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THE EFFECT OF SEA SIDE QUAY WALL ROUGHNESS AND INCLINATION ON BED SCOUR INDUCED BY SHIP BOW-THRUSTERS

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Abstract: In order to increase their transport efficiency, modern ships are built with increasingly larger propellers and bow-thrusters. The combination of larger propellers with greater power and a reduction in bed clearance has created higher levels of bed scour action affecting berthing structures. Therefore, propeller-induced scours need to be considered in the design of quay wall structures. In this study, an experimental investigation was carried out to examine the effect of sea side wall roughness and wall inclination angle on the scouring action induced by bow-thruster in front of the quay wall. Two different kinds of sea side quay wall surfaces (glass and concrete) as an indicator of wall roughness and four different sea side wall inclination angles (α = 90°, 75°, 60°, and 45°) were considered in this study. The results showed that the eroded area has been decreased with the increase of the sea side wall roughness and inclination.

Keywords: *Quay wall, bow-thruster, bed scour, wall roughness, wall inclination.*

1.0 Introduction

As the shipping industry is growing, there is a highly concern about the consequences of the use of large bow-thrusters in order to make ships more maneuverable. Bow-thrusters are of great help for the navigation at quay walls, but near quay walls the jet generated by the bow-thruster during the berthing/de-berthing process introduces severe velocities and turbulence at the bottom which can cause scour of the bed alongside a quay wall. These results in a reduction of the passive ground pressure and can eventually lead to a collapse of the quay wall (Pianc, 2015). Therefore, it has become one of the most important issues for the design and maintenance of navigation channels and harbor structures. Evidence reported by (Bergh and Cederwall, 1981) shows severe damages induced by propeller jets in 25 quay structures in Swedish harbors. (Chait, 1987) documented scour damage of many ports in South Africa.

Recently, in order to develop a better understanding of the scouring action due to jet velocities, several researchers such as (Van Doorn, 2012 and Nielsen, 2005) performed physical model research in order to investigate the diffusion or spreading of velocity field due to bow-thrusters of vessels moored near a vertical quay. (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.

Few studies had been carried out to find the effect of the wall roughness which can derive the turbulence generation and dissipation and hence the flow field in most of the situations; however, as far as the jet due to bow-thruster on the quay wall is concerned. (Nielsen, 2005 and Van Blaaderen, 2006) concluded that the effect of wall-friction associated with wall roughness leads almost no difference with the situation where the quay wall is modelled hydraulically smooth surface as a result of their numerical and physical modellings. There is limited work available for the study of the effect of wall inclination on the scour induced by ship bow-thrusters. Exemplars of such action have been well reported by (Römisch, 2001) who determined the flow velocities near quay walls under a small angle ranged from 0° corresponds to a vertical wall up to the maximum angle of 40° corresponds to a very steep slope of (1:1.16). (Van Doorn, 2012) reported that the amount of flow directed to the bottom is negligible for a slope angle 1:2.5 and 1:1.15 which matched with the results of the numerical model suggested by (Jurjen de Jong, 2014).

The present research is an attempt to investigate experimentally the effect of roughness and inclination of the sea side face of the quay wall (perpendicular to the axis of the propeller) on the scouring action induced by bow-thrusters in front of the quay wall.

2.0 Experimental Set-up

Experiments were conducted in the wide flume located in the Coastal Engineering Laboratory, Faculty of Engineering of 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 were made of glass as shown in Figure 1. The model tests are focused on sea-going vessels which moored at a vertical solid face quay wall. The model of the ship is a simplified version of the container ship called “Pride of Rotterdam”. This ship was used to have comparable relative dimensions to real-life situations with a length of 215.0 m, width of 30.0 m, a draught of 14.24 m, and a bow-thruster of diameter 2.50 m as 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 which based on the assumption that bow-thrusters will be used at the berth at 100% power. 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 for a period of a few minutes. The experimental model is geometrically scaled at a scale of 1/25 (Schokking et al., 2003). Prototype and model dimensions are also given in Table 1.

A complete bow-thruster tail piece is used for the model tests with a tunnel tube of diameter 110 mm as shown in Figure 2. In the scale model, the thruster is controlled by the use of an engine with adjustable RPM. A frequency regulator is used to decrease the RPM to the required number of rotations per minute, which ranged from 3000 to 5000 rpm.

