A SYSTEMATIC STUDY ON ROPES MODELLING OF THE INTERAC- TION FORCES BETWEEN A SAILING SHIP AND A SHIP MOORED AT A QUAY WALL WITH A COMPLEX GEOMETRY

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SUMMARY

This study aims to present the feasibility to model complex quay wall structures in ROPES, to obtain passing ship forces on a moored ship to be subsequently used in mooring analysis. As a case study, a composite quay wall is modelled. The quay consist of a submerged sheet pile, slightly deviating from vertical position, and whirl chambers constructed atop of the sheet pile. The whirl chambers are sloped spaces, subdivided by vertical walls placed along the berth line. The whirl chambers block the longitudinal flow, while they allow for emptying and filling the chambers by flows perpendicular to the berth line.

The quay model is built following a step-wise approach to control the results of modelling, to correct modelling inaccuracies and to gain confidence in the final results. Different test results and conclusions are presented, as well as unexpected behavior of ROPES as found for some parameters.

NOMENCLATURE

LOA	Length overall (m)
B	Beam (m)
d	Draught (m)
TAW	Reference level for vertical coordinates (like a bottom level, a water level)

1 INTRODUCTION

During the assessment of the safety of a moored ship it was necessary to determine the forces caused by a ship sailing in the port basin alongside of the moored ship. The purpose of the assessment was to define the limiting sailing ship speeds. The limiting sailing ship speeds were obtained by analyzing the responses of the moored ships that were to be obtained after feeding the passing ship forces into a dynamic mooring analysis software. The mooring analysis were to be performed with dynamic module of OPTIMOOR package, which is a rather simple version of DMA package, but it allows for rapid analysis of multiple cases. OPTIMOOR model has simple method of calculating passing ship forces, but only for very simple open water case and vertical wall case. More complex berth configurations put a question whether OPTIMOOR built-in models correctly approximate the passing ship forces.

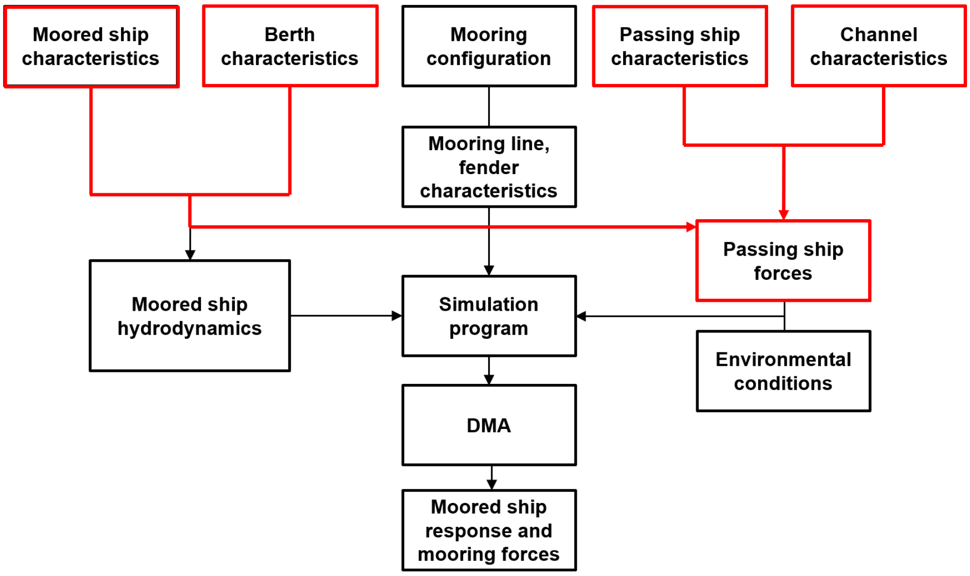

Figure 1. Project (responses of moored ship to passing ship forces) structure

The geometry of the berth is unusual, because it consist of a composite quay wall: a submerged sheet pile, slightly deviating from vertical position, and whirl chambers constructed atop of the sheet pile. The whirl chambers are sloped spaces, subdivided by vertical walls placed along the berth line. The whirl chambers block the longitudinal flow, while they allow for emptying and filling the chambers by flows perpendicular to the berth line. The cross section is presented in Figure 2.

