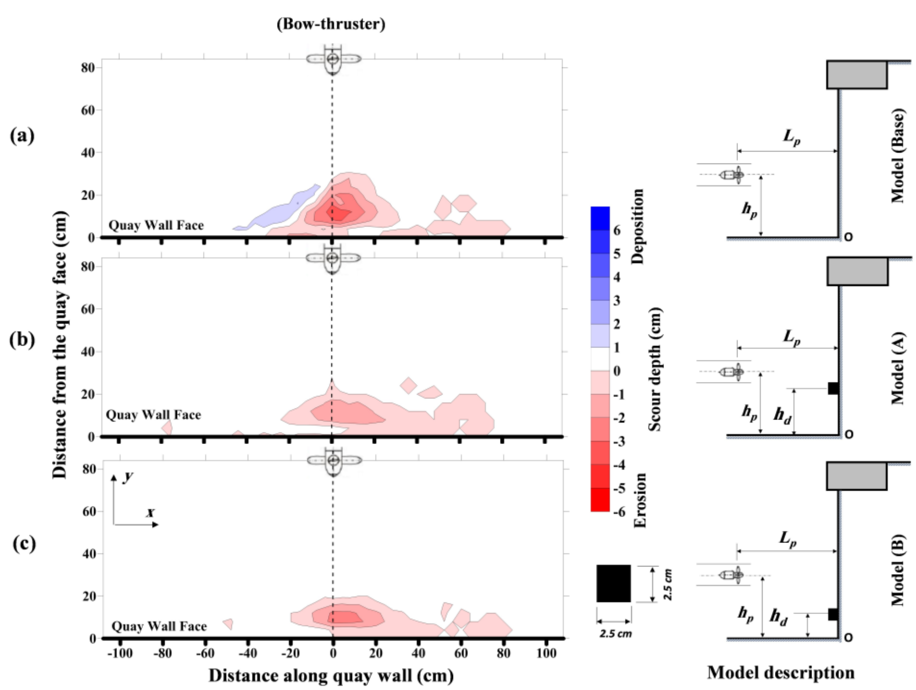

Figure 7 Effect of a single flow deflector on bed scour, (h_p/h_w = 1/3, y_d/h_p = 0.12, b_d/L_p = 0.03): (a)Basic model, (b) h_d/h_p = 0.68 (model A), and (c) h_d/h_p = 0.36 (model B).