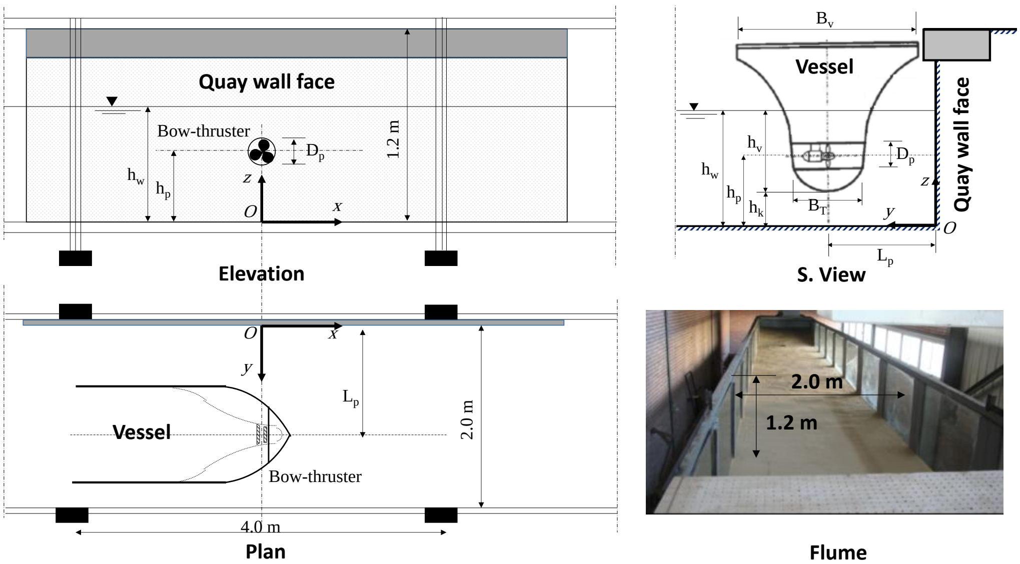


Figure 1: General layout of the flume to show the positioning and dimensions of the ship

Jet velocity was measured at the axis of rotation of the bow-thruster by using velocity meter type which is able to measure one-dimensional flow up to 4.5 m/s. Before each experiment, the sandy bed with the median grain size of D_{50} = 0.3 mm levelled 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*, *z* for each grid node with respect to the origin point, *O*, as shown in Figure 1. The flume was then slowly filled with water to avoid disturbing the leveled sand bed. Once the predetermined water depth was reached, the bow-thruster was turned on. During the experiment, the sandy bed was monitored visually through the glass walls of the flume until the bed deformation begins to be constant.

Table 1: Model Scale

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
Maximum tunnel thruster Length	B_T [m]	20.00	0.80
Height of propeller axis above bed	h_p [m]	5.00	0.20
Distance from propeller axis to quay face	L_p [m]	21.00	0.84
Diameter of propeller (bow)	D_p [m]	2.50	0.10
Diameter of tunnel thruster	D_T [m]	2.75	0.11
Water depth	h_w [m]	15.75	0.63
Keel clearance	h_k [m]	1.50	0.06

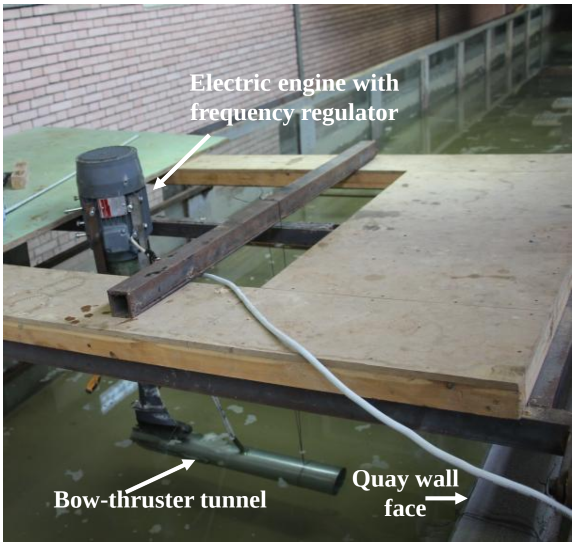


Figure 2: The modeled bow-thruster used in experiments

After the experiment, the same process of surveying was repeated and the differences between z values at the nodes express the depth of scour happened to the sandy bed. Determinations of the deposited and eroded volumes were made using Surfer 11.0 software after knowing the measured bed levels before and after each test.