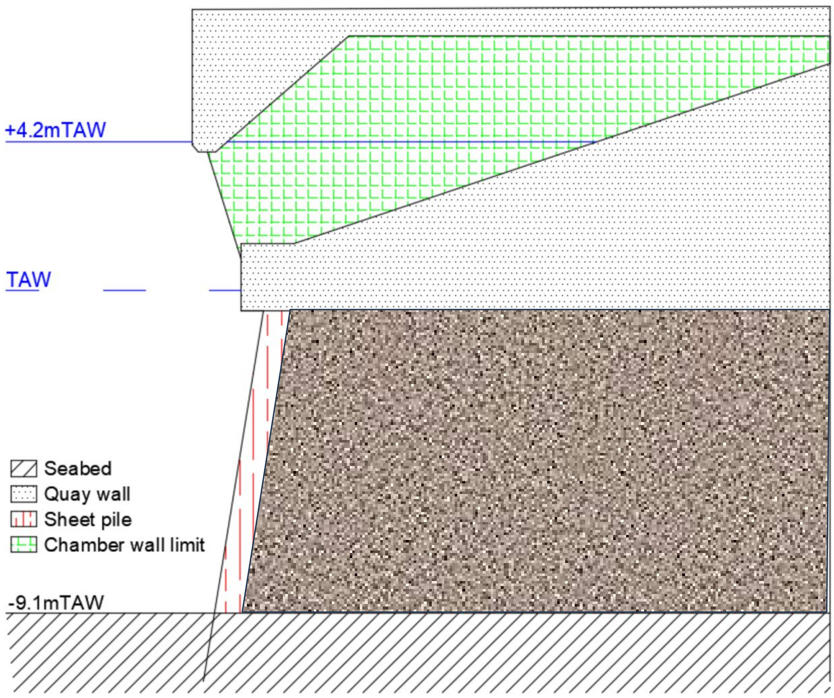

Figure 2. Cross section of the quay wall

ROPES package was developed to calculate interaction forces between sailing ships and between a sailing and moored ships. ROPES package is typically used for relatively simple geometries of the berths. However, it was also used for more complex situations, like modelling of groynes, submerged quays, passages between bridge pillars, berth pockets with conical connections to the basin slopes. This is why ROPES is also selected for modelling of this composite quay wall.

Different approaches can be followed to derive the passing ship forces on the moored vessel for this specific quay wall:

- CFD approach
- Increasing the distance between the moored ship and the wall, in the simple (vertical) quay wall model in ROPES
- More complex panel method in ROPES

The CFD approach is resource-consuming and is not suitable for providing data for mooring analysis involving larger number of sailing/passing ship combinations, with varying passing distance and passing speed, and when the mooring analysis is to be performed with OPTIMOOR package.
The increase of distance between the ship side and the quay wall is a heuristic approach, the increased volume between the ship side and the wall is to model the effect of the whirl chamber volume. The amount of the necessary distance increase is unknown and it is unknown whether the obtained forces would be a good approximation of the situation.
The last approach was chosen for the task. The panel models of the berth are developed sequentially, increasing the complexity of these models: a simple wall, a wall with slopes but without lateral baffles, and finally a wall with slopes and added lateral baffles. The development of the described final model is done stepwise to control the results of modelling, to correct modelling inaccuracies and to gain confidence in the final results. As a result, the final model captures all important components of the quay wall with whirl chambers as described.

2 OBJECTIVES

The objectives of the study include first the explanation of the modelling approach of the passing ship forces for a case of complex berth geometry consisting of a composite quay wall with a submerged sheet pile and whirl chambers. Then, the presentation of the sensitivity analysis of passing ship forces calculated for the different studied berth geometry models and panel sizes. Finally, the description of the quality check issues that appeared during the study for this complex berth modelling.

3 METHODOLOGY

3.1 PASSING SHIP FORCES MODEL ROPES

Passing ship forces exerted on the moored ship are obtained with the Software ROPES, developed by PMH (Pinkster Marine Hydraulics) for the prediction of ship-ship 6-degrees of freedom interaction forces in (shallow) water. The resulting time series of forces and moments can later be used in a dynamic mooring model.

Ships have significantly increased in size and number over the last decades. Ports and waterways are accommodating these ships and at the same time new terminals are designed in the existing infrastructure. In restricted water, the moored vessels can be strongly affected by hydrodynamic forces induced by passing ships. The Joint Industry Project (JIP) ROPES project was initiated to investigate these effects, to develop a numerical model for predicting these loads and to validate this model.

To this end, systematic scale model tests as well as extensive full-scale measurements were conducted. The research was conducted as a joint industry project (JIP) with the support of port authorities, terminal operators, vessel operators, engineering companies, suppliers of mooring equipment and research institutes, mainly led by MARIN, DELTARES, SVASEK and PMH (van den Boom et al., 2014). The detailed description of the ROPES software (equations, applications, constrains on the use) is given in PIANC publication (J.A. Pinkster, H.J.M. Pinkster, 2014), in IOP (J.A. Pinkster, 2004) and in SNAME paper (J.A. Pinkster, 2009).

The effect of passing ships is complicated to analyze as it involves complicated physics, as defined by Talstra and Bliek (2014), which include the following parameters:

- 3-D geometry of the port

- Bathymetry of the waterway
- Displacements and draughts of involved vessels
- Passing distance, and sailing ship trajectory wrt moored ship
- Passing speed

Note that in the ROPES model, the effect of passing vessel speed variations on the passing ship forces is accounted for during post-processing, by quadratic scaling of the forces and re-scaling of time points labelling these forces.

