A Study of The Shallow Water Effect on The Ship Resistance and Squat

(Case Study :TUKS Tuban)

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Accepted on November 19, 2024
Approved on January 16, 2025

***Abstract*— The large tides have a significant effect on the safety of the ship. Ships sailing in shallow waters due to large tides can cause increased resistance values and allow ships to squat. At TUKS Tuban, the depth of seawater from the seabed to the surface is about 8 m which must be passed by a ship with a draft of 6.7 m, so an analysis is needed to compare the resistance value of the ship when sailing in deep water with shallow water using Computational Fluid Dynamics (CFD) simulation and to find out how much the ship's bottom drops due to squat. Resistance analysis has been done on a Platform Supply Vessel (PSV) with a displacement of 6892 tons using CFD simulation based on Reynolds-Averaged Navier-Stokes Equation (RANSE). This study focused on three depth variations, 32 m, 16 m, and 8 m, each depth simulated at six speed variations, 8 knots, 10 knots, 12 knots, 14 knots, 16 knots, and 18 knots. Squat analysis has been done based on the CFD simulation results. The simulation results using CFD method show that the ship sailing at 8 m depth produces greater resistance compared to the ship sailing at 16 m depth at all speed variations. Based on the CFD simulation results, the pressure value at the bottom of the ship that operated at a depth of 8 m at speeds of 14 knots, 16 knots and 18 knots has decreased, thus at this speed when the ship sails in waters with a depth of 8 m, it has the possibility to experience grounding due to squat.**

Index Terms—Computational Fluid Dynamics (CFD);* PSV, *Shallow Water, Ship Resistance, Squat

I. INTRODUCTION

Ocean transportation has become an ideal choice for transporting goods in international trade as it offers large capacity and low cost. In 2015, more than 80% of international trade was transported by ships [1]. However, events such as the stranding of MV EVER GIVEN, one of the world's largest container ships, on March 23, 2021 in the Suez Canal emphasize the enormous challenges faced by ships when sailing in narrow and shallow waters [2]. The grounding of the ship for more than 6 days hampered the traffic of other vessels in the Suez Canal, and caused an estimated loss of billions of dollars [3]. The limited depth and width of the waters were factors influencing the stranding, which significantly affected the ship's maneuverability and increased the risk of a Squad [4].

Similar to ships which operate in restricted waters such as when crossing the Suez Canal, Platform Supply Vessels (PSV) perform a vital role in supplying logistics for offshore facilities [5]. PSV act as couriers to deliver goods and equipment to and from offshore facilities such as oil drilling rigs. PSVs often have to operate in dangerous waters, including shallow and narrow waters, increasing the risk of squads [6][7].

The phenomenon of Squad Effect occurs when waves from the hull of a ship collide with the seabed, causing the vessel to submerge to a greater extent and risk making contact with the seabed, particularly when sailing at a certain velocity [8].

Squat effect analysis can be performed using experimental or numerical methods by utilising Computational Fluid Dynamics (CFD) software, which offers better efficiency in terms of cost and time [9][10]. CFD allows detailed analysis of the fluid flow that occurs on ships while sailing in various waters, including shallow waters. In this study, the focus is on the use of CFD software for the analysis of fluid flow around a PSV vessel as it traverses shallow waters. The objective is twofold: firstly, to identify potential squads, and secondly, to study the effect of PSV operations in shallow waters on changes in vessel resistance values.

II. METHOD

A. *Numerical Modelling and Dimension of PSV*

CFD simulations were conducted using a full-scale or 1:50 model (Figure 1) to analyze the total drag and pressure on the ship's bottom at speeds of 8 knots, 10 knots, 12 knots, 14 knots, 16 knots, and 18 knots. These simulations were conducted at water depths of 8 m and 16 m, corresponding to full-scale conditions. The dimensions of the full scale ship are specified in Table 1.

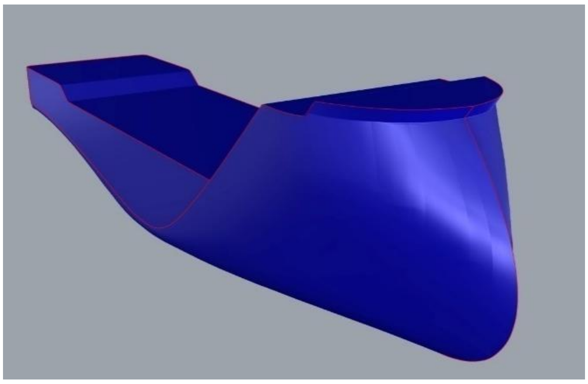

Fig. 1. PSV 3-Dimension Model

TABLE I. TABLE STYLES

	Value	*Unit*
Length over all	83.4	m
Length perpendicular	76.5	m
Breadth	18	m
Height	8.0	m
Draugth	6.7	m
Displacement	6892	ton

B. *Numerical Properties and Setup*

The simulation is expressed using CFD based Navier-Stokes Equation are used to describe the movement of fluids, taking into account factors such as pressure, viscosity, and external forces [11].