3.0 Results and Discussion

3.1 The Effect of Bow-Thruster Speed

At the beginning of the experiments, it was necessary to know the effect of bow-thruster speed on the scouring action along the quay wall. The experiments were first carried out at four different speeds 0.30, 0.40, 0.45, and 0.50 m/sec, respectively. The glass material is chosen for the quay wall face. The bow-thruster located at a constant height above the bed (h_p = 21 cm) and constant clearance distance between the bow-thruster to the quay wall face (L_p = 84 cm).

Figure 3 shows the results of the contour plots of the bed scour measurements at each speed. Both Figure (4-a) and (4-b) show the scour profiles of the bed surface parallel to the quay wall at y = 8 cm, and parallel to the bow-thruster axis at x = -8 cm, respectively. The results indicate that the scour area is nearly symmetrical along the bow-thruster centerline with a slight asymmetrical deposition on its transverse sides speedily at high speeds. These findings are similar to the results of (Hong et al., 2013). Moreover, the results imply that an increase in the bow-thruster speed will lead to an increase in the eroded volume. This increase in scour values in the presence of the quay wall could be related to the quay structure obstruction and jet diffusion mechanisms.

Additionally, as the jet speed increases, the turbulence force increases, which lead to the increase of the bed hole depending on the diameter of the bed sediments. By inspecting the results, it had been found that the eroded volume increased by 30 % when the speed increased from 0.3 m/sec to 0.4 m/sec. While, it increased by 200% when the speed increased from 0.4 m/sec to 0.45 m/sec. These results imply that there is no fixed relationship between speed and bed eroded volume, which may be occurring due to the turbulence and complex characteristics of the resulted unsteady flow induced by bow-thruster when changing its speed in the proximity and at a fixed distance of the quay wall.

