

Investigation of the motions and added resistance of dhow vessel in regular head waves using CFD method

Abouzar Ebrahimi^{1*}, Reza Dorostkar², Abuzar Abazari³

^{1*} Assistant Professor, Chabahar Maritime University; Ab_ebrahimi@cmu.ac.ir

² Marine Engineering Department, Sharif University of Technology; rezadorostkar.bnd@gmail.com

³ Associate Professor, Chabahar Maritime University; Abazari@cmu.ac.ir

ARTICLE INFO

Article History:

Received: 07 MAY 2025

Accepted: 19 NOV 2025

Keywords:

Dhow Vessel

CFD

Added Resistance

Regular Waves

ABSTRACT

Dhow vessels are among the earliest traditional vessels employed for fishing and transporting goods in some countries around the Indian Ocean and Persian Gulf for many years. So far, no research has been done on the hydrodynamics and resistance of these vessels, and the body form of these vessels has been designed in a totally classical and experimental way. One of the most critical issues in the hydrodynamic design and safety of vessels is the added resistance to waves. In this research, the effect of different waves on the hydrodynamic resistance of a dhow vessel has been numerically investigated. The numerical method used in this research is computational fluid dynamics, and StarCCM software was used for this purpose. KCS model results were used to validate CFD results, and finally, the added resistance of the dhow vessel in waves with different lengths and 3 wave heights was investigated. Results show that at short and long wavelengths, the added resistance is lower than at moderate wavelengths. Also, for all three wave heights, the maximum added resistance occurred at a wavelength ratio of 1.8.

1. Introduction

The word dhow or 'Lenj' in Persian, is used for various types of traditional sailing vessels with one or more masts with sails found in the Indian Ocean, Red Sea, Persian Gulf and the Oman Sea [1]. Nowadays, diesel engines and propellers are employed for the propulsion of dhows instead of sails. In Iran, Dhow vessels are also used for cargo transport and fishing. Often, dhows sail in areas with significant waves and the propulsion system cannot provide the thrust force necessary, so the waves overcome the vessel and ultimately cause it to break and sink. Consequently, it is necessary to evaluate the added resistance and motion of this vessel in waves. In the present research, the added resistance and motion of the dhow in the Persian Gulf waves have been investigated using a numerical method.

There has been no comprehensive study on the added resistance and motions of dhow vessels in the waves. Moreover, added resistance is important to commercial ships, including oil tankers and container ships, and there has been a lot of research on this topic. In the study by Storm-Tejsen et al [2] the added resistance in waves was studied experimentally for a vessel with a

60 series hull form. Pinkster [3] and Faltinsen [4] used the three-dimensional potential theory method to calculate the resistance in short waves on a floating structure and then compared the results with experimental results.

Moctar et al. [5] numerically calculated the added resistance of a 14,000 TEU containership and a medium size cruise ship in long and short waves of different frequencies. Sadat-Hosseini et al. [6] calculated the motions and added resistance of KVLCC2 model in short and long head waves by means of URANS and validated it with experimental data. Yu et al. [7] studied the added resistance and motions of the KVLCC tanker model under the impact of 14 regular waves have been investigated using experimental and computational methods. Ebrahimi et al. [8] studied the resistance of catamaran vessel using CFD method and investigated the effect of interference of demi-hull waves on total resistance.

In the study by Park et al. [9], the added resistance of a large tanker was estimated experimentally and numerically in an oblique sea with an angle of 0 to 180 degrees. The model tests were carried out in the SSPA

seakeeping basin. The results showed that the computational results were in good agreement with the experimental results.

Shivachev et al. [10] studied the added resistance and motion responses of KRISO container ship (KCS) at six different trim angles experimentally and numerically using CFD. Ship motions and added resistance were measured for several wavelength conditions considering short and long wave ranges with a wave slope of 1 to 60. Experimental and numerical results for pitch motions and added resistance were compared with CFD results and showed reasonable agreement with experimental data for ships in head waves.

In the study of Diaz et al. [11], they investigated experimentally and numerically a small fishing vessel. First, they tested a model in the towing tank, and their experimental and numerical results showed a good agreement. Using experimental and numerical results, they proposed a modified bow form that reduces vessel resistance by 10 percent.

In the study of Seif et al. [12], they numerically investigated the flow around the hull of a 500-tonne Dhow. In this research, they used ANSYS Fluent software to model the flow and calculate vessel resistance at different speeds.

2. Main Characteristics of Dhow Vessel

In this paper, we studied a model scale of a fishing dhow vessel with 130 tones displacement. The body plan view and 3D CAD view of this vessel are shown in Figures 1 and 2, respectively. Also, the main dimensions of the full scale and model of dhow vessel are presented in Table 1. The COG of a full scale vessel is located about 10 meters from aft perpendicular and 2 meters above the keel.

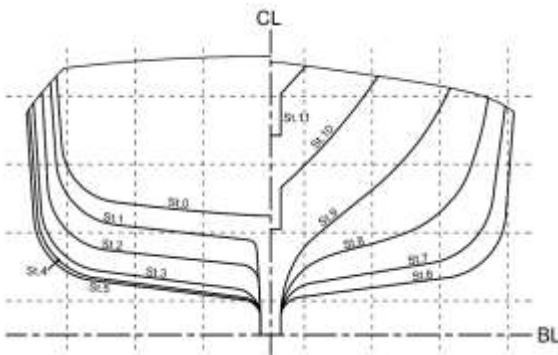


Figure 1. Body plan view

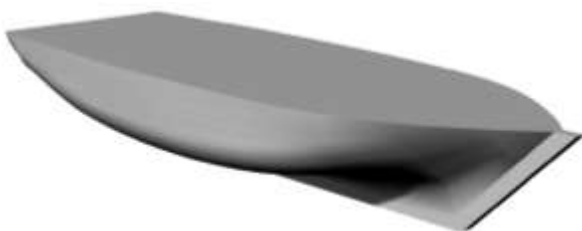


Figure 2. 3D CAD of dhow vessel

Table 1. Main dimensions of dhow vessel

Characteristic	Value	
	Full Scale	Model
Length (m)	21.1	0.95
Breath (m)	7.1	0.32
Height (m)	3.3	0.14
Draft (m)	2.2	0.1
Design Speed (m/s)	5.14	1.1

3. Numerical method

Nowadays, numerical methods are widely used to study the hydrodynamics of vessels. The reason for this is the low cost and availability of this method compared to the experimental method. Computational fluid dynamics is one of the most widely used numerical methods, which uses finite volume methods (FVM) to discretize the governing equations.