The ROPES computational tool assumes that the pressures originating from the passing vessel can be described by double body 3-D potential theory, so neglecting free surface effects, vorticity of fluid flow and viscous effects. The obtained results proved that ROPES compute the passing forces exerted on the moored ship accurately. Pinkster (J.A. Pinkster, M.N. Ruijter, 2004, J.A. Pinkster, 2009, J.A. Pinkster, 2004) developed two different methods to calculate passing ship forces – without and with accounting for free surface effects (the first is so called double body flow, while the second combines the first one and the diffraction analysis program). For relatively slowly ships sailing in a channel, when the moored ship is placed along the channel side, the results obtained separately by these two methods are practically the same, so the ROPES system implementing the double body flow model is judged as suitable one for the presented analysis. The second model (coupled double body and diffraction analysis) is used when the energy transfer via surface waves is important (channel-attached port basins or other channels where the soliton propagation is to be accounted for).

Vessels navigating in restricted waters create a pressure wave which is observed as a water draw down. When sailing in a shallow and narrows waterways, this effect can be relevant. The water level raises ahead of the vessel and the flow accelerates alongside the hull to fill up behind the vessel. When there is a ship moored in the waterway, this water dray down can create resonant horizontal motions and large loads in the mooring lines. Besides, this increase in motions may also imply a stop in cargo handing operations, such as using container cranes, loading arms for oil and LNG and automated dry bulk excavators that normally allow only limited horizontal vessel motions.

3.2 MODELING OF PASSING SHIP FORCES IN COMPLEX BERTH SITUATION

ROPES is considered adequate for this study for the following reasons:

- The critical aspect of the studied berth is a potential problem, accelerated flows, which makes it feasible to be modelled with the panel method.
- The berth is located along a channel side and it is therefore not required to use the coupling with a diffraction model like XBEACH, DIFFRAC or similar (cf. discussion above).

The channel (port basin) is modelled along a sufficient length in order to exclude the effect of the channel ends on the passing ship forces. The channel panel model includes both channel sides modelled with panels, while the channel bottom is considered to be a horizontal plane without panels to model it. The berth area model differs from the channel side model, and the berth area is modelled separately to capture the complex berth geometry. The more complex berth model is developed near the moored ship, a simpler model is used further from the berth. It is assessed that the details of the complex whirl chambers located far from the moored ship will have negligible effect on the flow near the moored ship and on the sailing ship.

The quay wall consist of an inclined sheet pile which continues up to the whirl chambers section. The final model of the quay geometry has been built in several steps, from an almost vertical wall, through a two slopes model, till the model with two slopes and the chamber walls blocking the longitudinal flow. This was done to control the modelling results by monitoring the trends in the results.
The whirl chambers are modelled on the quay segment only slightly longer than the length of the moored vessel (see Figure 10), considering that the flow acceleration outside of the berth is not affecting the results. The sizes of the panels was also decreased for the quay part with whirl chambers, comparing to the panels on the channel side outside of the berthing area.

For the quay and channel side models we used squared panels, as much as possible, to avoid the numerical problems related to high aspect ratios of rectangular panel sides; where it was needed we used triangular panels. The panel models of the vessel hulls were adopted from ROPES library of ships, and they were originally developed by ROPES authors (prof. Pinkster).

The results between the simple wall model and the whirl chambers model are expected to be similar in patterns of forces, while the differences are expected in peak forces. The lateral baffles of the whirl chambers are expected to block the longitudinal flow, so the longitudinal forces would be similar in cases of the wall-only model and whirl chambers model, while some flows may occur in the lateral direction, thus changing slightly the lateral and the yaw forces. It is so, because the volume of the whirl chambers is relatively small comparing to the volume of the whole water column along the ship between the ship side and the berth wall.

4 DATA

Figure 3 shows the geometry of the channel, fairway and berth as implemented in this case study. One side of the channel (marked black) is sloped, and the banks have two different slopes, and part of it is at angle to the channel axis. The other side of the channel (marked red) is straight, and it has the quay wall with whirl chambers.

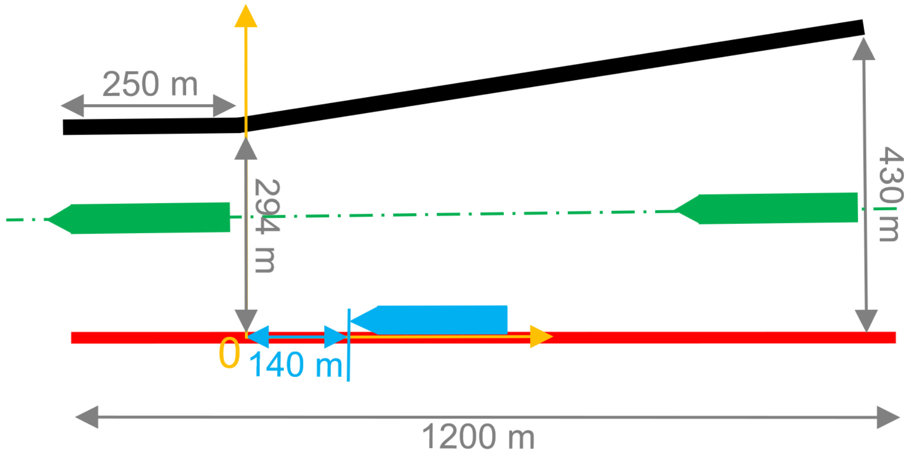

Figure 3. Sketch of the channel, fairway and moored vessel at berth

The bottom in the channel is modelled in ROPES as a horizontal plane, resulting in constant water depth of 13.3 m. The channel bottom level is at -9.1 mTAW and the still water level is at +4.2 mTAW. The cross section of the moored vessel at berth is presented in Figure 4.