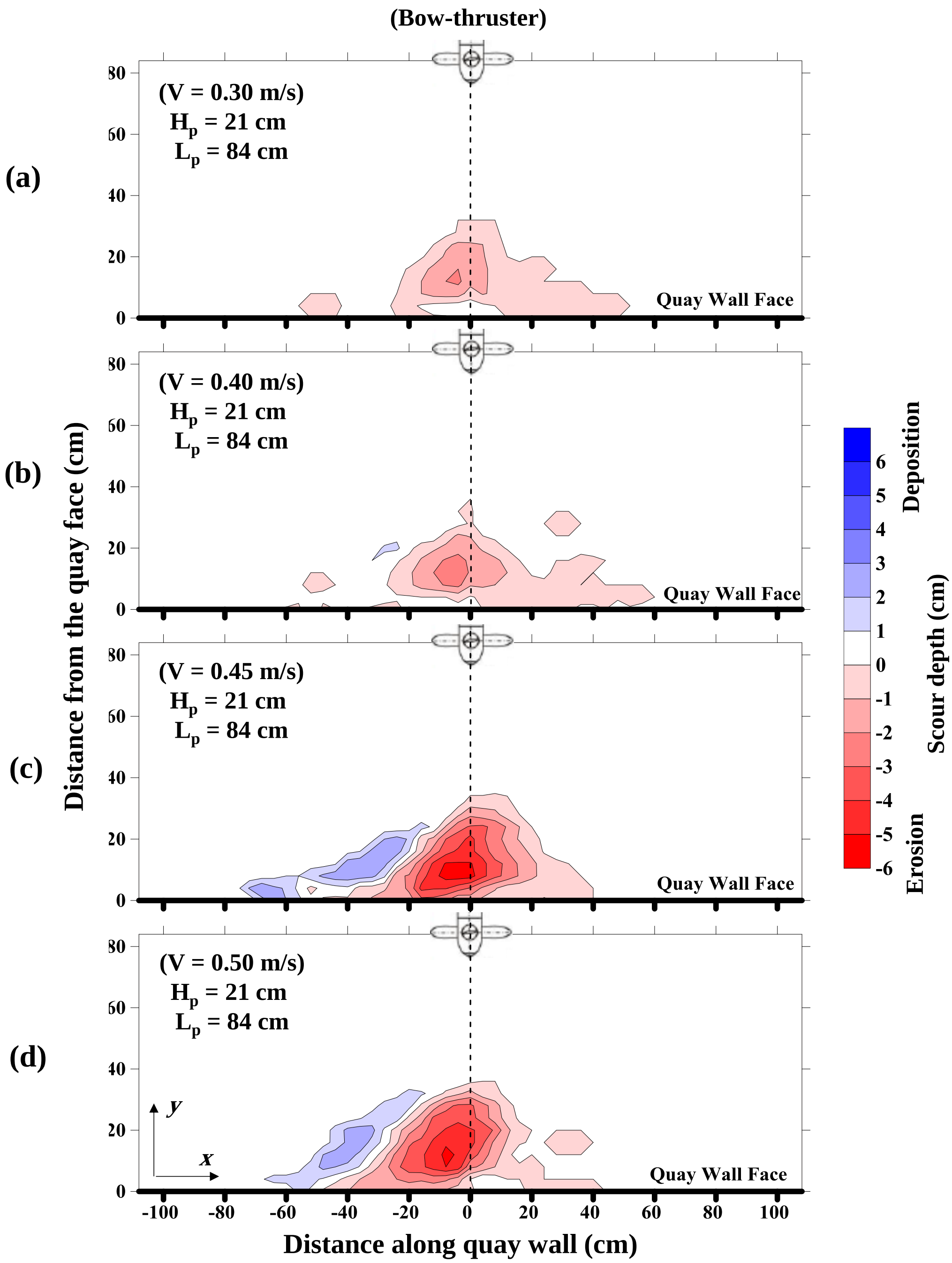


Figure 3: Effect of Bow-thruster speed on bed scour: (a) V= 0.30 m/s, (b) V = 0.40 m/s, (c) V = 0.45 m/s and (d) V = 0.50 m/s.

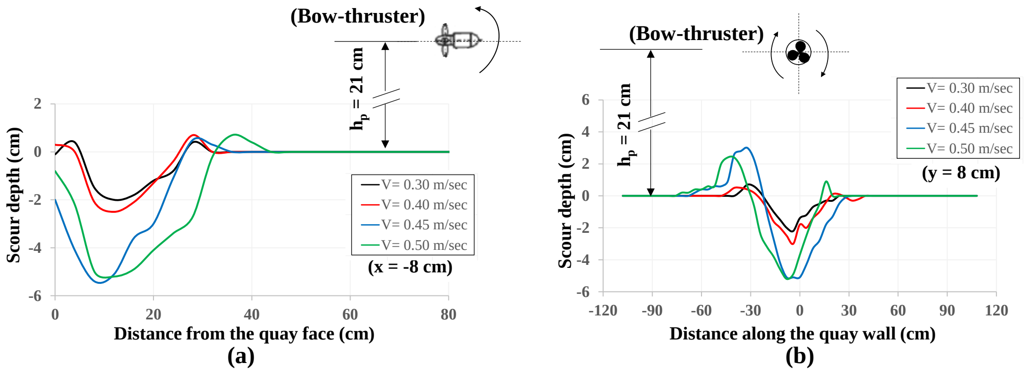


Figure 4: Scour profiles of the bed surface at different Bow-thruster speeds: (a) at x = -8 cm, and (b) at y = 8 cm.

3.2 *The Effect of Wall Face Roughness*

Secondly, the laboratory experiments were carried out to investigate the effect of wall face roughness on the scouring action along the quay wall. Two different quay wall surfaces had been investigated. The smooth quay wall surface tested by using glass face, while the rough surface tested by concrete face. In these experiments, the effect of wall roughness had been tested under two bow-thruster speeds (V = 0.30 and 0.45 m/sec) with constant h_p = 21 cm and L_p = 84 cm.