The equations to be solved in CFD method are the incompressible Navier–Stokes equations. The references for this method are Versteeg and Malalasekera [13] and Moukalled et al. [14]. To simulate turbulent flow, three general methods can be employed; Reynolds-Averaged Navier-Stokes Equations (RANSE), direct numerical simulation (DNS) and large eddy simulation (LES). Among these three methods, the RANSE method has a lower computation cost and has good accuracy. A RANSE method was used in the present study. Numerical models have been carried out in a three-dimensional, unsteady, turbulent flow mode. Navier-Stokes equations have been expressed as follows:

$$\rho \left(\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} \right) = \rho g - \nabla p + \mu \nabla^2 \vec{u} \tag{1}$$

In these equations, \vec{u} , g , p and μ are the velocity vector, gravitational acceleration, pressure and viscosity of the fluid, respectively. The flow around the ship hull is always turbulent and the main characteristic of these flows is the fluctuating flow field. Instead of directly modeling these equations, they can be simplified by the Reynolds averaging method, which is called RANS equations. Time-averaged equations are obtained in the following form:

$$\frac{\partial}{\partial x_i} (\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} (-\rho \overline{u'_i u'_j}) + \frac{\partial}{\partial x_j} \left[\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{2}{3} \delta_{ij} \frac{\partial u_l}{\partial x_l} \right]$$

In the above equations, the term $-\rho \overline{u'_i u'_j}$ shows turbulence effects and is called Reynolds stresses. Turbulence models are used to solve the equations

using Reynolds stresses according to known flow parameters [10].

Solution domain

Choosing the appropriate computational domain can lead to a reduction in solution time and ensure that the results are accurate. In this research, according to previous works, the dimensions mentioned Figure 3 have been selected for the solution domain.

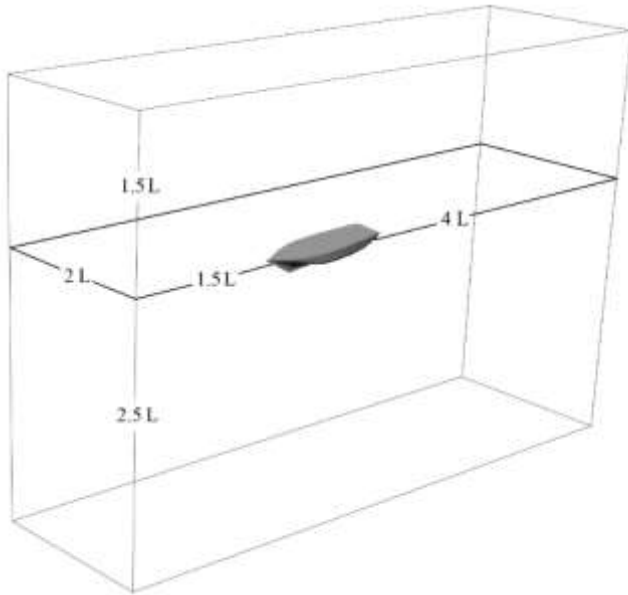


Figure 3. Computational domain dimensions

SST model with standard coefficients was chosen for the turbulence model. Table 2 shows the boundary conditions applied to the virtual towing tank and ship geometry. DFBI Morphing (dynamic fluid body interaction) was used to specify the ship's motion. Also, Volume of Fluid (VOF) flat waves were used to model the free surface.

Table 2. Boundary conditions

Boundary	Boundary Type
Dhow - Deck	Wall
Dhow - Hull	Wall
Tank - Bottom	Wall
Tank - Inlet	Velocity Inlet
Tank - Outlet	Pressure Outlet
Tank - Port Side	Symmetry plane
Tank - Starboard Side	Symmetry plane
Tank - Top	Velocity Inlet

3.1 Mesh generation

As a part of all numerical methods based on equation discretization, mesh generation is one of the most important steps. Even though, with the development of computers, there are fewer mesh size limitations than in the past, reducing computing costs has always been

one of the main objective of researchers. In this study, with reference to previous experiences, a trimmed cell mesh with 2.7 million cells was used for simulation of the vessel.

Also, Considering the two DOF of the vessel in waves, that is pitch and heave, to improve the simulation of ship motions, the overset mesh has been used for modeling the motion of the dhow vessel. In this method, the domain is composed of two parts, the overset region and the background, where the overset region slides over the background region. The details of this grid is shown in Figure 4.