In this study, the simulation boundary conditions are shown in Table 2. Boundary conditions are necessary to define the simulation conditions around the PSV model. This definition is employed to generate a simulation that corresponds to the actual situation.

TABLE II. BOUNDARY CONSTAIN

Boundary	*Definition*
Inlet (to determine how fluid flow enters a domain)	- Velocity of fluid base on service speed of ship (PSV) - Intensity Length Scale 5%
Outlet (to define how the fluid outflow of the domain)	Static pressure
Opening (the simulation is defined as an open flow)	Static pressure with zero gradient of turbulence
Wall of Boundary	Free slip
PSV 3D Model	No slip

C. *Grid Generator*

This study has used unstructured grids due to PSV shape. The unstructured grids that are more flexible and can conform to complex shapes as shown in Figure 2.

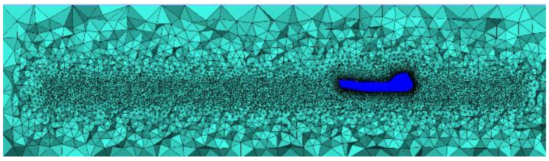

Fig. 2. Unstructured Grid for PSV Model

III. RESULT AND DISCUSSION

A. *Mesh Validation*

The objective of mesh validation is to identify the optimal number of meshes with efficient running time. This mesh validation simulation was executed at a velocity of 14 knots at a water depth of 16 meters to obtain mesh validation. The quantity of meshes utilized exerts a substantial influence on the calculation of total resistance and total pressure. The optimal mesh size is determined by gradually decreasing the mesh size until the simulation results no longer show significant changes.

TABLE III. MESH VALIDATION BASED ON TOTAL RESISTANCE

	Number of element	*Total Resistance*	*Difference*	*Running timr*
Mesh 1	1,843,605	5.559 kN	-	4h41m
Mesh 2	2,293,908	5.189 kN	6.65%	5h34m
Mesh 3	2,625,171	5.181 kN	0.15%	6h49m

According to the results of the mesh validation, as shown in Table 3, the difference in total resistance between Mesh 2 and Mesh 3 is 0.15% less than 2%. Therefore, Mesh 2 is selected for simulating all cases in this study.

B. *Total Resistance*

CFD simulations were performed using a unstructured mesh with a total mesh of approximately 2.2 million elements. In the CFD simulation, the RANS equation was applied as a mathematical model with K-Epsilon as the turbulence setting and it has been determined that 10^{-5} is the convergence limit. The results obtained from CFD simulations are the total resistance at a depth of 8 m and 16 m at the model scale. To determine the total resistance at full scale, an extrapolation process is carried out. The extrapolation results are shown in tables 4 and 5.

C. *Total Pressure*

As was the case with the total resistance at depths of 8 m and 16 m at model scale, the total pressure obtained from CFD simulations is also the total pressure at model scale. Therefore, it is necessary to extrapolate to determine the total pressure at full scale are shown in tables 6 and 7.

TABLE IV. TOTAL RESISTANCE AT 16 M DEPTH

Froude Number (Fr)	*Speed (knot)*	*Total Resistance Coefficient (Ct)*	*Total Force Ship (kN)*
0.156	8	0.611	219
0.193	10	0.616	301
0.230	12	0.622	411
0.267	14	0.628	649
0.303	16	0.631	758
0.340	18	0.632	1082

TABLE V. TOTAL RESISTANCE AT 8 M DEPTH

Froude Number (Fr)	*Speed (knot)*	*Total Resistance Coefficient (Ct)*	*Total Force Ship (kN)*
0,156	8	0.641	295
0,193	10	0.656	425
0,230	12	0.662	602
0,267	14	0.674	815
0,303	16	0.678	1370
0,340	18	0.682	1878

TABLE VI. TOTAL PRESSURE AT 16 M DEPTH

Froude Number (Fr)	*Speed (knot)*	*Total Pressure Coefficient (Cp)*	*Total Pressure Ship (kPa)*
0,156	8	0.311	8.93
0,193	10	0.311	8.93
0,230	12	0.308	8.91
0,267	14	0.298	8.88
0,303	16	0.291	8.79
0,340	18	0.288	8.69