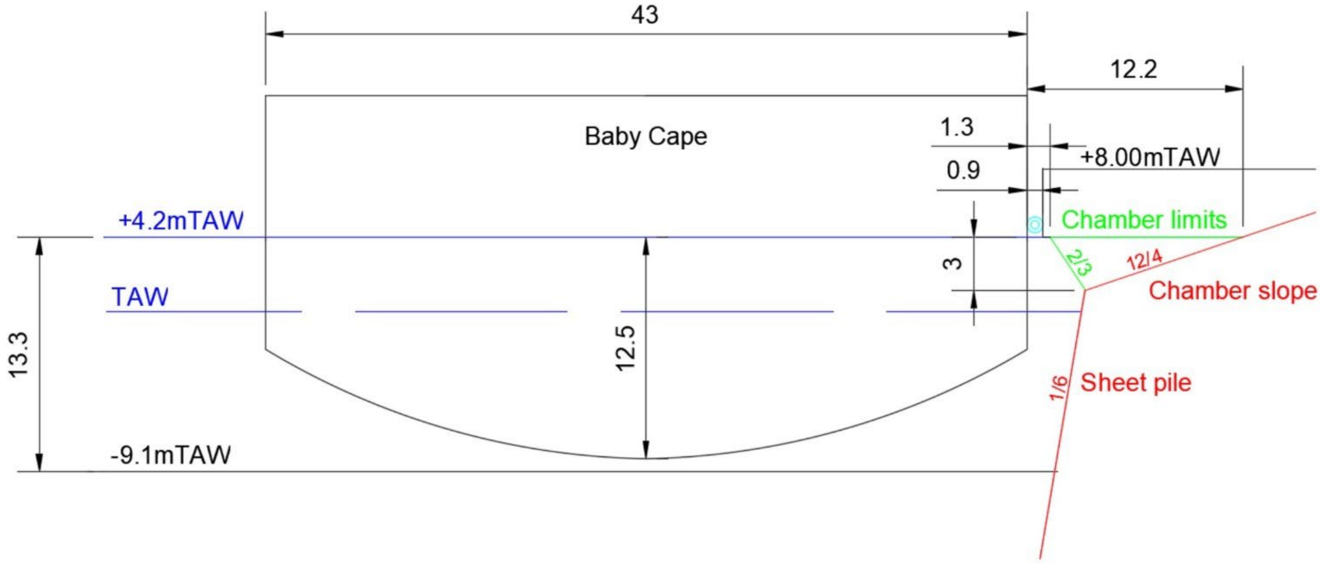

Figure 4. Cross section of the berth with the whole chambers model and a moored vessel at berth as defined in ROPES

The distance between the sheet pile and the center of the fairway is 125 m. The passing distance hull-hull between the passing and moored vessel is defined as presented in Figure 5.