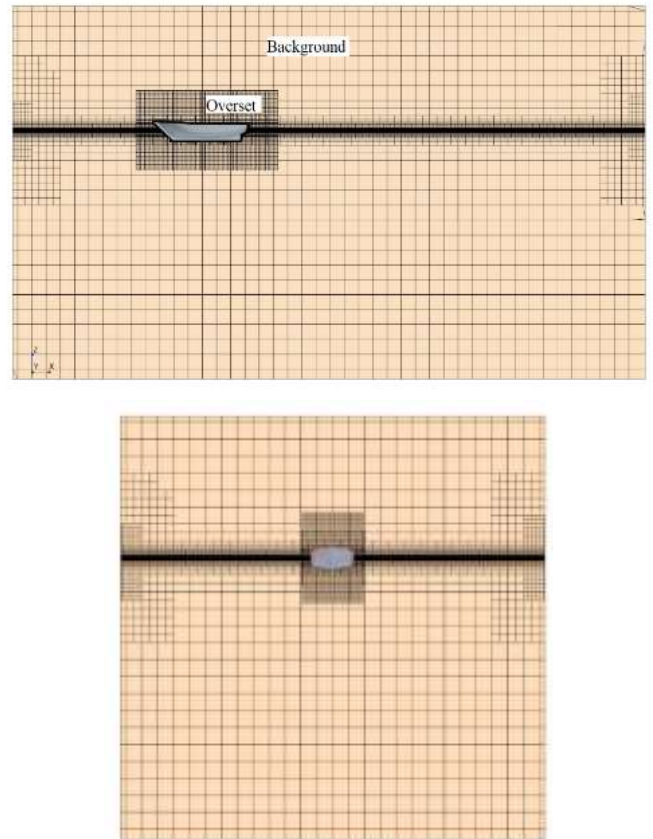


Figure 4. Mesh details of domain

3.2 Validation

After choosing the optimal grid and applying solver settings, it is required to validate the numerical results. To validate the present study results, KRISO container ship (KCS) resistance data was used. This ship is used in many numerical solution researches as a workbench to verify the results. SIMMAN workshop [15] presented an experimental data of this model and its resistance and motions under different wave conditions. Main geometric particulars of KCS model are given in Table 3.

Table 3. Main particulars of KCS ship model [15]

LBP (m)	6.0702
BWL(m)	0.8498

T (m)	0.2850
C_B	0.65
$\nabla (m^3)$	0.9571
U (m/s)	2.017

Figures 5 and 6 show the 3D CAD geometry and generated mesh for the KCS model.



Figure 6. CAD view of KCS container ship model

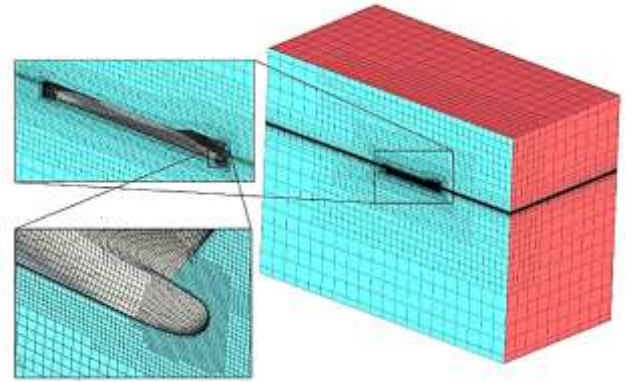


Figure 5. Details of mesh generated for KCS model

In Figure 7 the total resistance coefficient of KCS model in the present study is compared with experimental results of [15] in head waves with wave length (λ) of 11.84 m, wave height of 0.196 m and $\lambda/LBP=1.95$.

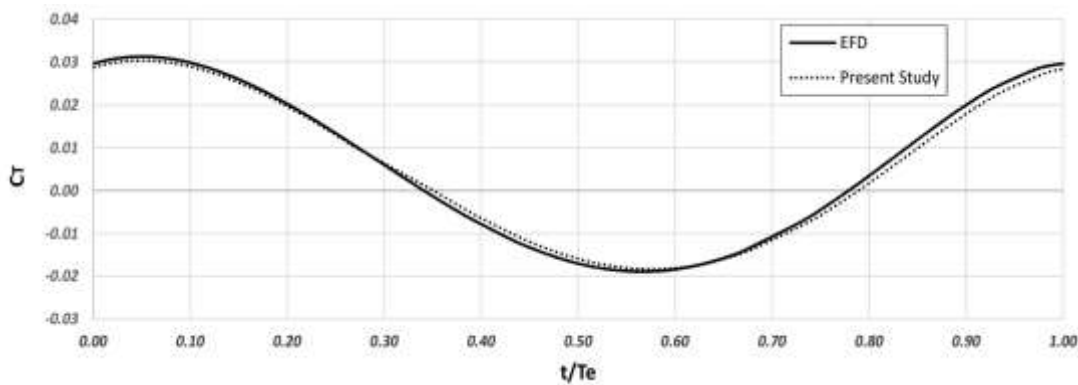


Figure 7. Validation of total resistance coefficient (C_T) for KCS ship

As shown in the above figure, the present study results are in reasonable agreement with experimental results. Therefore, we can use these mesh and solver settings to obtain the added resistance of the dhow vessel in different waves.

4. Added Resistance in Waves

The speed that a ship can achieve in calm water depends on its total resistance, propeller efficiency and engine power. In rough sea conditions, resistance may change due to forces imposed by waves and wind; and the resulting change in propeller load usually reduces propeller efficiency. Consequently, the ship's speed at a given engine power is usually reduced by these effects. This involuntary reduction of speed is often no more than two or three knots, but may result in significant financial losses for merchant ships.

A ship moving in regular waves will have oscillating resistance. In head waves, the mean value of resistance will be higher than calm water and the difference may

be attributed to waves. The total resistance (R_T) of the ship in waves can be written as:

$$R_T = R_c + R_{aw} \tag{3}$$

Where R_c is the ship resistance in calm water and R_{aw} is the wave added resistance.

In the present study, the movement of the dhow vessel has been investigated in several different regular waves. The characteristics of these waves are presented in the

Table 4. L_w/L is ratio of wave length to dhow model length.