Figures 5 and 6 show the results of the contour plots of the bed scour measurements at each speed. The results, in case of bow-thruster speed 0.30 m/sec, showed that the total eroded volume of the smooth and rough wall surfaces was 1348.0 cm^3 and 743.0 cm^3, respectively. While, in case of bow-thruster speed 0.40 m/sec, the total eroded volume of the smooth and rough wall surfaces were 3252.0 cm^3 and 2350.0 cm^3, respectively. Therefore, the significant results imply that wall roughness have an effect on reducing the scouring process by 45% and 30% for bow-thruster speed 0.30 m/sec and 0.45 m/sec, respectively. Figure 7 shows example photos for the bed surface at different wall roughness. Therefore, we may conclude that a part of the energy of the bow-thruster jet is dissipated due to the wall friction associated with wall roughness. For the purpose of comparison, Figure (8-a) shows the typical scour profiles of the bed surface parallel to the bow-thruster axis at x = -8 cm. While, on the other direction, Figure (8-b) shows the typical scour profiles of the bed surface parallel to the quay wall have been selected at y = 8 cm. The results clearly show the reduction in the eroded bed area through the cross profile due to the effect of wall roughness.

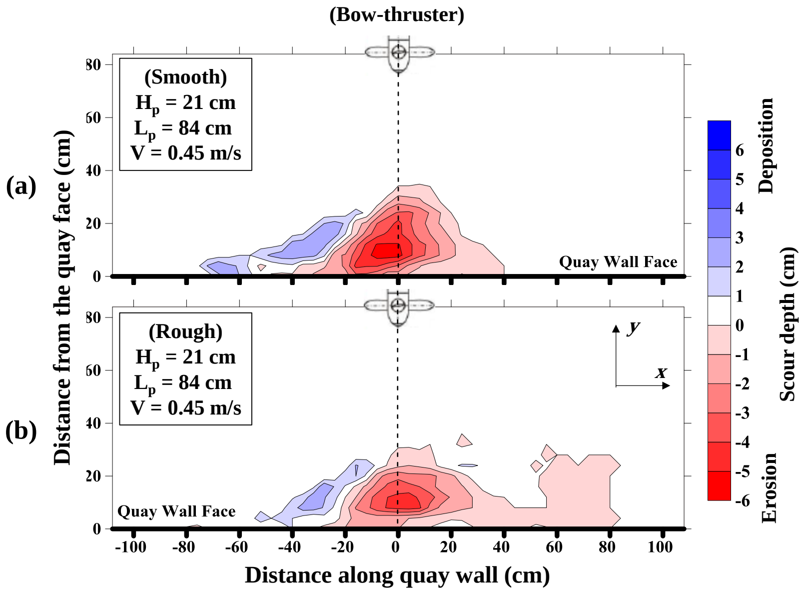
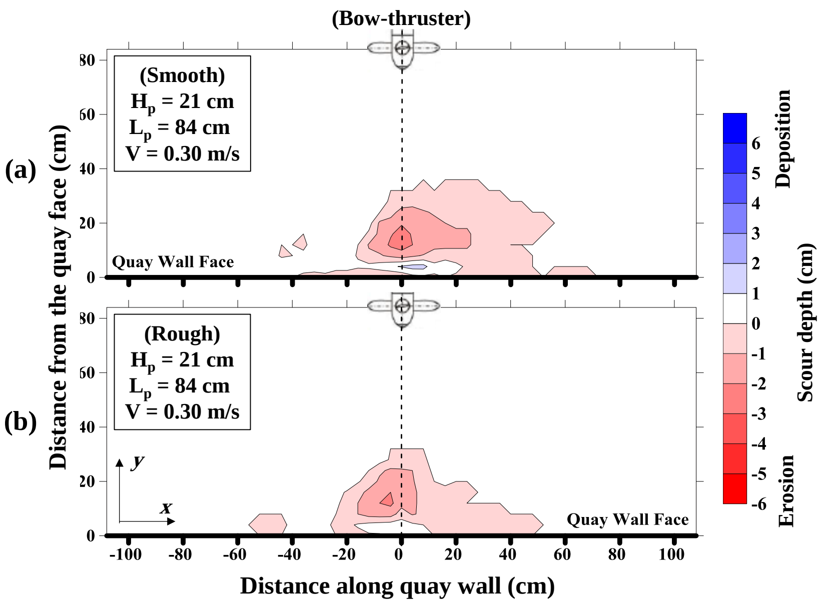