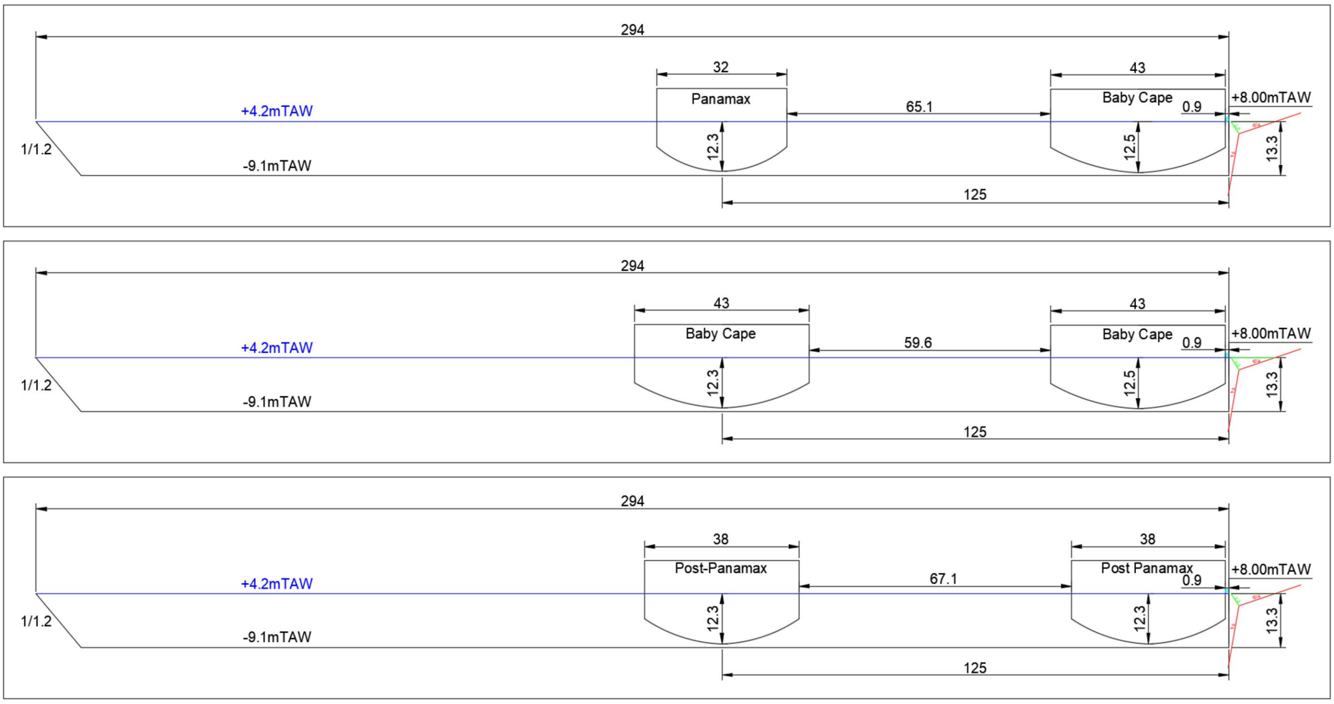

Figure 5. Schematization of the cross section of the channel and vessels for scenario 1 Panamax-Baby Cape

Table 1 shows the characteristics of the different vessels used for the simulations in ROPES. The initial simulations are performed with the first scenario, Baby cape moored and Panamax passing. However, additional checks are performed for the Baby cape moored and Baby cape passing and also the Post Panamax moored and passing. The moored and sailing ship are placed in the ROPES channel and berth models in accordance with the selected scenario. The sailing ship follows a straight line trajectory, parallel to the berth line, with a prescribed constant speed, and on the sailing distance as shown in Figure 3. The passing speed is 1m/s, and the results were later scaled to the actual passing speed (about 5 knots).

Table 1. List of vessels simulated in ROPES and vessel characteristics

	moored ship					passing ship						
nr.	Class	LOA	B	d	UKC	Class	LOA	B	d	UKC	passing dist.	sailing speed
[-]	[-]	[m]	[m]	[m]	[m]	[-]	[m]	[m]	[m]	[m]	[m]	[m/s]
1	Baby Cape	255	43	12.5	0.8	Panamax	229	32	12.3	1.0	65.1	1.0
2	Baby Cape	255	43	12.5	0.8	Baby Cape	255	43	12.3	1.0	59.6	1.0
3	Post-Panamax	229.2	38	12.5	0.8	Post-Panamax	229.2	38	12.3	1.0	67.1	1.0

5 MODELING AND RESULTS

5.1 MODELING

The quay wall is modelled as a set of more complex panels. As mentioned, the panes were squares in most cases (sometimes triangles were used). Note that screenshots from ROPES contain diagonals for better visualization. The different panel models defined in ROPES are presented in Figure 6. A systematic development is performed and a check of ROPES model of increased complexity:

- Step 0: a complete vertical wall
- Step 1: a wall with 2 inclined sheets, one almost vertical, and the other virtually closing the space of whirl chambers, to investigate the forces at different distances from the berthing line,

- Step 2: a wall with the inclined submerged sheet pile and the bottom slope of the whirl chambers, to investigate the effect of the additional volume of the whirl chambers, but without the blockage of the longitudinal flow,
- Step 3: a wall with the inclined sheet pile and the whirl chambers with transversal vertical walls blocking the longitudinal flow, the final model.