TABLE VII. MESH VALIDATION BASED ON TOTAL RESISTANCE

Froude Number (Fr)	*Speed (knot)*	*Total Pressure Coefficient (Cp)*	*Total Pressure Ship (kPa)*
0,156	8	0.111	2.31
0,193	10	0.101	2.26
0,230	12	0.0998	2.11
0,267	14	0.0958	1.96
0,303	16	0.0931	1.63
0,340	18	0.0918	1.27

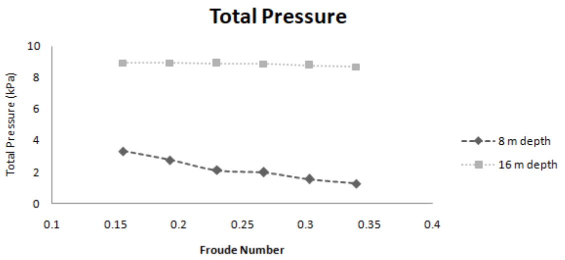

Fig. 3. Total Pressure at 8 m and 16 m of depth

As illustrated in Figure 3, the variation in total pressure is depicted as a function of depth and variations in ship speed. At a depth of 16 meters, there is no substantial change in total pressure at any given speed. In contrast, at a depth of 8 meters, the total pressure shows a significant change. Ships operating at a depth of 8 m at speeds between 14 and 18 knots (Fr 0.26 - 0.34) are at risk of squatting due to a significant decrease in total pressure.

IV. CONCLUSION

Two significant phenomena occur when a vessel navigates in shallow waters: an increase in the total resistance value and a decrease in total pressure at the bottom of the ship.

- The rise in resistance is due to an increase in fluid flow within the narrow space between the ship's bottom and the seabed, which is a distance of 1.3 meters. This increased in fluid velocity leads to an increased coefficient of frictional resistance, thereby becoming a contributing factor to the rise in resistance value.
- The phenomenon of a pressure drop in the space between a ship's bottom and the seabed can be explained by the principles of hydrodynamics and Bernoulli's principle. The narrowness of this gap, which increases the fluid flow velocity, results in a decrease in pressure.

ACKNOWLEDGMENT

We would like to thank everyone who played a role in this research, particularly the Vocational College, whose support and facilities made this research smooth and ensured the paper's timely publication.

REFERENCES

[1] Lee, Jade Man-yin, and Eugene Yin-cheung Wong. "*Suez Canal blockage: an analysis of legal impact, risks and liabilities to the global supply chain*", MATEC web of conferences, Vol. 339, EDP Sciences, 2021.

[2] Maljkovic, M., Pavic, I., Mestrovic, T., & Perkovic, M., “*Ship Maneuvering in Shallow and Narrow Waters: Predictive Methods and Model Development Review*”, Journal of Marine Science and Engineering, 12(8), 1450, 2024.

[3] Jie, Luo, Sun Hao, and Zhang Peng. "*The scheme of re-floating a grounded vessel and risk analysis based on MV*

Ever Given", American journal of traffic and transportation engineering: 51-55, 2022.

[4] Matonin, A., Penkovskaya, K., Menshikov, V., "*Organizing effective ship emergency squad subject to expenses on equipment and personnel trainin*", Vestnik of Astrakhan State Technical University. Series: Marine engineering and technologies, 2020(1), 54-59, 2020.

[5] Silva, V., Wang, A., Filho, V., et al., "*Routing and scheduling of platform supply vessels in offshore oil and gas logistics*", Computers and Operations Research, 164, 2024.

[6] Sagin, S., Karianskyi, S., Sagin, S., et al., "*Ensuring the safety of maritime transportation of drilling fluids by platform supply-class vessel*", Applied Ocean Research, 140, 2023.

[7] Vieira, G., Pereira, D., Taheri, S., et al. "*Optimized Configuration of Diesel Engine-Fuel Cell-Battery Hybrid Power Systems in a Platform Supply Vessel to Reduce CO2 Emissions*", Energies, 15(6), 2022.

[8] Briggs, M., Kopp, P., Ankudinov, V., et al. "*Comparison of measured ship squat with numerical and empirical methods*", Journal of Ship Research, 57(2), 73-85, 2013.

[9] Huynh, V., Tran, G., "*Improving the accuracy of ship resistance prediction using computational fluid dynamics tool*', International Journal on Advanced Science, Engineering and Information Technology, 171-177, 2020.

[10] Feng, D., Ye, B., Zhang, Z., et al., "*Numerical simulation of the ship resistance of kcs in different water depths for model-scale and full-scale*", Journal of Marine Science and Engineering, 8(10), 1-25, 2020.

[11] KumarPatel, P., Premchand, M., "*Numerical Investigation of the Influence of Water Depth on Ship Resistance*", International Journal of Computer Applications, 116(17), 10-17, 2015.