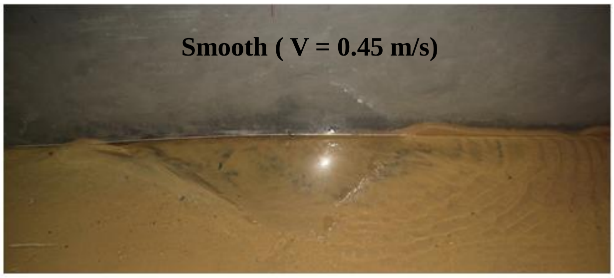
Figure 5: Effect of wall roughness on bed scour with Bow-thruster speed V= 0.30 m/s:



(a) Smooth surface (b) Rough surface.

Figure 6: Effect of wall roughness on bed scour with Bow-thruster speed V= 0.45 m/s:
(a) Smooth surface, (b) Rough surface

(a)



(b)

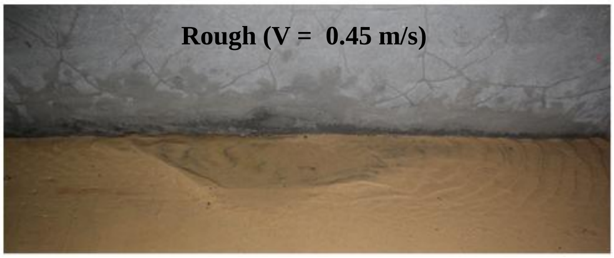


Figure 7: Bed Scour at different wall roughness at V = 0.45 m/sec: (a) Smooth wall (glass face), and (b) Rough wall (concrete face)

3.3 The Effect of Wall Face Inclination

The third group of laboratory experiments was carried out to investigate the effect of inclination of sea side face of the quay wall in the scouring process induced by the bow-thrusters in front of quay wall. This experimental work was divided into four model sets of different inclinations for the sea side face of the quay wall (α = 90°, 75°, 60°, and 45°). The experiments were carried out at a constant bow-thruster speed (V = 0.4 m/sec). Despite the difference in front face wall inclination, the position of bow-thruster face was fixed at the centerline of the bow-thruster with respect to quay wall face (L_p = 84 cm).

The bow-thruster was installed at a constant height above the bed (h_p = 21 cm). Arrangements of these sets of experiments, including all different parameters are shown in the right panel of Figure 9. While, the left panel of Figure 9 shows the results of the contour plots of the bed scour measurements for each model. It may be inferred that the eroded area represented by its length and its width decreases with the decrease of wall inclination angle. The same findings could be observed through Figure (10-a) which shows the scour profile of the bed surface parallel to the quay wall at y = 8 cm, and Figure (10-b) which shows the scour profile of the bed surface at the centerline of the bow-thruster axis at x = 0 cm. The reason for the reduction of the eroded area due to the effect of wall inclination may be related to the reduction of the part of the water jet, which is directed to the bottom (Q_{Bottom}) with respect to the upper part (Q_{Upper}) as explained in Figure 11. Therefore, we can suppose that the bow-thruster jet energy was dissipated by the wall inclination. These results are similar to the results reported by (Römisch, 2001).

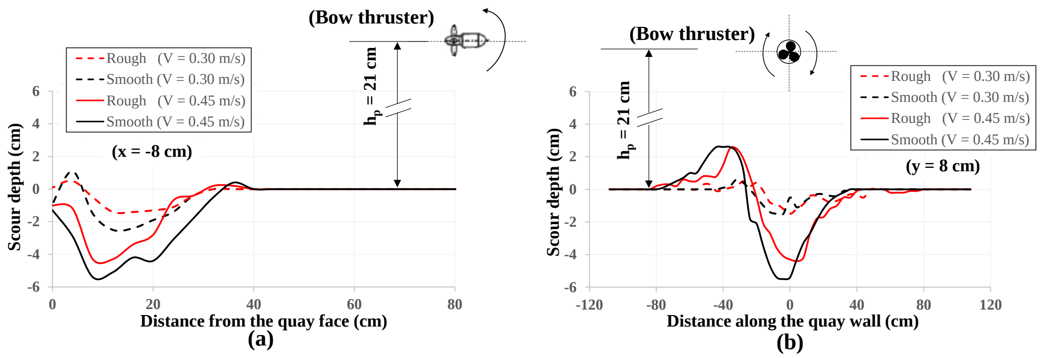


Figure 8: Scour profiles of the bed surface at different wall roughness: (a) at x = -8 cm, and (b) at y = 8 cm.