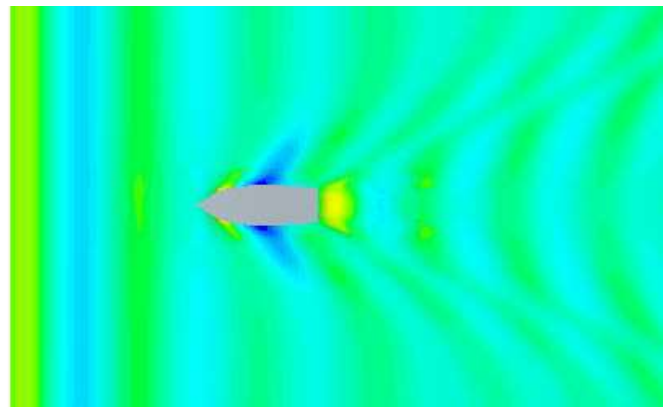
Table 4. Characteristics of waves

Wave No.	Wave height (cm), H	Lw/L
1	3	0.65
2	3	0.8
3	3	1.2
4	3	1.643
5	3	1.8
6	3	2
7	3	2.5
8	5	0.65
9	5	0.8
10	5	1.2
11	5	1.643
12	5	1.8
13	5	2
14	5	2.5
15	10	0.65
16	10	0.8
17	10	1.2
18	10	1.643
19	10	1.8
20	10	2
21	10	2.5

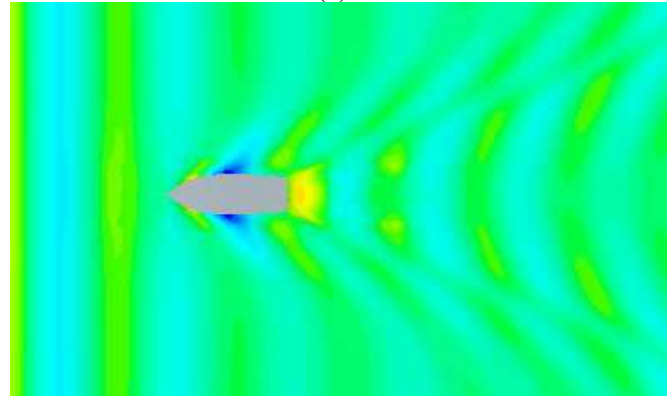
All numerical analysis was carried out in design speed of dhow vessel and all waves encounter the vessel in head sea state.

5. Numerical Results

In the following figures, the surface waves generated around the bow and stern of the dhow hull and the interference of these waves with regular head waves are displayed, at 2 wavelengths.

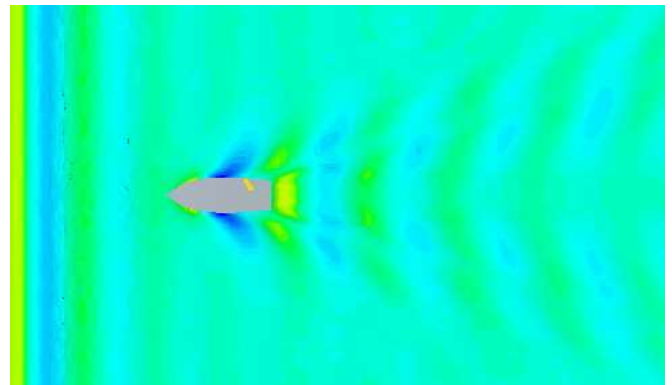


(a)

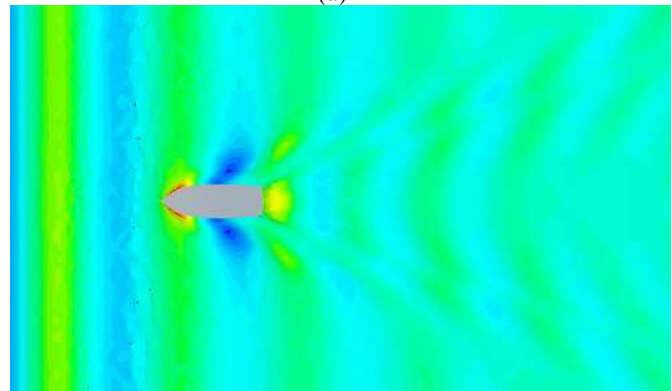


(b)

Figure 8. Waves elevation around ship for wave of H=3 cm; (a): Lw/L=0.65, (b): Lw/L=1.2

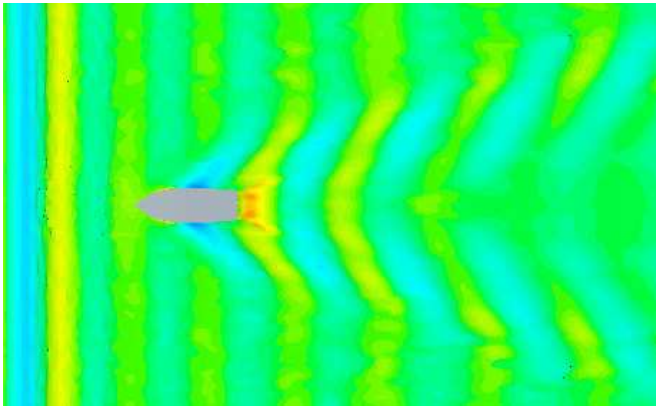


(a)

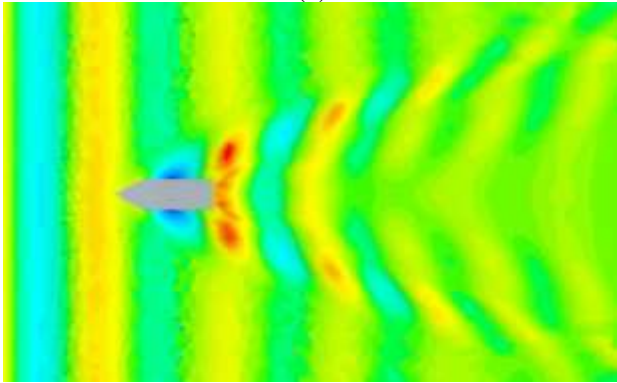


(b)