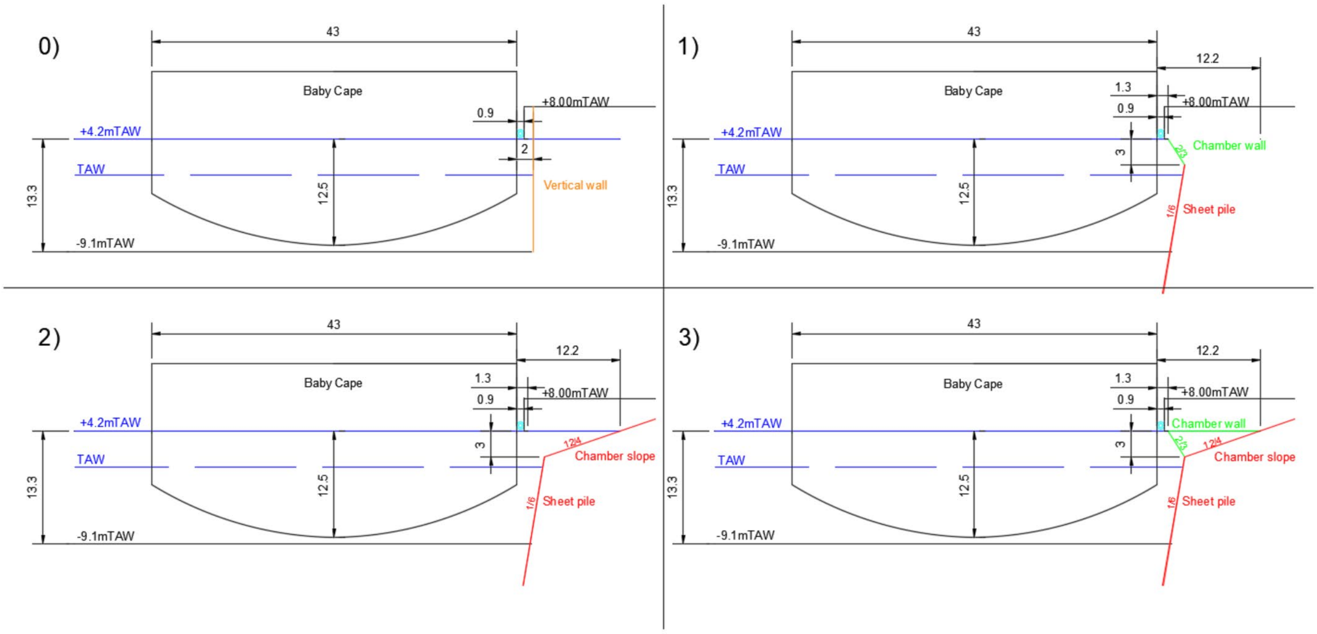

Figure 6. Cross section of the moored vessel at berth as defined in ROPES for the different step-wise models (marked 0) 1) 2) 3))

Figure 7 shows the 3D view of the panel model in Step1, the almost vertical wall, and Step 2, the two slopes model; the translucent blue surface is the water level, the grey surface is the channel bottom and the red/green surfaces are the parts of the quay wall. The development of the described models was done stepwise to control the results of modelling, to correct modelling inaccuracies and to gain confidence in the final results. As a result, the final model (Step 3) captured all important components of the quay wall with whirl chambers as described.

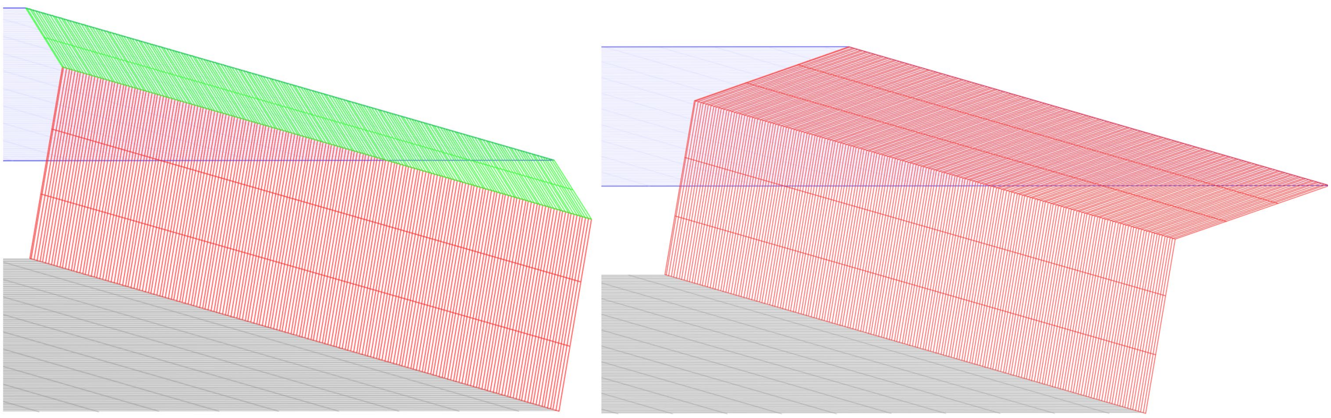

Figure 7. 3D view of the panel models in Step 1 (left figure) and Step 2 (right figure)

Figure 8 shows the schematization of the channel sides and of the berth, i.e., the details of the ROPES panel models. The bank slope opposite to the berth is defined in ROPES with a panel size of 5 m. The channel on the berth side uses model from Step 2 (no transversal walls of whirl chambers) and it is defined with a panel size of 3 m, except for the berth area. The panel model of the berth covers the location of the moored ship and extends slightly over the bow and stern of the moored ship; it is more detailed, with a panel size of 1.5 m. The whirl chambers are modeled in the berth area; they are spaced every 12.5 m and the perpendicular walls of chambers have a wall thickness of 1 m. The model with whirl chambers has the length of 374m, so it is abut 50% longer than the maximum length of the moored vessels.

