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Research Article

Experimental Analysis of Single Propeller Scour Dynamics Near Vertical and Parallel Quay Walls

Erdal Kesgin [1, *], Rumeysa Kuzgun[2], R. İlayda Tan Kesgin[3] and Kadir Gezici [4]

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[1]Istanbul Technical University, Faculty of Civil Engineering, Department of Civil Engineering, 34469, Maslak, Istanbul, Türkiye; kesgine@itu.edu.tr
[2]Fatih Sultan Mehmet Vakıf University, Faculty of Engineering, Department of Civil Engineering, 34015, Zeytinburnu, Istanbul, Türkiye; rumeysa.kuzgun@stu.fsm.edu.tr
[3]Fatih Sultan Mehmet Vakıf University, Faculty of Engineering, Department of Civil Engineering, 34015, Zeytinburnu, Istanbul, Türkiye; ritankesgin@fsm.edu.tr
[4]Atatürk University, Faculty of Engineering, Department of Civil Engineering, 25240, Yakutiye, Erzurum, Türkiye; kadirgezici@atauni.edu.tr
*Corresponding Author

Abstract: Ship propeller jet-induced scour while berthing and unberthing poses a significant threat to berth structure stability. With the increase in size and capacity of vessels, the propeller-generated flow interaction with seabed erosion is gaining significance for port facility management. The present investigation experimentally investigates single propeller jet-induced scour behavior around quay walls of various wall configurations. Flume experiments in the laboratory were conducted with the use of sand of median grain diameter d_{50} = 1.2 mm, 10 cm diameter propellers, and Froude numbers of 4.71 and 6.23. The role of rotational speed of the propeller, gap (G) vertically, and the propeller-wall distance were studied under conditions of unconfined (no-wall) and confined (parallel and vertical wall) cases. The results show that for unconfined cases, deeper gaps decrease scour depth and greater rotational speed increases it. In confined cases, deeper separation between the wall and the propeller decreases scour depth, and wall orientation significantly influences the scour profile. These kinds of results enhance understanding of the mechanisms of sediment transport near quay walls and allow for the development of predictive models for estimating scour.

Keywords: scour; erosion; propeller jet; quay wall; berthing structure.

Araştırma Makalesi

Dikey ve Paralel Yanaşma Yapıları Önünde Tekil Pervane Kaynaklı Oyulma Dinamiklerinin Deneysel Olarak Araştırılması

Özet: Yanaşma ve ayrılma sırasında gemi pervanelerinin oluşturduğu jet akımları, yanaşma yapılarının stabilitesini ciddi şekilde tehdit edebilir. Giderek artan gemi boyutları ve kapasiteleriyle birlikte, pervane kaynaklı akımlar ile deniz tabanı erozyonu arasındaki etkileşimin anlaşılması, liman altyapısının korunması açısından kritik hale gelmiştir. Bu çalışma, çeşitli duvar konfigürasyonları altında tekil pervane jetlerinin oluşturduğu oyulma desenlerini deneysel olarak incelemektedir. Deneyler, ortalama tane çapı d_{50} = 1,2 mm olan kum kullanılarak, 10 cm çapında pervaneler ve 4,71 ile 6,23 arasında değişen Froude sayılarıyla gerçekleştirilmiştir. Duvar bulunmayan (yapısız) ve duvar bulunan (dikey ve paralel) koşullar altında; pervane dönüş hızı, dikey boşluk (*G*) ve pervane-duvar mesafesinin oyulma üzerindeki etkileri analiz edilmiştir. Sonuçlar, yapısız durumda pervane ile yatak arasındaki mesafe arttıkça oyulma derinliğinin azaldığını; dönüş hızı arttıkça ise oyulmanın derinleştiğini göstermektedir. Yapılı koşullarda ise pervane-duvar mesafesi arttıkça oyulma derinliği azalmış, duvar yöneliminin de oyulma profili üzerinde önemli etkiler oluşturduğu belirlenmiştir. Elde edilen bulgular, rıhtım duvarları yakınında oluşan sediman taşınım mekanizmalarının anlaşılmasına katkı sağlayarak oyulma tahmin modellerinin geliştirilmesine olanak sunmaktadır.

Anahtar Kelimeler: oyulma; erozyon; pervane jeti; rıhtım duvarı; yanaşma yapısı.

1. Introduction

Vessels are utilized as transportation vehicles in the seas for various purposes. Over time, with increasing demands and expectations for further growth in the future, the capacity, size, and technology of vessels are continuously evolving. During berthing and unberthing maneuvers, the high-speed water jets generated by vessel propellers can cause significant damage to port infrastructure. The erosion caused by propeller jets near berth structures can compromise the stability of these structures.

Water jets, generated during vessel berthing and unberthing, contribute to scouring and sediment accumulation mechanisms, leading to significant damage in navigation channels, seabeds, port slopes, quay walls, and piles. These effects can pose serious risks to port structures. A study conducted in United Kingdom's ports indicated that 42% of major ports experienced seabed scouring due to propeller effects, with 29% of these cases requiring urgent remedial measures [1].

With the increasing demands and advancing technologies, vessel sizes are also growing, leading to more powerful propellers and stronger jet flows. Various types of vessels, during their berthing and unberthing maneuvers, generate high-velocity jet flows from their propellers, which mobilize the seabed material, resulting in scouring or sediment deposition on the seabed.