Figure 9. Waves elevation around ship for wave of H=5 cm; (a): Lw/L=0.65, (b): Lw/L=1.2



(a)

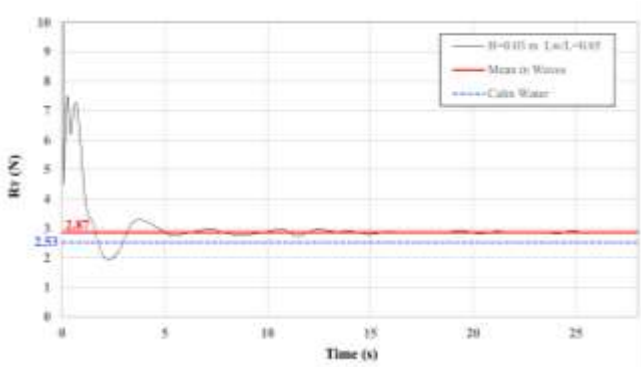


(b)

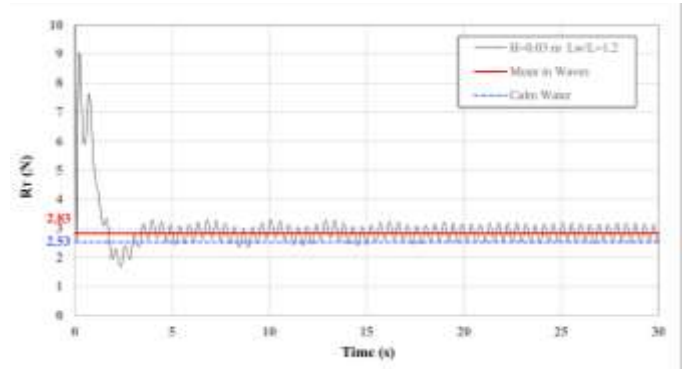
Figure 10. Waves elevation around ship for wave of $H=10$ cm; (a): $L_w/L=0.65$, (b): $L_w/L=1.2$

As can be seen in the figures, in higher waves, in some cases, the wave breaks on the vessel deck. Also, the interference between the sea waves and the hull generated waves is clearly evident, particularly at the aft of the vessel.

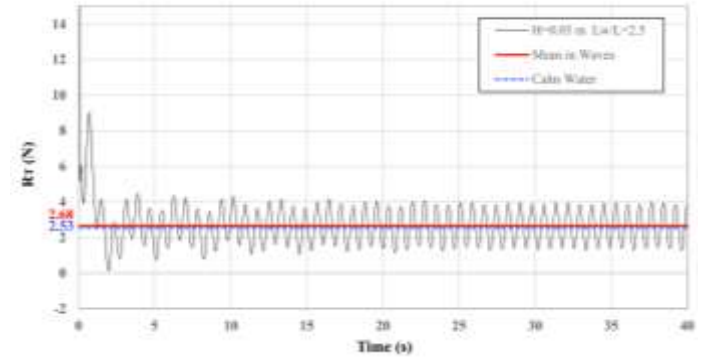
As the numerical modeling is done in an unsteady state, for checking the convergence of the numerical results, the time history of total resistance should be evaluated over time. After checking the resistance, it was observed that after about 35 seconds, the resistance reached a steady state and the solution could be stopped. The time history of total resistance for some waves is shown in the figures below. Also, the mean value of resistance in waves and calm water is shown in figures.



(a)

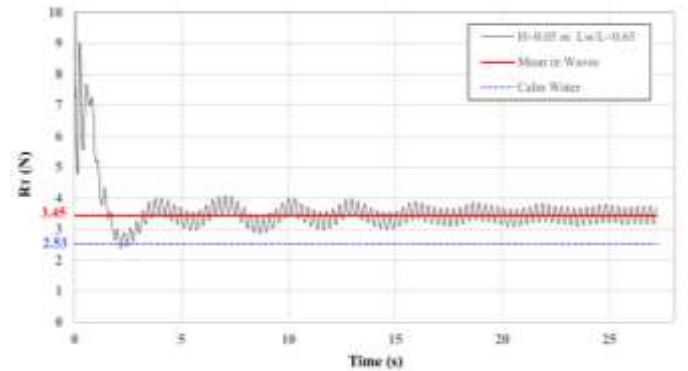


(b)

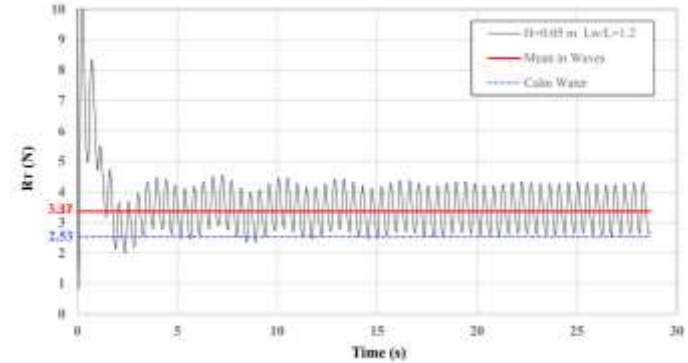


(c)

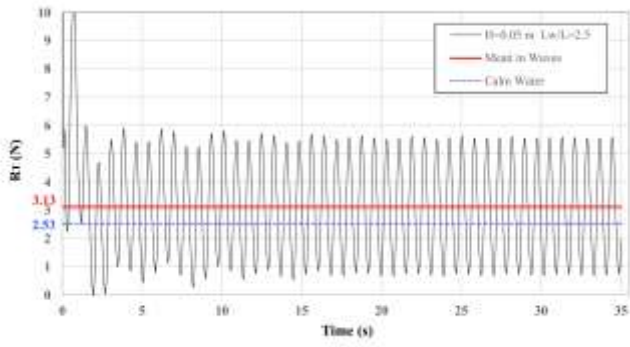
Figure 11. Comparison of ship total resistance in calm water and wave of $H=3$ cm; (a): $L_w/L=0.65$, (b): $L_w/L=1.2$, (c): $L_w/L=2.5$