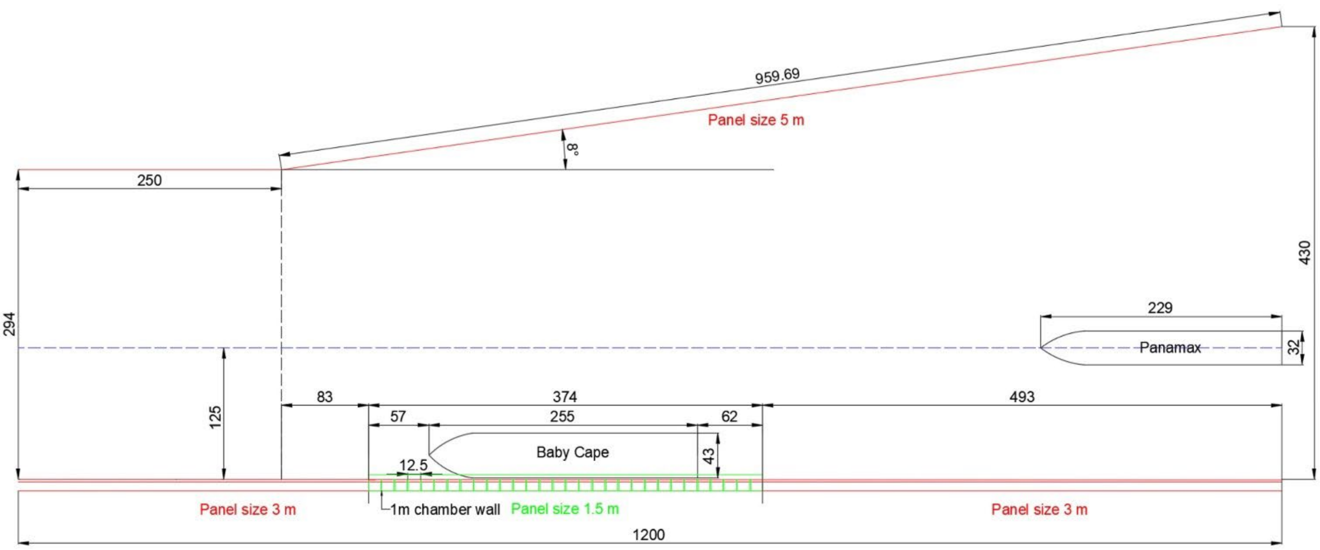

Figure 8. Schematization of the channel and berth panel model

Figure 9 and Figure 10 show the 3D views of the panel model in ROPES for the Step 3 final model. In these figures it is possible to identify the different panel sizes and how the whirl chamber walls have been fitted into the berth panel model.