The Propeller-generated submerged jet flows can reach extremely high velocities, depending on the vessel and propeller characteristics. These powerful jets can cause significant erosion, posing serious risks to port structures. At the propeller outlet, flow velocities can reach up to 11-12 m/s, with bed shear velocities as high as 3-4 m/s [2]. When these high-speed jets interact with quay structures, they can dislodge seabed materials, leading to scouring or sediment deposition. Over time, these processes can compromise the stability and integrity of port infrastructure.

To determine the amount of erosion caused by the flow from vessel propellers and to identify the influencing parameters, both experimental and numerical methods have been employed in the literature. Initial studies focused on the scouring mechanisms under unrestricted conditions, where no berth structure was present under the influence of a circular wall jet or propeller jet [3-8]. Later studies, however, investigated scouring under restricted conditions, considering the presence of berth structures of different types and positions and analyzing the effects of the jet mechanism in such cases [9-15]. Some of these studies are summarized below. In his experimental study, [3] investigated the extent of local scouring around vertical piles under the influence of a wall jet flow, considering them as an open berth structure. The study aimed to identify the characteristic parameters that play a significant role in the scouring mechanism. Two different experimental setups were used: one examining scour hole development without any structure, and the other focusing on local scour around a vertical cylindrical pile caused by a circular wall jet. [3] classified two primary mechanisms influencing the development of scour holes around the vertical pile: the structure mechanism and the jet diffusion mechanism. They concluded that the structure mechanism was primarily driven by the presence of the pile itself, while the jet diffusion mechanism was more influenced by the propeller jet flow. In the structure mechanism, the flow impinging on the pile generates a strong downward flow in front of the structure. The horseshoe vortex effect, which occurs near the seabed, creates a swirling flow structure, leading to scouring at the base of the pile. This type of scouring mechanism is similar to the scour mechanism observed around bridge piers.

[4] conducted an experimental study to investigate the scouring effects caused by a propeller jet in the absence of berth structures. Their findings highlighted the temporal development of the scour hole under the influence of propeller jet flow, concluding that the densimetric Froude number is the most critical factor influencing scour hole formation. Building on this, [16] developed a two-dimensional scour model to predict scour profiles for both single and twin-propeller vessel systems using the Gaussian normal probability distribution. Their experimental study examined both configurations, testing two different propeller types. The vertical distance between the propeller axis and the seabed (G) was set at 27.5 mm and 55 mm, with experiments conducted at rotation speeds of 500 and 700 rpm. The results revealed that propeller jet scour profiles can be categorized into three distinct regions: a small scour hole located beneath or just behind the propeller, a larger scour hole in front of the propeller, and a sedimentation or deposition zone further downstream.

The erosion caused by a single propeller has been extensively studied by researchers such as [17-20]. Experimental studies have demonstrated that the location of maximum scour (X_{mu}) is closely related to the propeller gap (G) [21]. In recent decades, numerous studies have focused on the scour mechanisms induced by single propeller jet flows near quay walls and berthing structures [5, 9, 11, 13, 22, 23]. [9] investigated scour development under both unconfined conditions and scenarios involving quay walls, proposing a predictive formula for estimating the maximum scour depth based on the distance between the propeller and the wall (X_w). [11] conducted experimental studies on scour formation at the toe of quay walls, considering the influence of rudders on scour patterns. [24] further explored the effects of key parameters such as propeller-to-wall distance (X_w), propeller diameter (D_p), rotational speed (n, rpm), and gap (G) on scour profiles in both confined and unconfined conditions.

This study presents a novel experimental investigation of single-propeller-induced scour by comparing unconfined conditions with two distinct quay wall configurations: vertical and parallel. Laboratory tests were conducted using sand with a median grain size of 1.2 mm. The research also examines variations in scour characteristics resulting from single jet flow generated by a 10 cm diameter propeller considering different propeller rotational speeds and gap distances. Unlike previous studies that primarily focused on perpendicular wall interactions or twin-propeller systems, this research systematically analyzes the influence of wall orientation and propeller-to-wall distance on scour development.

The inclusion of parallel wall scenarios and detailed parametric evaluation fills a significant gap in the current literature. These findings offer valuable insights for designing safer berthing structures and improving predictive scour models.

2. Material and Methods

2.1. Experimental Setup

The experimental study was performed in a laboratory flume designed to simulate the effects of ship propeller jets on the seabed under both unconfined and confined flow conditions. As shown in Figure 1, the flume is located in the Hydraulics Laboratory of Istanbul Technical University and is equipped with transparent glass sidewalls. It measures 6.2 meters in length, 1.52 meters in width, and 1.2 meters in depth. For the experiments, a sand bed was installed at the base of the flume with dimensions of 2.0 m (length), 1.5 m (width), and 0.30 m (depth).