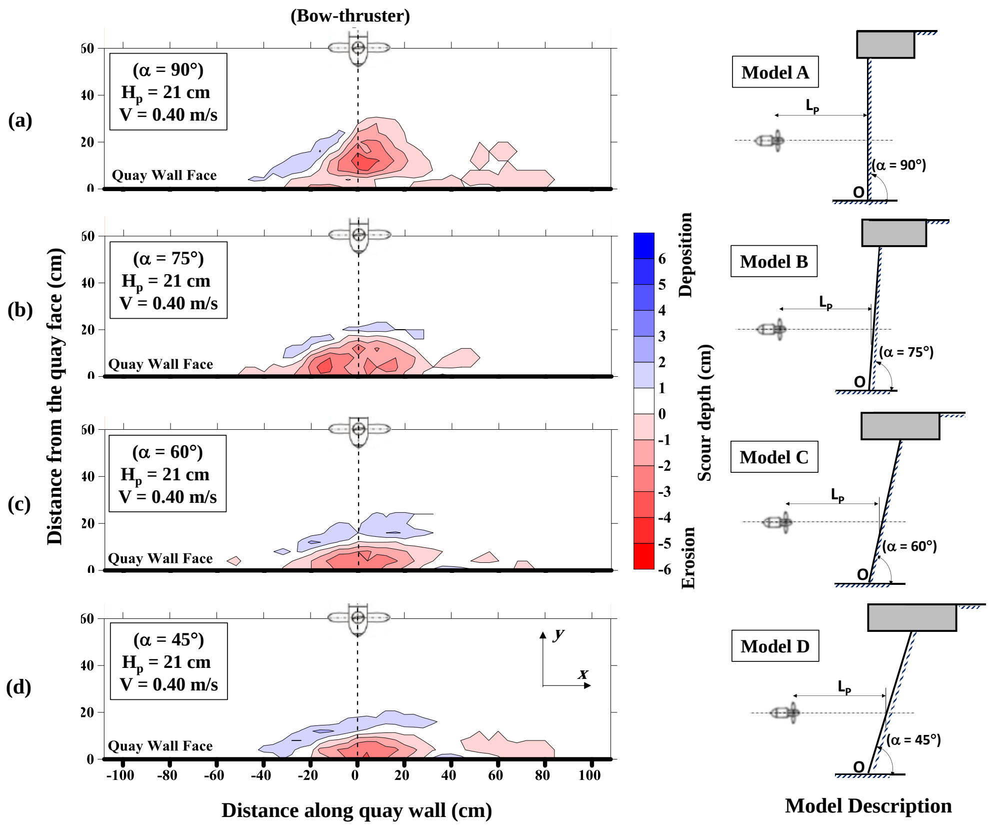


Figure 9: Effect of wall face inclination on bed scour: (a) Model A at $\alpha = 90°$, (b) Model B at $\alpha = 75°$, (c) Model C at $\alpha = 60°$, and (d) Model D at $\alpha = 45°$

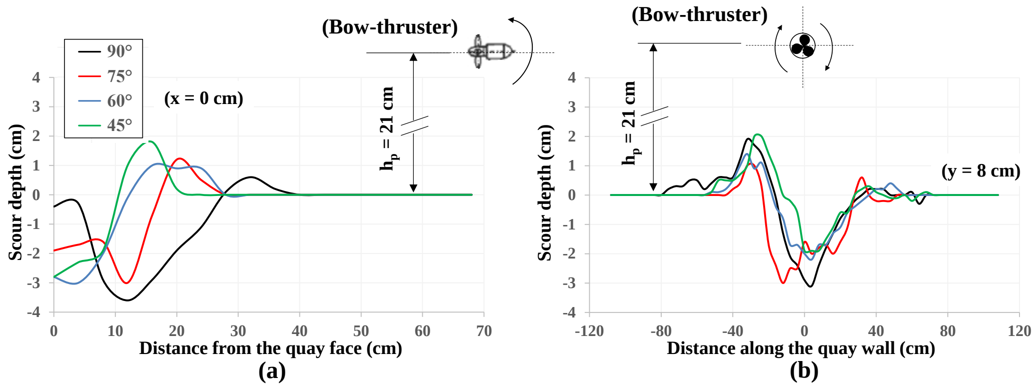


Figure 10: Scour profiles of the bed surface at different wall face inclination: (a) at x = 0 cm, and (b) at y = 8 cm.