(a)

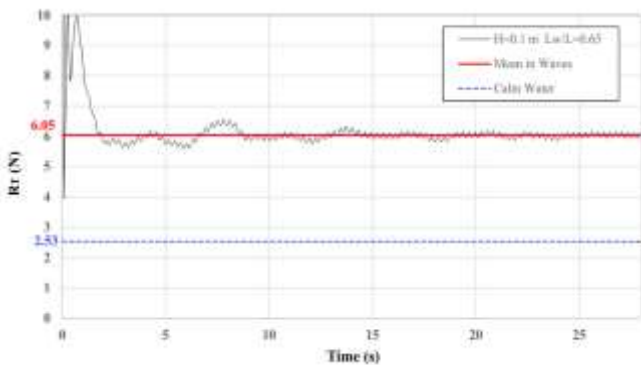


(b)

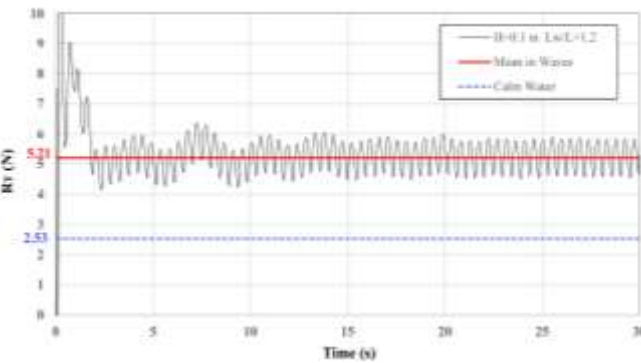


(c)

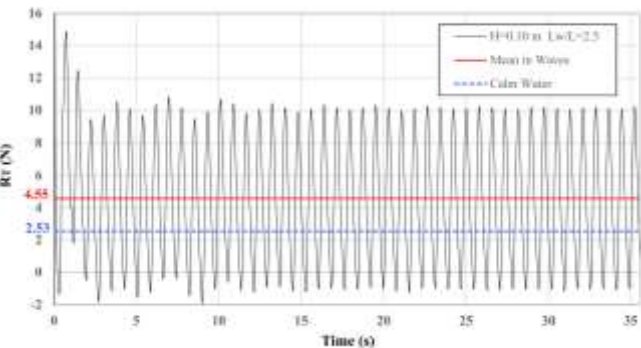
Figure 12. Comparison of ship total resistance in calm water and wave of H=5 cm; (a): Lw/L=0.65, (b): Lw/L=1.2, (c): Lw/L=2.5



(a)



(b)



(c)

Figure 13. Comparison of ship total resistance in calm water and wave of H=10 cm; (a): Lw/L=0.65, (b): Lw/L=1.2, (c): Lw/L=2.5

As can be seen, at short wave lengths, vessel resistance fluctuations are much less than at long wave lengths. At short wave lengths, vessel resistance is always

greater than calm water. The longer the wave length, the greater the maximum resistance, and the minimum resistance is less than in calm water.

To better examine the effect of waves on the resistance of vessel, the wave added resistance value for all waves is shown in the figure below.

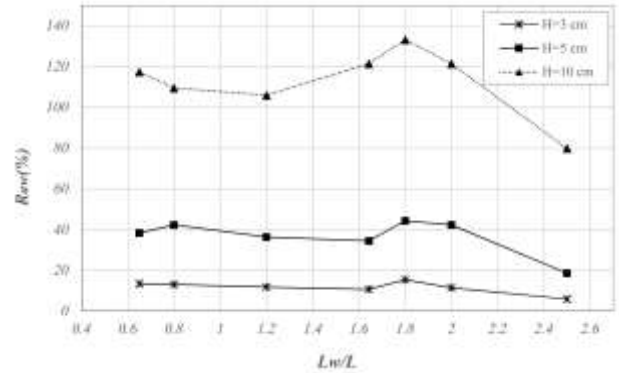
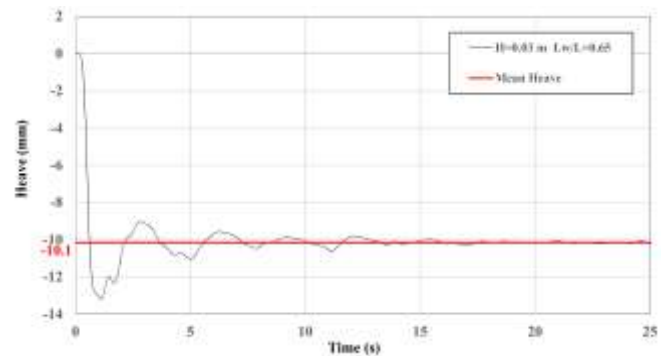


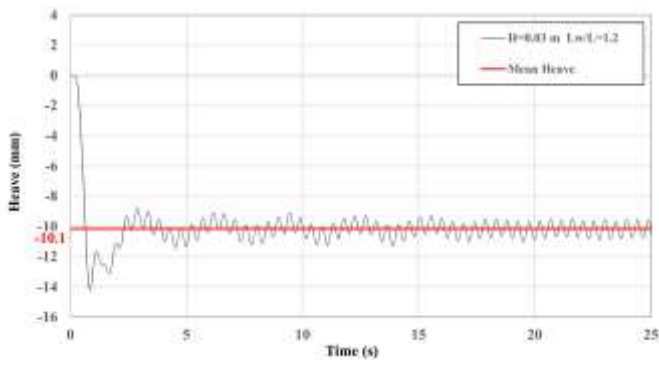
Figure 14. Added resistance of dhow vessel in all wavelengths

As can be seen, at short and long wavelengths, the added resistance is lower than at mean wavelengths (Lw/L between 1.6 and 2). For all three wave heights, the maximum added resistance occurred at a wavelength ratio of 1.8. The maximum added resistance of dhow vessel in wave heights of 10, 5 and 3 cm is 133 %, 44 % and 17 % respectively.