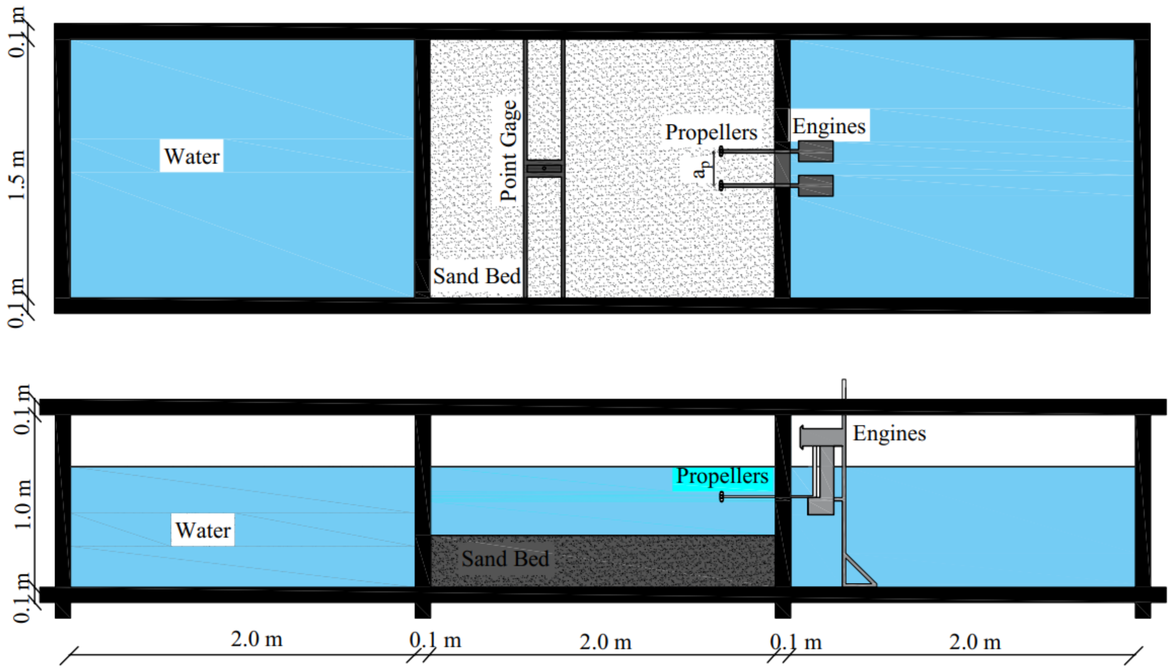


Figure 1. Experimental setup.

To allow for variation in experimental parameters, a specially designed acrylic-box system was mounted on a movable platform. This setup made it possible to adjust the vertical gap (G) between the propeller and the sand bed, as well as the horizontal positioning of the propeller relative to quay walls. As depicted in Figure 2, the system was flexible in both vertical and horizontal directions, enabling precise control over propeller elevation and lateral positioning.

A four-bladed Wageningen B-series propeller with a diameter of 10 cm was used in all experiments. The propellers were fabricated using 3D printing technology and constructed from PLA (Polylactic Acid) material. Experiments were conducted at two rotational speeds: 355 rpm and 470 rpm. The gap (G) between the propeller and the bed was set at two levels: 10 cm and 15 cm. Additionally, the horizontal distances between the propeller and the quay walls were defined as multiples of the propeller diameter ($2D_p$, $3D_p$, and $5D_p$).

This configuration allowed the investigation of how variations in propeller speed, vertical gap, and distance to structural boundaries affect scour development. Further technical specifications and propeller design details can be referenced in [6].

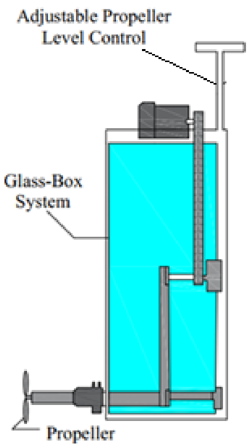


Figure 2. Propeller control system.

2.2. Methodology

Before starting the experiments, the sand bed was leveled using two fixed metal plates, and the propeller gap was adjusted to the desired condition. Subsequently, the flume was gradually filled with water from the network supply via a pipeline, ensuring that the water level in the channel reached the desired height (h=0.7 m) without disturbing the sand bed. In this state, the initial profile of the sand bed was measured, and the baseline profile was recorded. This equilibrium time was determined to be 150 minutes. At the end of this period, the propeller was stopped, and the sand bed profile was re-measured using a limnimetre to obtain the scour/deposition profile.

Additionally, a bypass system, consisting of pipelines passing underneath the sand bed and along both sides of the flume, was installed to prevent return flows within the experimental setup. The experiments with perpendicular walls were conducted using a plate measuring 1 m in height and 1.5 m in width, whereas for parallel wall experiments, a plate of 1 m in height and 3 m in width was used.

In this study, the experimental conditions listed in Table 1 were carried out under various conditions. In total, 4 experiments were conducted under the no-wall condition, while 12 experiments were performed for each of the vertical wall and parallel wall configurations, resulting in a total of 28 experimental tests. Furthermore, the distances between the propeller and the vertical (X_w) and parallel (Y_w) quay walls were also set at $2D_p$, $3D_p$, and $5D_p$.

Table 1. Experimental Conditions

Quay Wall	D_p (cm)	G (cm)	n (rpm)	(X_w, Y_w) (cm)	Experiment
No Wall	10	10	355	-	D-1
			470	-	D-2
		15	355	-	D-3
			470	-	D-4
Vertical Wall	10	10	355	$2D_p$	D-5
				$3D_p$	D-6
				$5D_p$	D-7
			470	$2D_p$	D-8
				$3D_p$	D-9
				$5D_p$	D-10
		15	355	$2D_p$	D-11
				$3D_p$	D-12
				$5D_p$	D-13
			470	$2D_p$	D-14
				$3D_p$	D-15
				$5D_p$	D-16
Parallel Wall	10	10	355	$2D_p$	D-17
				$3D_p$	D-18
				$5D_p$	D-19
			470	$2D_p$	D-20
				$3D_p$	D-21
				$5D_p$	D-22
		15	355	$2D_p$	D-23
				$3D_p$	D-24
				$5D_p$	D-25
			470	$2D_p$	D-26
				$3D_p$	D-27
				$5D_p$	D-28

2.3. Vertical and Parallel Walls

The presence of structural walls such as quay walls significantly alters hydrodynamic propeller jet stream behavior by enhancing near-bed levels of turbulence as well as shear stress, which in turn increases the likelihood of scour. In line with vessel berthing, quay walls can be perpendicular (vertical) or parallel to the axis of a propeller jet.