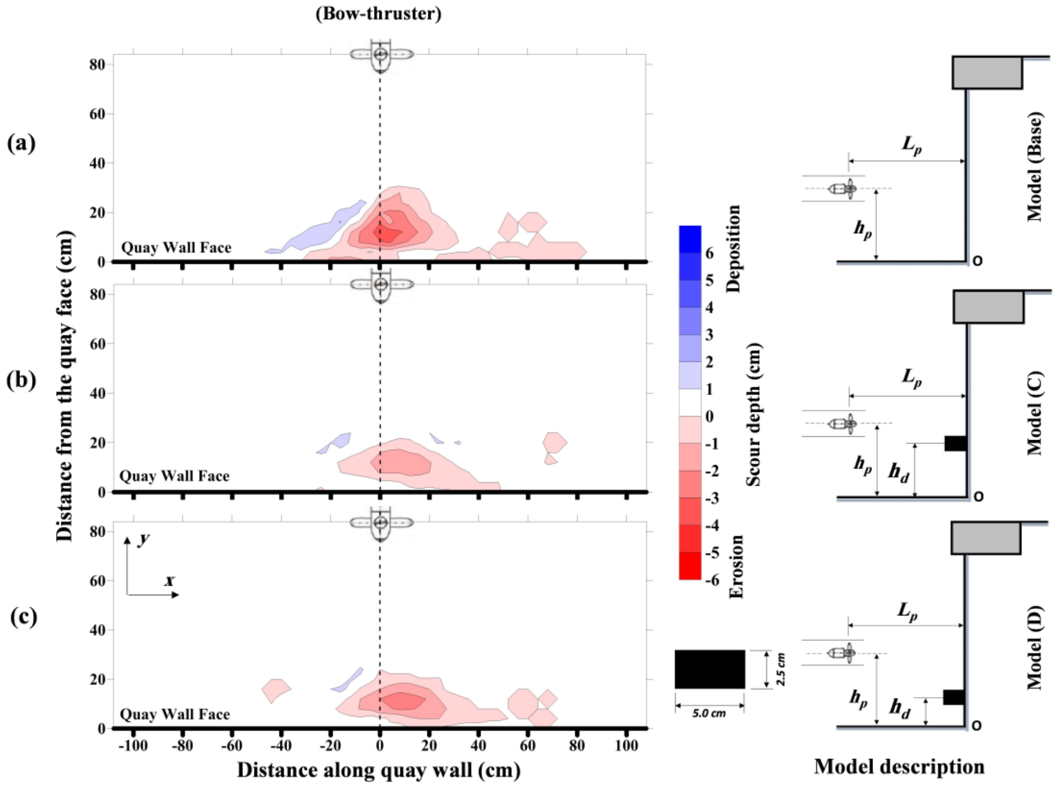

Figure 8 Effect of a single flow deflector on bed scour, (h_p/h_w = 1/3, y_d/h_p = 0.12, b_d/L_p = 0.06): (a) Basic model, (b) h_d/h_p = 0.68 (model C), and (c) h_d/h_p = 0.36 (model D).

In Figure (9-a), the scour profiles at y/L_p = 0 shows that there is no considerable bed erosion observed in front of the quay wall for all the four models tested using a single deflector compared with the scour profile of the base model which shows obvious erosion with significant scour depth directly in front of the quay wall solid face. While in Figure (9-b), the scour profiles at y/L_p = 0.143 assures the positive effect of using the flow deflector for the purpose of minimizing bed scour against the bow-thruster effect. The figure shows that there is an obvious decrease in the scour depths of all the four models (A, B, C, and D) by about 30 to 45% when compared with the results obtained from the base model.

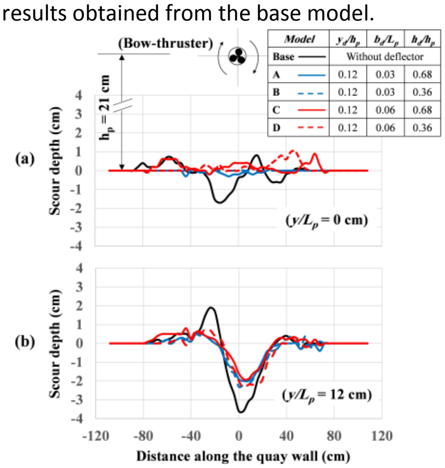

Figure 9 Typical scour profiles of the bed surface parallel to the quay wall for different flow deflectors models: (a) y = 0 cm ($y/L_p = 0$), and (b) y = 12 cm ($y/L_p = 0.143$).

In the other direction, Figure 10 shows the typical scour profiles of the bed surface parallel to the bow-thruster axis at x = +8 cm (x/D_p = +0.8), and x = -8 cm (x/D_p = -0.8). The results prove clearly that for all the four models tested using a single deflector, a reduction in the eroded bed area through the cross profile had been happened when compared with the base model. It is also clear from the figure that both dimension and position of the deflector have a significant effect on the value Y_s. For the base model and without using deflector, Y_s = 0 and Y_s/Lp = 0, which means that erosion takes place directly in front of the quay wall solid face.

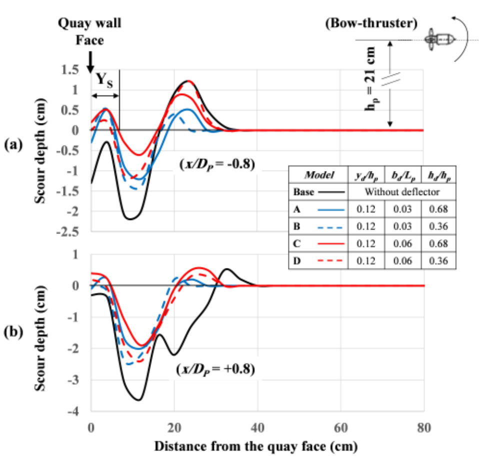

Figure 10 Typical scour profiles of the bed surface parallel to the bow-thruster axis for different flow deflectors models: (a) x = +8 cm ($x/D_p = 0.8$), and (b) x = -8 cm ($x/D_p = -0.8$).