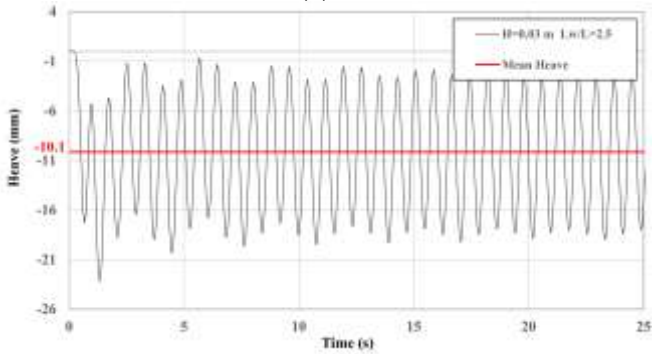
Heave is one of the most significant motions of a vessel in waves. This motion has a considerable effect on the added resistance of the vessel. Because this can result in an increase in the frictional and pressure resistance of the vessel. In the following, variations in the heave motion of the vessel at all 3 wave heights (for 3 different wavelengths) are shown.



(a)

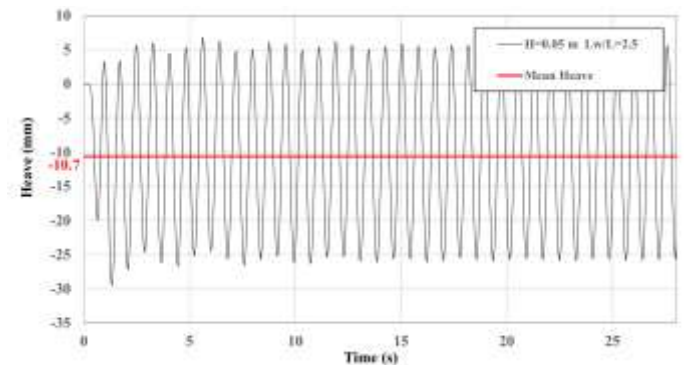


(b)



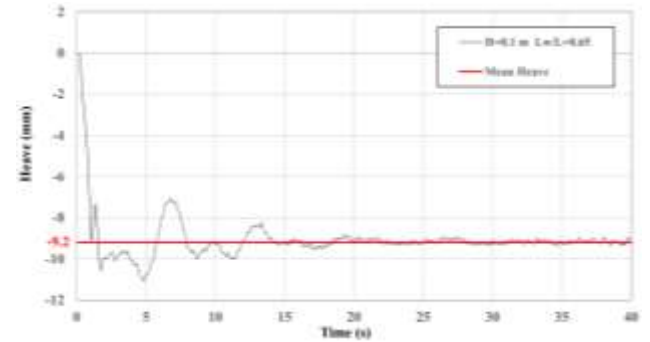
(c)

Figure 15. Heave motion of dhow vessel in wave of H=3 cm; (a): Lw/L=0.65, (b): Lw/L=1.2, (c): Lw/L=2.5

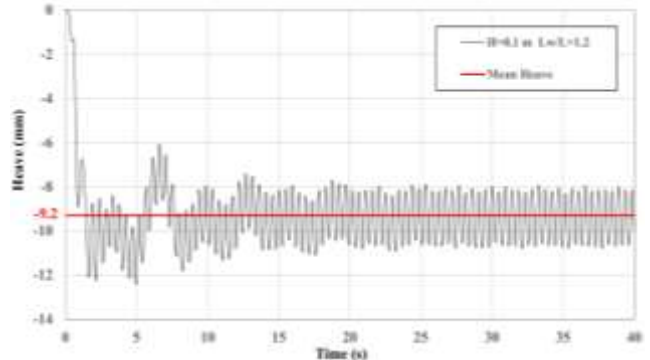


(c)

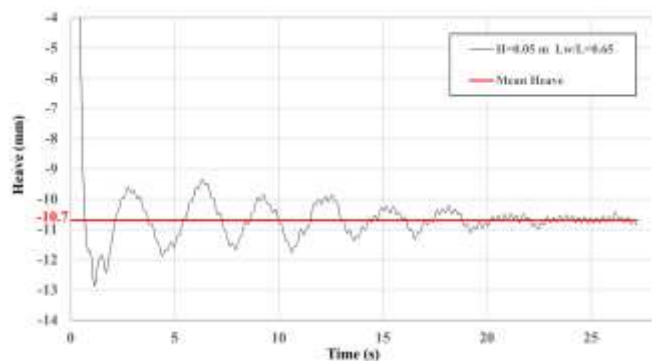
Figure 16. Heave motion of dhow vessel in wave of H=5 cm; (a): Lw/L=0.65, (b): Lw/L=1.2, (c): Lw/L=2.5



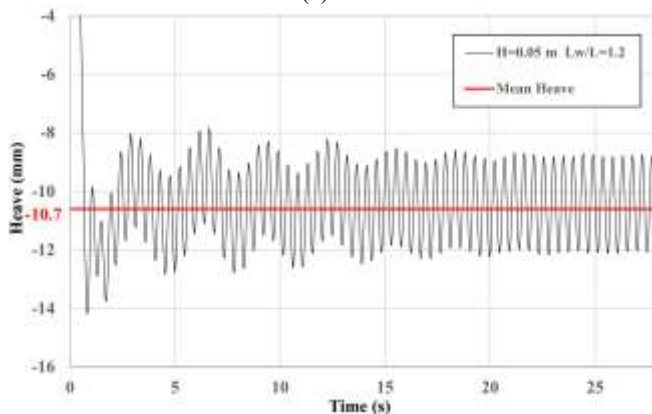
(a)