Within the experimental setup of this study, both wall orientations were tested systematically. Horizontal distances from the propeller to the quay wall were labeled as X_w for vertical setups and Y_w

for parallel setups, as shown in Figure 3. The distances were varied to represent diverse operational modes by setting them at 2, 3, and 5 times the propeller diameter ($2D_p$, $3D_p$, $5D_p$).

A review of the literature indicates that most of the earlier work has been concerned primarily with the effect of perpendicular quay walls, while research work with parallel wall arrangements is relatively limited. Furthermore, most of the earlier work has considered single-propeller systems alone. For example, [9] conducted experiments with a single propeller and a wall perpendicular to it, while [24] developed empirical correlations for predicting maximum scour depth as a function of propeller-wall distance for similar configurations. By contrast, studies examining parallel wall effects, such as those of [1], are comparatively limited in number.

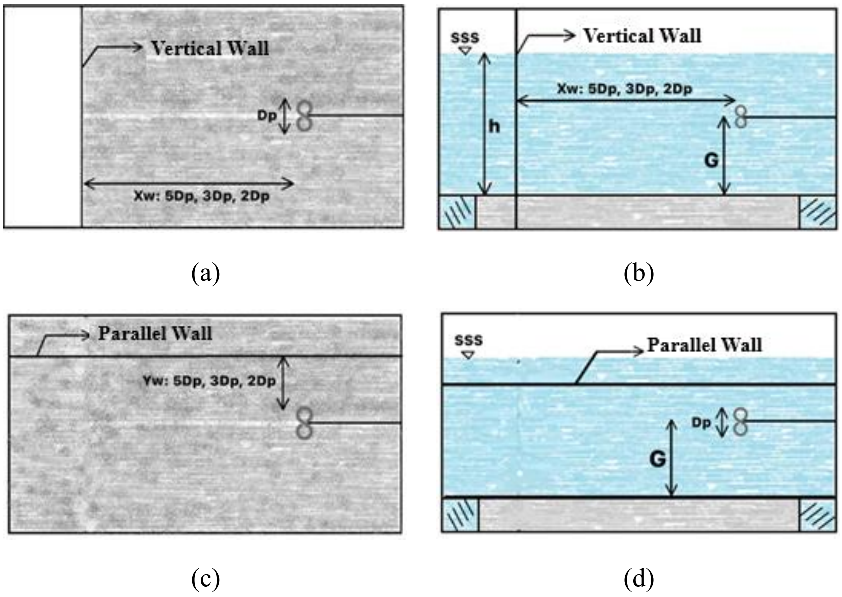


Figure 3. Quay wall positions with experimental parameters: a) vertical wall-plan view, b) vertical wall-side view, c) parallel wall-plan view, d) parallel wall-side view.

Moreover, the key experimental parameters used throughout this study are summarized in Table 2.

Table 2. Definition of Key Experimental Variables

Symbol	Unit	Description
D_p	cm	Propeller diameter
G	cm	Vertical gap between propeller and sand bed
n	rpm	Propeller rotational speed
X_w	cm	Horizontal distance from propeller to vertical wall
Y_w	cm	Horizontal distance from propeller to parallel wall
S_{max}	cm	Maximum scour depth
F_{rd}	–	Densimetric Froude number
X_{mu}	cm	Distance from propeller face to maximum scour location

3. Results and Discussion

3.1. No Wall Conditions

The development of the scour profile reached equilibrium conditions after a certain period, and the progression of the scour hole stabilizes. Beyond this point, no significant changes are observed in the development of the scour profile. Accordingly, after this period, the dimensions of the scour hole remain unchanged.

In this study, the duration during which the scour hole depth remains constant after reaching the maximum scour depth was determined by considering similar studies in the literature. Additionally, this duration was verified through a sample test. In similar conditions, [6, 13, 24] determined this period to be 150 minutes. It was also observed that when approximately 30% of this period had elapsed, more than 70% of the maximum scour depth (S_{max}) had been reached. This indicates that a significant portion of the scour hole development occurs within a relatively short time compared to the total experimental duration.

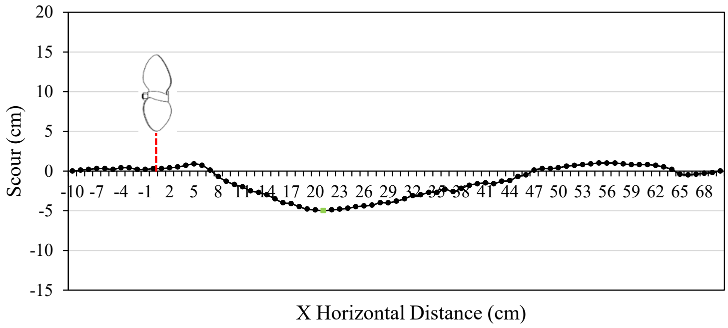
This period was measured considering that no changes occurred in the scour hole after reaching the maximum scour depth (with a tolerance of ±1 mm), and scour profiles were obtained accordingly. A similar approach was adopted in the present study. The scour profile reaches equilibrium conditions within a specific period after the initiation of propeller rotation. To ensure validation, the experiments were repeated under identical conditions, and it was assumed that scour depth stabilized after 150 minutes. Within the scope of this study, scour profiles were obtained under different test conditions, and the final scour profile measurements at the end of the 150-minute period were analyzed.