While, the values of Y_s/Lp for models A, B, C and D have values greater than zero, which means than the start point of bed erosion had been moved away from the quay face because of the use of flow deflector. The values of Y_s/Lp are variable according to location of the profile, but its range in general around 0.06. Therefore, the results assure that the final shape of the eroded area was found to be dependent on the position and the dimensions of flow deflector.

These results indicate that model C has the greatest effect on moving bed scour away from the solid quay wall face. The configuration of model C, not only transfer the starting position of bed erosion away from the solid quay wall face, but also cause accretion of bed materials just in front of the quay wall. Also, by clear observation of both profiles, the configuration of model C provides less eroded area. The previous finding with minimizing bed eroded volume and transferring its location away from the quay wall may give better quay wall stability and deformation than that obtained without using the flow deflector. The reason behind those results may relate to the position of the flow deflector close to the bow tunnel within the lower half of the water jet cone induced by the bow-thruster and also due to the increase of its width. These may speed up the formation of the vortex that may deviates the water streamlines and decreases the water jet energy in the form of turbulence.

3.2 The Effect Of Using Triple Flow Deflectors On Minimizing The Bed Scour

Based on the shape of water jet induced by the bow-thruster shown in Figure 2 and the results of section 3.1, the effect of using triple flow deflectors on the scouring process had been tested and compared with the base model. Model set E consisted of triple deflectors which were distributed within the lower half of the cone shape of the water jet at three relative heights h_{d1}/h_p = 0.67, h_{d2}/h_p = 0.45 and h_{d3}/h_p = 0.23, respectively. The description of the model set is shown Figure 6 and Table 3. The left panel of Figure 11 shows the results of the contour plots of the bed scour measurements of model E compared with the basic model. The results confirm that there is also a decrease of the eroded volume of bed in comparison with the basic model.

For the purpose of comparison, typical scour profiles of the bed surface parallel to the quay wall have been selected at y = 0 cm (y/L_p = 0), and y = 12 cm (y/L_p =0.143) as shown in Figure 12. The results of Figure (12-a) show that there is an obvious amount of accretion of bed materials just in front of the quay wall due to the presence of the flow deflectors of Model E. On the contrary, an obvious amount of erosion is found in the case of the base model. These findings can help to increase the stability of the quay wall. The other typical scour profiles shown in Figure (12-b) also reveal the decrease in the scour depth of the model E compared to the base model.

For the purpose of checking the performance of the model E, Figure 13 shows the typical scour profiles of the bed surface parallel to the bow-thruster axis at x/D_p = +0.8 and x/D_p = -0.8. It is also clear from the figure that the starting point of bed erosion of model E had been moved away from the quay wall solid face with less eroded area when compared with the base model.

Finally, the efficiency of different flow deflector models in reducing bed erosion with respect to the base model is shown in Figure 14. The results revealed that there is an obvious reduction in the bed eroded volume compared with the results of the basic model by about 40%, 40%, 63%, 33% and 33% for model A, B, C, D and E, respectively.