It must be noted that the amount of reduction of the erosion in the first 15 degrees, between 75° and 90°, had more effect than the rest of other results. The results indicate that the erosion decreased by about 71% with the range of wall face inclination between 75° to 90°, while it decreased by 7% and 12% for the range between 60° to 75° and between 45° to 60°, respectively. Figure 12 assure these findings, which need more future experiments within this range of wall inclination.

4.0 Conclusions

Laboratory experiments on sea bed scour, in front of quay wall, due to bow-thruster action were conducted. The following conclusions are drawn from the study:

a. Firstly, the effect of bow-thruster speed on the scouring action along the quay wall has been tested at four different speeds 0.30, 0.40, 0.45, and 0.50 m/sec, respectively.

b. The results imply that as the bow-thruster speed increased, the eroded volume increased which could be related to the quay structure obstruction and jet diffusion mechanisms. The results showed that there is no fixed relationship between the speed and the eroded volume. It increased by 30 % for low speed and 200% for high speed.

c. The effect of wall roughness on the scouring action along the quay wall was investigated by selecting two different materials for quay wall surface. The significant results implied that the wall roughness has an effect on the scouring process which related to the dissipation of a part of the energy of the bow-thruster jet due to the wall-friction associated with wall roughness. The results showed that the eroded volume decreased by about 45% and 30% for bow-thruster speed 0.30 m/sec and 0.45 m/sec, respectively.

d. Four models of different quay wall inclination angle (α = 90°, 75°, 60°, and 45°) were tested in order to examine their effect on the scour action along the quay wall. The results confirmed that the eroded area decreased with the decrease of the wall inclination. The results indicate that the erosion decreased by about 71% with the range of wall face inclination between 75° to 90°, while it decreased by 7% and 12% for the range between 60° to 75° and between 45° to 60°, respectively. This reduction of the eroded area could be referred to the reduction of the part of the water jet, which is directed to the bottom (Q_{Bottom}) with respect to the upper part (Q_{Upper}). Therefore, we could conclude that an updated research is required to understand the mechanism of wall inclination in the erosion process in front of quay wall structures.

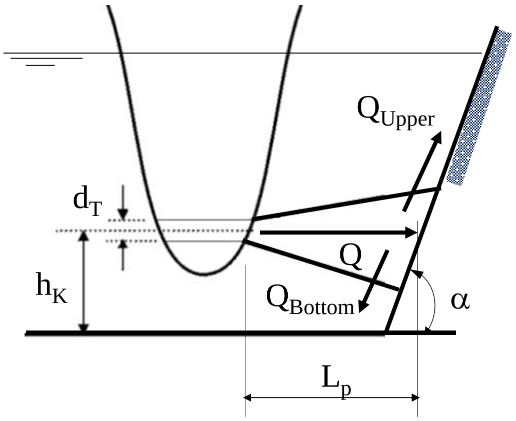


Figure 11: A schematic diagram to explain the effect of wall face inclination on water jet

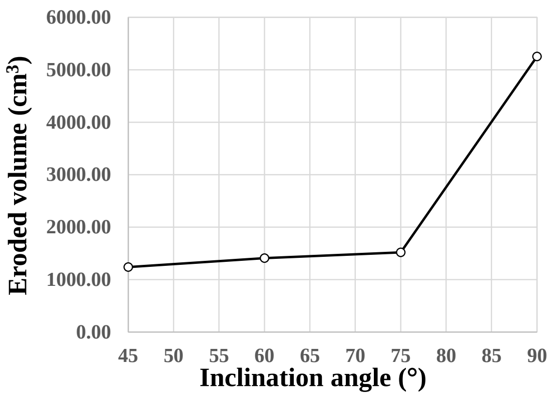


Figure 12: Relationship between the eroded volume and wall face inclination angle

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