As shown in Figure 4a, under the influence of a single propeller with a gap (*G*) of 10 cm and a rotational speed of 355 rpm, the maximum scour hole depth (S_{max}) was measured as 5 cm. Under the same conditions, when the propeller rotational speed increased (Figure 4b), S_{max} increased to 7 cm.

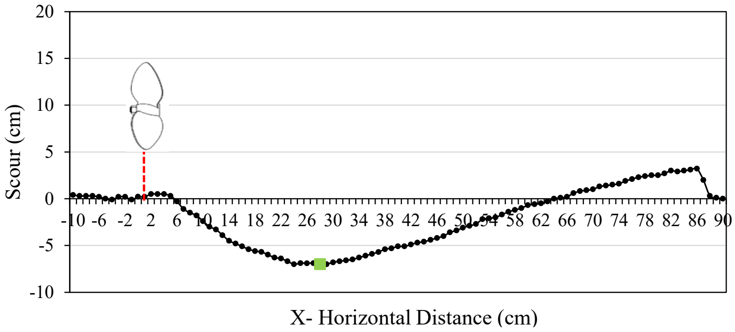
Similarly, in the scour hole profiles presented in Figures 4a and 4c, when the propeller gap was increased from G = 10 cm to G = 15 cm at the same rotational speeds, a decrease in scour hole depths was observed. As the scour hole depth decreased, the height of the accumulation zone formed behind the scour hole also decreased, whereas the scour width increased. Furthermore, as the propeller gap increased from G = 10 cm to G = 15 cm (e.g., Figures 4a and 4c), not only did the scour depth decrease, but the location of the maximum scour point also shifted further downstream, indicating a longer jet trajectory before maximum impact with the bed.

The scour profiles obtained from these four experiments under the influence of a single propeller jet effect also exhibit similarities to the scour profile reported by [4]. According to their findings, two distinct scour holes were observed: a smaller one directly beneath the propeller and a deeper, larger scour hole along the propeller axis.

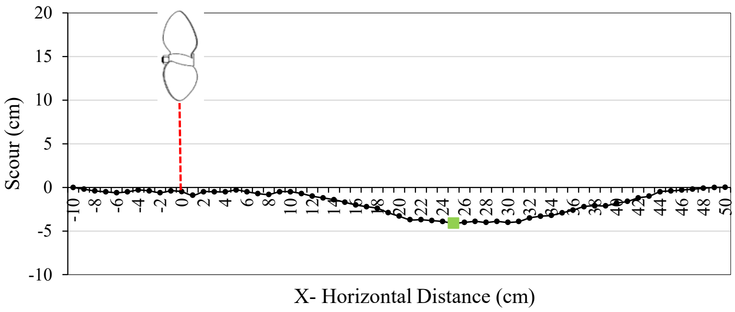
$$Fr_d = 2.1\frac{G}{D_p} \tag{3.1}$$



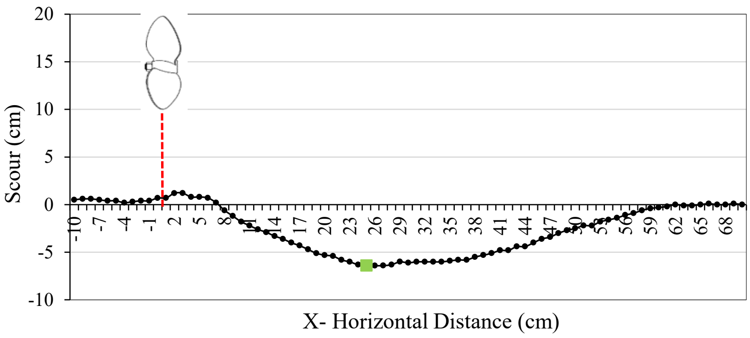
(a)



(b)



(c)



(d)

Figure 4. The scour profile under the influence of a single propeller and the appearance of the scour formed at the end of the experiment: a) G=10, n=355 rpm, b) G=10, n=470 rpm, c) G=15, n=355 rpm, d) G=15, n=470 rpm

Furthermore, as observed in all four experiments, it was determined that the vertical distance of the propeller from the bed and the propeller rotational speeds significantly influence the maximum scour hole depth. [12] expressed the critical condition for the onset of scour under the influence of a single propeller in terms of the densimetric Froude number using Equation 3.1. In this study, experiments were initiated single propeller with diameter of and 10 cm (Figure 5). Accordingly, it was observed that the critical scour initiation expression provided by Tan and Yüksel (2018) is consistent with the experiments conducted in this study using different bed materials.

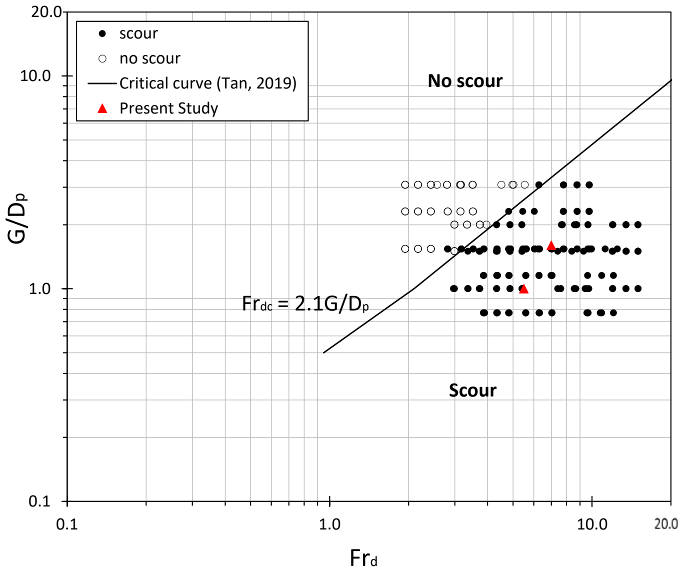


Figure 5. The occurrence of critical scour under the influence of a single propeller