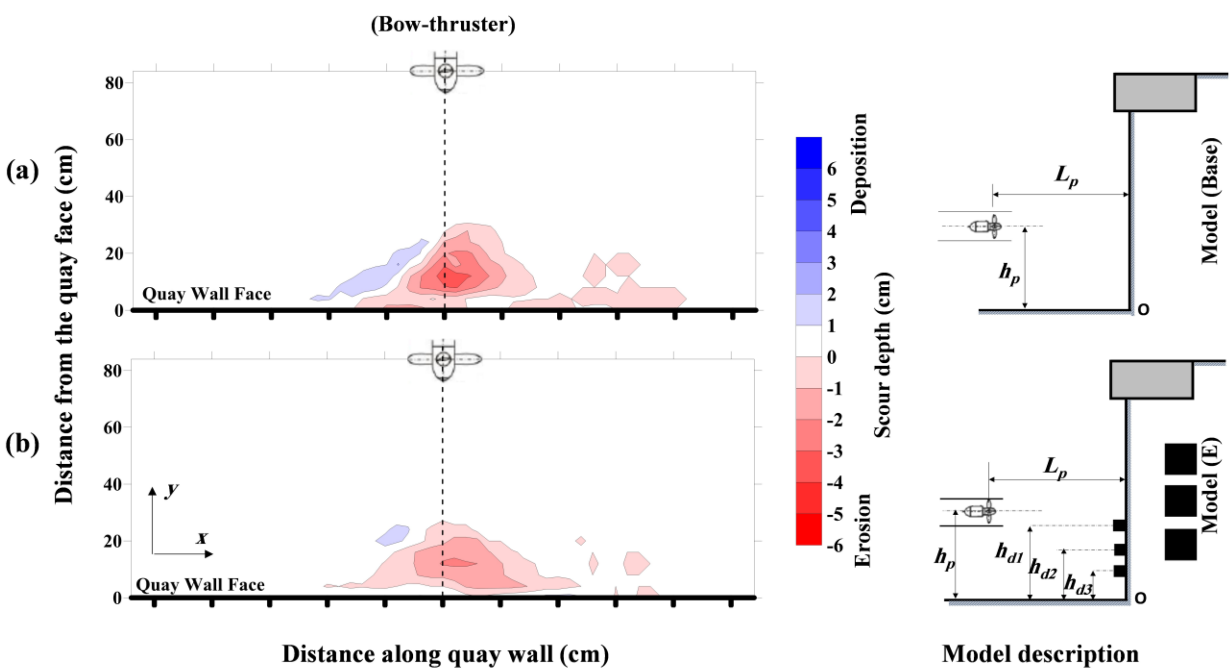

Figure 11 Effect of a triple flow deflector on bed scour, (h_p/h_w = 1/3, y_d/h_p = 0.12, b_d/L_p = 0.06):

(a) Basic model, and (b) triple model (model E)

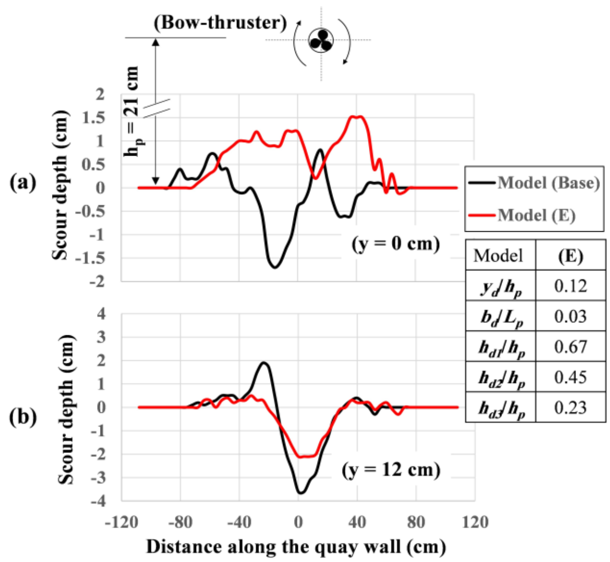

Figure 12 Typical scour profiles of the bed surface parallel to the quay wall for model (base) and model (E): (a) $y = 0$ cm ($y/L_p = 0$), and (b) $y = 12$ cm ($y/L_p = 0.143$).

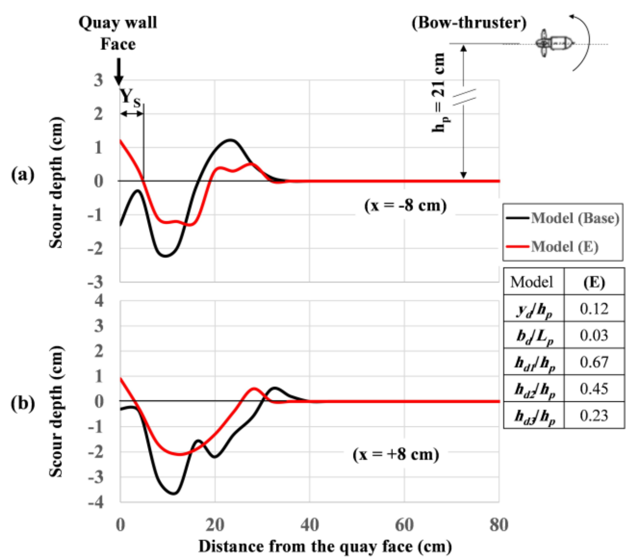

Figure 13 Typical scour profiles of the bed surface parallel to the bow-thruster axis for model (base) and model (E): (a) $x = +8$ cm ($x/D_p = 0.8$), and (b) $x = -8$ cm ($x/D_p = -0.8$).