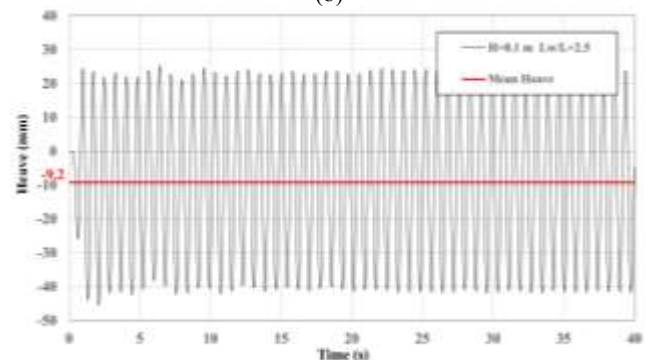
(b)



(a)



(b)



(c)

Figure 17. Heave motion of dhow vessel in wave of H=10 cm; (a): Lw/L=0.65, (b): Lw/L=1.2, (c): Lw/L=2.5

A study of the vessel's heave motion at different wavelengths and wave heights reveals the following:

- In all waves, the vessel suffers sinkage (increased draft) when encountering waves, which increases the

vessel's resistance, where for all waves, the mean heave is approximately 1 centimeter.

- Each wave height produces approximately the same mean heave at all wave lengths.
- The amplitude of heave motion is increasing with the increment in wave height and wavelength.

For further clarification of the effect of waves on vessel heave, the maximum heave of the vessel at different wave heights and wavelengths is shown in the Figure 18.

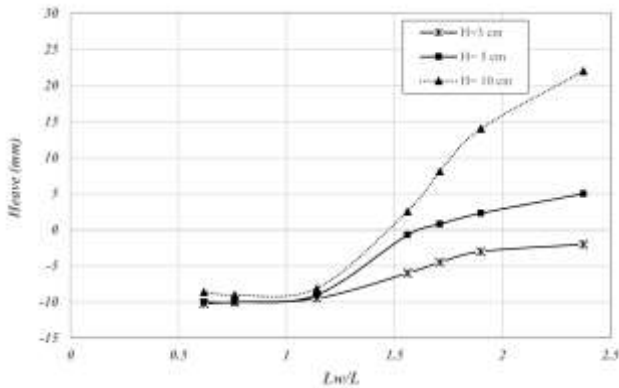


Figure 18. Maximum heave of dhow vessel at different wave conditions

As can be seen in the figure, the maximum heave of the vessel increases with increasing wave height.

6. Conclusions

This study was carried out in order to examine the effect of regular head waves on the added resistance of a dhow vessel. The vessel was numerically simulated at three different wave heights and several different wavelengths for each wave height, and the following results were obtained:

- As a result of encountering waves, the vessel suffers sinkage (increased draft), which increases its resistance, with a mean heave of approximately one centimeter for all waves.
- The mean heave produced by every wave length is approximately the same regardless of the wave height.
- In general, the amplitude of heave motion increases as wave height and wavelength increase.

When the height of the waves increases, the maximum heave of the vessel increases as well.

7. References

[1] Vosmer, T., 1997. Indigenous fishing craft of Oman. *International Journal of Nautical Archaeology*, 26(3): p. 217-235.

[2] Strom-Tejsen, J., 1973. Added resistance in waves. *Trans SNAME*, 81: p. 109-143.

[3] Pinkster, J., 1979. Mean and low frequency wave drifting forces on floating structures. *Ocean Engineering*, 6(6): p. 593-615.

[4] Faltinsen, O.M,1980. Prediction of resistance and propulsion of a ship in a seaway. *13th Symposium on Naval Hydrodynamics*, Tokyo.

[5] Moctar, O.e., et al., 2016. Numerical and Experimental Analysis of Added Resistance of Ships in Waves. *Journal of Offshore Mechanics and Arctic Engineering*, 139.(1)

[6] Sadat-Hosseini, H., et al., 2013. CFD verification and validation of added resistance and motions of KVLCC2 with fixed and free surge in short and long head waves. *Ocean Engineering*, 59: p. 240-273.

[7] Yu, J.-W., et al., 2017. Effect of ship motions on added resistance in regular head waves of KVLCC2. *Ocean Engineering*, 146: p. 375-387.

[8] Ebrahimi, A., M. Rad, and A. Hajilouy , 2014. Experimental and Numerical Studies on Resistance of a Catamaran Vessel with Non-Parallel Demihulls. *Scientia Iranica*, 21(3): p. 600-608.

[9] Park, D.-M., et al., 2019. Experimental and numerical studies on added resistance of ship in oblique sea conditions. *Ocean Engineering*, 186: p. 106070.

[10] Shivachev, E., et al., 2020. Impact of trim on added resistance of KRISO container ship (KCS) in head waves: An experimental and numerical study. *Ocean Engineering*, 211: p. 107594.

[11] Díaz-Ojeda, H.R., F .Pérez-Arribas, and S.R. Turnock, 2023. The influence of dihedral bulbous bows on the resistance of small fishing vessels: A numerical study. *Ocean Engineering*, 281: p. 114661.

[12] Seif, M.S. S.H. Sadat Hosseini, 2004. Numerical Solution of Viscous Flow around Dhow Vessel. 6th *Iranian Marine Industries Conference*, Tehran (In Persian).

[13] Malalasekera, W., H. Versteeg, 2007. An introduction to computational fluid dynamics. *Pearson education limited*.

[14] Moukalled, F., et al., 2016. The finite volume method. *Springer*.

[15] Workshop on Verification and Validation of Ship Manoeuvring Simulation Methods, 2008. <http://www.simman2008.dk/>