[9, 12] presented different equations to determine the horizontal distance (X_{mu}) from the propeller face to the location of the maximum scour hole. In their study, [12] revised the equation provided by [9] (Equation 3.2) to better predict the location of the maximum scour hole over a wider range of densimetric Froude numbers (Fr_d). The revised form of the equation is given as follows:

$$\frac{X_m}{G^{0.09}D_p^{0.91}}=Fr_d^{0.724} \quad (3.2)$$

In this study, the distance from the propeller to the location of the maximum scour under the influence of a single propeller, in the absence of any structures, was measured. This value was also calculated using the equations proposed by [9,12]. The results are presented in Figure 6. It was observed that the measured values differed from the predicted values obtained from the two formulas and exhibited a scatter similar to the experimental results reported by [9].

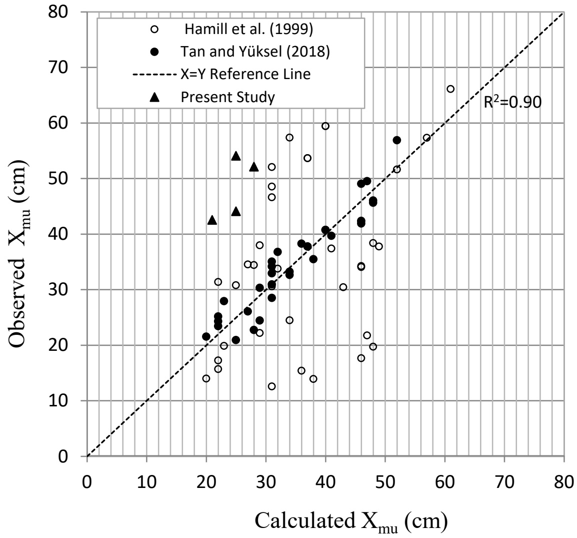


Figure 6. Comparison of the measured and maximum scour hole distance from the propeller face.

3.2. Vertical Wall Conditions

In this section, the experimental conditions were designed such that a berthing structure was placed in front of the single propeller, as specified in Table 1. The quay wall positioned directly opposite the single propeller jet stream confined the jet mechanism, leading to differences in the resulting scour profiles compared to those observed under unrestricted single propeller effects.

The location and magnitude of the maximum scour hole were found to vary depending on the presence or absence of the structure under identical conditions. The influence of the wall positioned in front of the propeller was further investigated by varying the distance between the propeller and the structure (X_w). In this study, the distances were set to X_w =2D_p, 3D_p, 5D_p, where D_p represents the propeller diameter. For each distance setting, different propeller gaps (G=10 and 15) and rotational speeds (n=355 and 470 rpm) were tested. A total of 12 experimental sets were conducted to comprehensively evaluate the effect of these parameters on scour development.

The results of this investigation provide insights into how structural constraints influence scour mechanisms, highlighting the impact of wall proximity and propeller operational settings on scour formation. The scour profiles generated under the influence of the propeller jet with the presence of the wall were compared to those obtained under identical experimental conditions without the wall, as presented below. The comparison indicates that as the distance between the wall and the propeller increases, the maximum scour hole depth decreases. Furthermore, it was observed that the scour formation becomes more similar to the scour profile in the absence of the wall across all tested experimental conditions (Figures 7-10).

These findings suggest that the wall's proximity to the propeller significantly affects the scour characteristics. When the wall is positioned closer, the wall effect intensifies, leading to deeper scour holes. However, as the wall is moved further away, the flow pattern becomes less restricted, resulting in scour profiles that resemble those observed without the presence of a structure. This behavior was consistently observed across all experimental scenarios, highlighting the influence of structural placement on scour development.

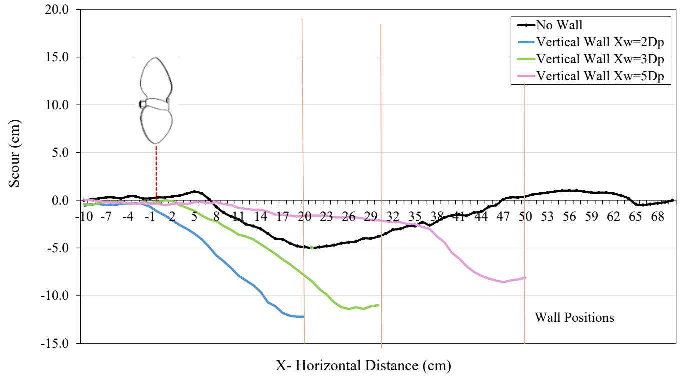


Figure 7. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 10 cm, n=355 rpm).

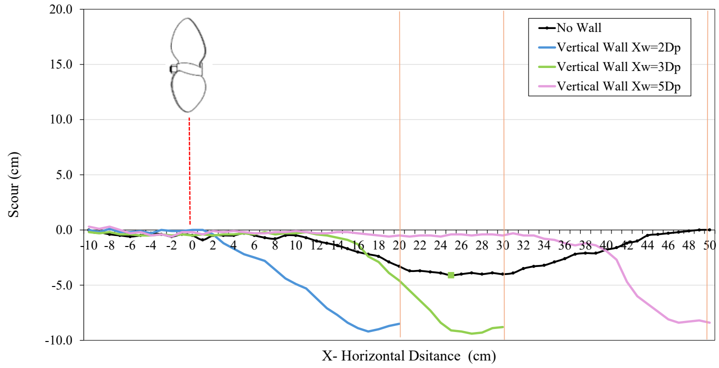


Figure 8. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 15 cm, n=355 rpm).