The results proved that the configuration of model C gives minimum eroded volume with minimum length and width of erosion. The reason for that results may relate to the position of the flow deflector close to the bow tunnel within the lower half of the water jet cone induced by the bow-thruster and also due to the increase of its width compared with the three deflectors' model. These can act as an obstacle witch may deviate the water streamlines and decrease the water jet energy in the form of turbulence. Furthermore, the results indicate that using a single deflector has the same or more effect on minimizing the eroded volume than using triple

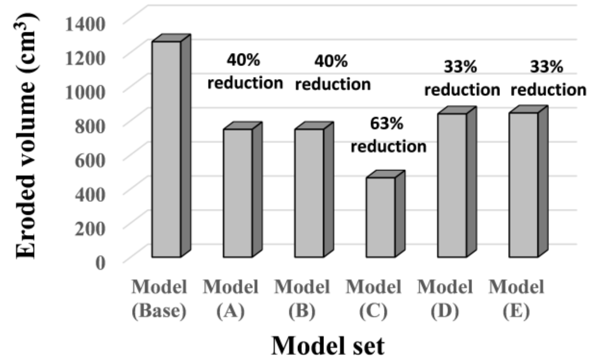

Figure 14 Efficiency of different flow deflector models on reducing bed erosion in comparison with the base model.

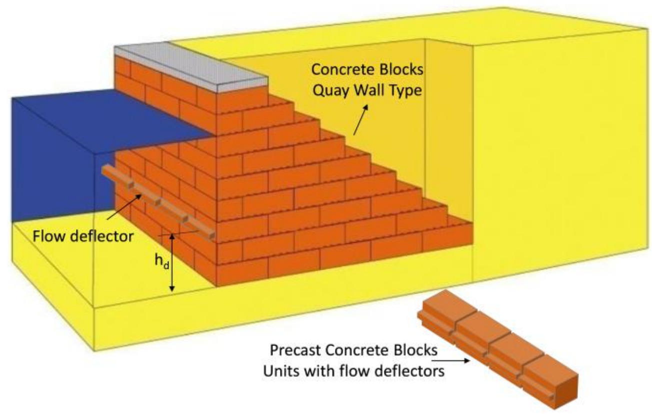

Figure 15 A proposal for flow deflector attached to Concrete Blocks Quay wall

deflectors. However, more experimental data are required to assure the applicability of the new system.

From the engineering point of view, we could suggest this system for the gravity vertical quay wall such as concrete blocks type and Caisson type. Here, Figure 15 presents simply the way for installment of the new system of flow deflector in case of concrete blocks type. The blocks at the position of the flow deflector could be easy produced as precast concrete blocks with additional flow deflectors units. For the caisson type, the vertical wall facing the harbor side could be redesigned with adding the flow deflector as a part of the wall. Therefore, finally, this proposed system requires more experimental investigation to assure its applicability.

4.0 CONCLUSIONS

The use of flow deflector attached to the solid face of quay walls for the purpose of minimizing bed scour induced by bow-thrusters had been experimentally investigated. Experimental tests had been carried out for single and triple deflectors attached to the quay face. Furthermore, different locations and dimensions for the deflector had been investigated. The research findings proved that the existence of the deflector attached to quay face has significant effect in disturbing the flow field generated by the bow-thrusters and as a result, the bed scour happens in front of quay wall reduces with a value up to 63 %, when compared with the measured profiles for bed surface without using any deflector.

The current study also proved that the width and level of the deflector with respect to the location of the bow-thruster has a sensitive effect on minimizing bed scour. Furthermore, the study also proved that the use of flow deflector not only, causes the volume and area of the eroded bed to reduce, but also to move away from the quay face.

The presence of the flow deflector within the diffusing path of a propeller wash, acting over a mobile sediment bed, was found to alter the shape and extent of the final eroded profile when compared with that basic model without flow deflectors. The final shape of the eroded area was found to be dependent on the position and the dimensions of flow deflector. These findings for the use of flow deflector attached to the quay face may be of considerable importance for stability of quay walls against erosion induced by bow-thrusters inside ports. Therefore, this proposed system requires more experimental investigation to assure its applicability taking the effect of hull of the ship with different number of propellers into consideration.

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