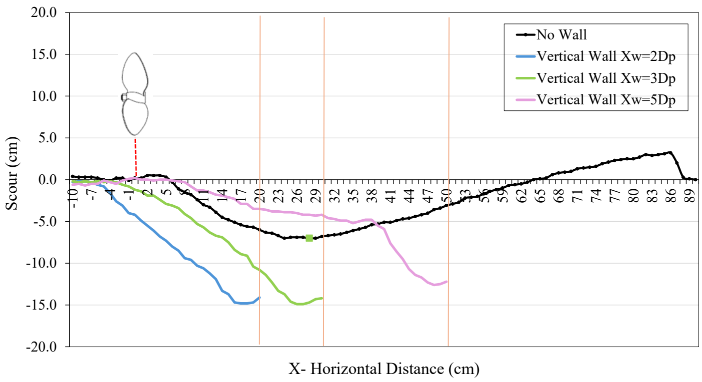


Figure 9. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 10 cm, n=470 rpm).

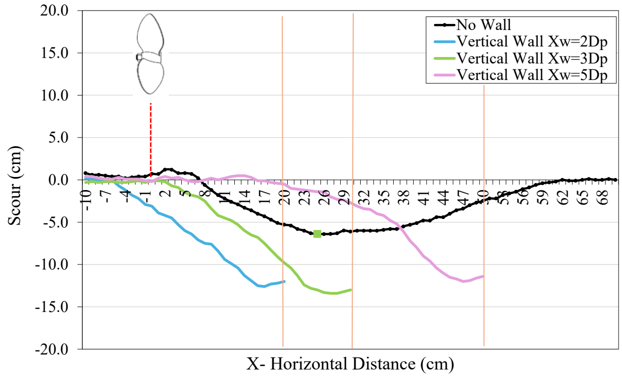


Figure 10. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 15 cm, n=470 rpm).

3.3. Parallel Wall Conditions

The scour formation influenced by a wall structure positioned parallel to the single propeller axis was examined, as shown in Figures 11-14. The experiments were conducted for different distances between the wall and the propeller (Y_w=2D_p, 3D_p, 5D_p), with varying propeller gap values (G=10 and 15 cm) and rotational speeds (n=355 and 470 rpm). A total of 12 experimental conditions were tested to comprehensively analyze the effect of these parameters on the scour development.

In the no wall condition, the maximum scour depth (S_{max}) was found to be lower compared to cases where a wall was present. This trend was observed consistently across all tested wall positions. It was further observed that as the distance between the propeller and the wall increased, both the scour depth and the deposition height decreased. For example, at a distance of 2D_p, the maximum scour depth was=6.8 cm, whereas at 3D_p, it decreased to 3.8 cm.

Figure 12 presents a comparison between the no wall experiment and three different parallel wall placements relative to the propeller axis (2D_p, 3D_p, 5D_p). In this case, the propeller gap was set to 10 cm, and the rotational speed was 470 rpm.

In Figure 13, the no wall experiment is compared with the wall placed at different distances (2D_p, 3D_p, 5D_p). For these tests, the propeller gap was set to 15 cm, and the rotational speed was 355 rpm. Figure 14 presents the scour profiles for the no wall experiment and wall placements at 2D_p, 3D_p, 5D_p with a propeller gap of 15 cm and a rotational speed of 470 rpm. These results highlight the significant impact of wall placement on scour characteristics, emphasizing that greater distances between the propeller and the wall result in reduced scour depth and accumulation.

An analysis of the conditions illustrated in Figures 11-14 reveals that increasing the distance between the propeller and the seabed (G) results in a significant reduction in the maximum scour depth. This finding indicates that scour intensity decreases as the propeller is positioned further from the bed.

Furthermore, observations from Figures 11-14 show that higher propeller rotational speeds (rpm) lead to a corresponding increase in maximum scour depth. This trend underscores the direct relationship between propeller speed and the severity of scour formation.

As evident from these profiles, in the presence of a wall, the maximum scour occurs at the heel of the wall, resulting in greater scour depths compared to the no wall condition. This indicates that the presence of the wall intensifies the scour process due to the restricted flow conditions.

Furthermore, in cases where the ship propeller impacts the wall perpendicularly, it can be observed from the profiles that the jet flow impinging on the wall creates a more confined and concentrated scour effect. The interaction between the jet and the wall enhances the local turbulence and shear stress, leading to more pronounced scour formation in the vicinity of the wall compared to an unconfined scenario.

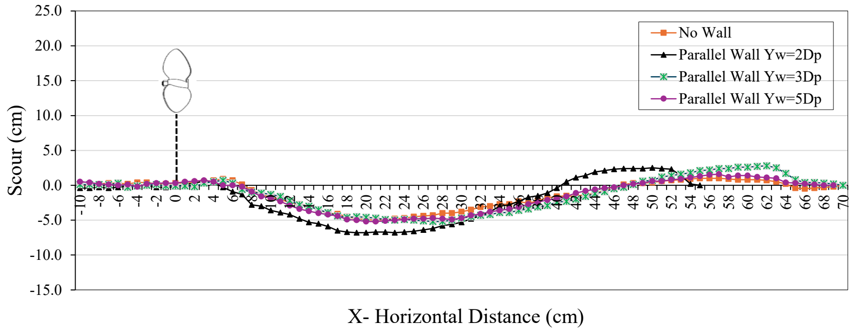


Figure 11. Comparison of the effects of no wall and parallel wall placement to the propeller axis on scour profiles under single propeller influence (D_p = 10 cm, G = 10 cm, n=355 rpm)

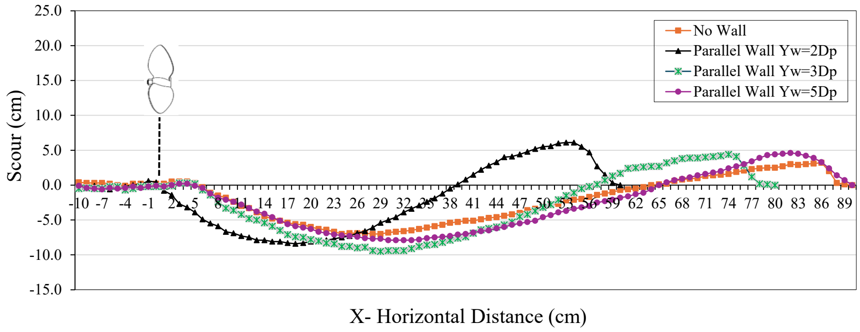


Figure 12. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 10 cm, n=470 rpm)

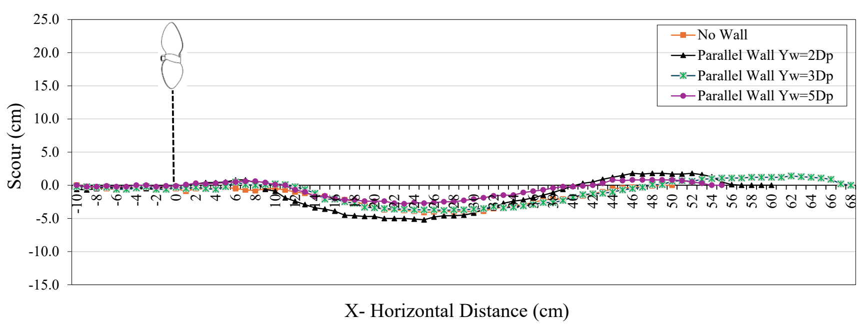


Figure 13. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 15 cm, n=355 rpm)

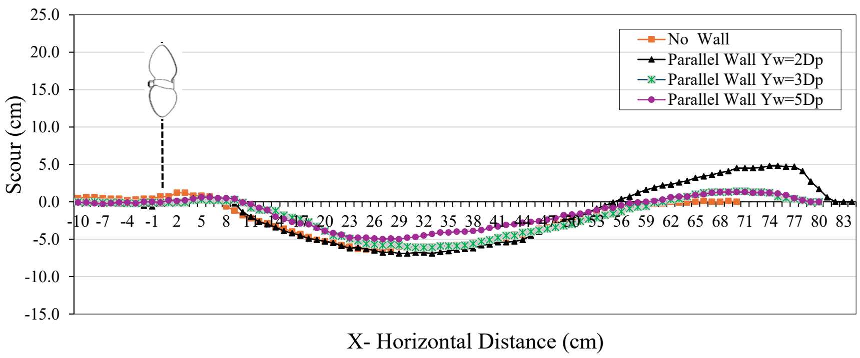


Figure 14. Comparison of scour profiles in front of a wall with unconfined (No-Wall) scour profiles under single propeller influence (D_p = 10 cm, G = 15 cm, n=470 rpm).

4. Conclusion

In this study, scour hole profiles generated by a 10 cm diameter Wageningen-B series ship propeller model at varying rotational speeds (355 and 470 rpm) and propeller-to-bed distances (G = 10 and 15 cm) were examined. Additionally, the scour mechanism induced by the ship propeller under different configurations, with and without the presence of a berthing structure, was investigated. For this purpose, the quay wall was positioned both perpendicular and parallel to the propeller axis. The effects of varying the distance between the structure and the propeller on scour hole formation were analyzed. This study aimed to determine how factors such as propeller rotational speed and propeller-to-bed distance influence scour under different berthing scenarios. In brief, the experimental findings can be summarized as follows:

- In the absence of a structure, the propeller gap and rotational speed were identified as critical parameters in scour formation. As the propeller-to-bed distance increased, the scour depth decreased, while higher rotational speeds resulted in deeper scour holes.
- When the quay wall was placed perpendicular to the propeller axis, the distance between the propeller and the wall significantly influenced the scour hole depth. It was found that as the distance increased, the depth of the scour hole in front of the wall decreased.
- The position of the propeller relative to the wall affected the scour profile. The development of the scour hole differed when the wall was placed parallel or perpendicular to the propeller axis.
- The experimental results for the parallel wall configuration demonstrated that the presence of a wall significantly increases the scour depth compared to the no-wall condition, with the maximum scour occurring at the heel of the wall due to flow confinement effects. Additionally, as the distance between the propeller and the wall increased, both the scour depth and deposition height decreased, indicating that greater separation reduces the impact of the propeller-induced flow on the seabed.

In addition to the findings obtained in this study, some recommendations are proposed for future research. This study considered a single bed material type and propeller diameter. Future studies could expand the scope by testing different bed material grain sizes and propeller diameters. Future studies could also investigate combine configurations of these structures analyze the resulting scour patterns. These findings contribute valuable insights into the design of quay walls and berthing strategies, supporting the development of safer berthing zones and more efficient maintenance planning for port infrastructure.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Research and Publication Ethics Statement

The authors declare that they comply with all ethical standards.

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