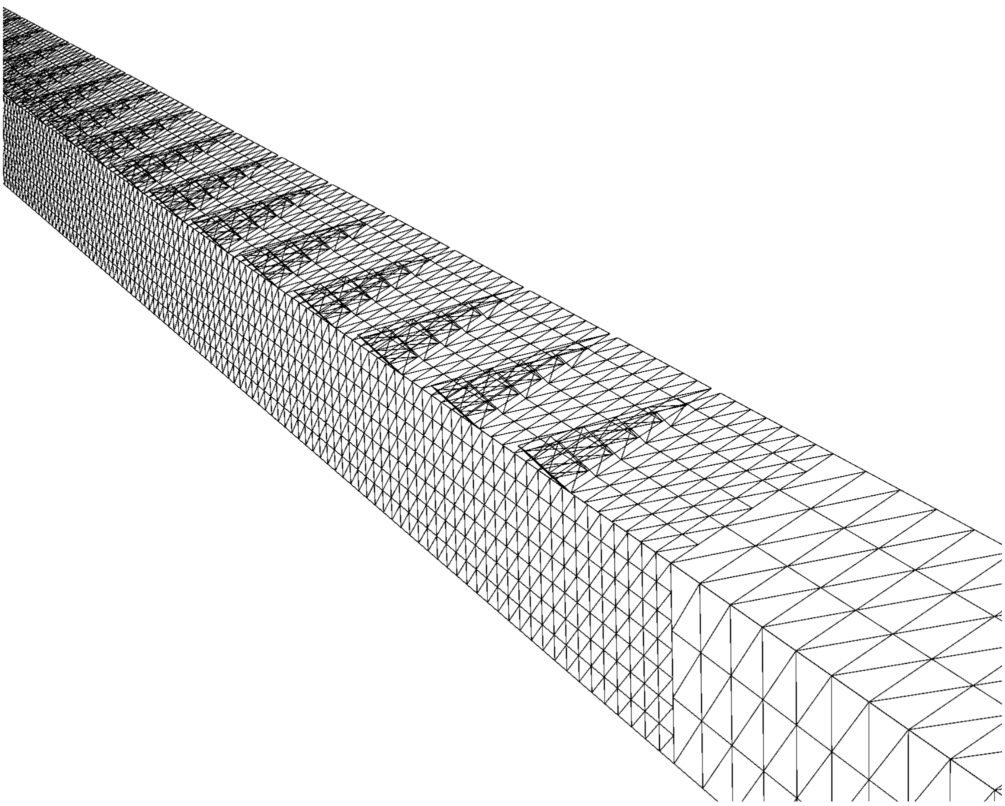

Figure 9 3D view of the different panel sizes used in the Step 3 ROPES model

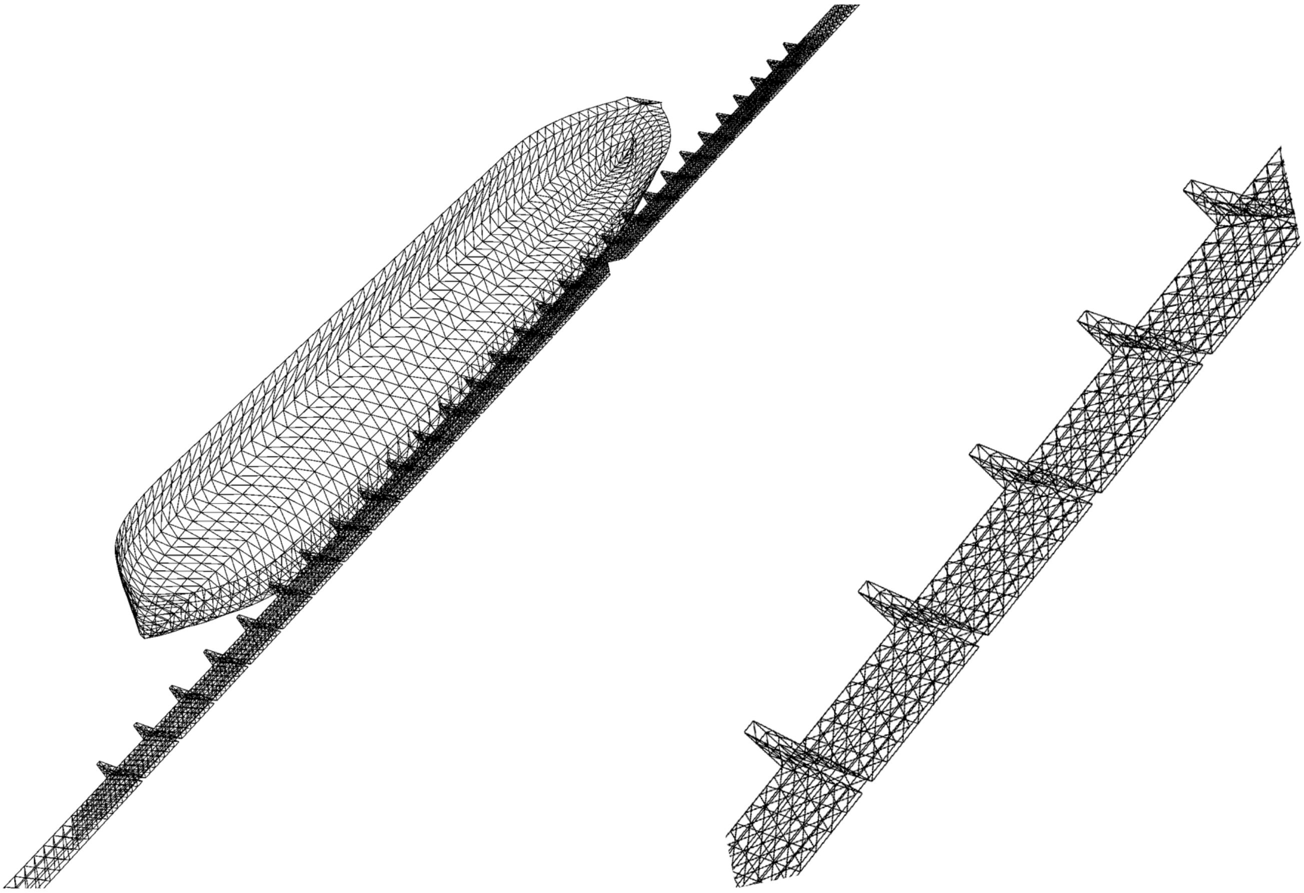

Figure 10. 3D view of the Step 3 panel model in ROPES with the moored vessel (left figure) and detailed 3D view of the whirl chamber walls (right figure)

In ROPES all simulations are done for a speed of 1 m/s in order to obtain results of better quality (the subsequent positions of the sailing ship on its trajectory are obtained by multiplication of velocity by the time step). The time varying forces to be applied to the moored ship at another sailing speed are then obtained by scaling the ROPES results by the squared passing speed and also the time steps are scaled by inverse of the passing speed.

The passing ship forces presented in the results refer to the forces on the moored vessel, unless otherwise mentioned. As it was described in the Methodology, when a ship navigates in restricted waters, there is a pressure wave which is observed as a water draw down. Water level raises ahead of the vessel and there is a return flow that accelerates alongside the hull to fill up behind the vessel. This is observed in the surge graphs as a negative surge motion when the passing ship approaches the moored ship, making the moored ship move towards the passing ship, and as the positive surge motion when the ship has passed the moored ship. In the sway graphs, it is represented as the positive peak when the passing ship sails right in front of the moored ship.

5.2 RESULTS

5.2 (a) Effect of panel size

The sensitivity of the forces to the panel sizes were checked in tests for each of the panel models in Step 0, Step 1 and Step 2. The resulting surge and sway forces are presented in Figure 11 to Figure 13. The peak force magnitude decreases when reducing the panel size from 3m to 1.5 m (more effect seen in sway force peak). This is specially visible for the Step 1 model – an almost vertical quay wall. For other models the variations in panel model sizes have not large results. However, the final model of the whirl chambers part of the berth was made with small panels.

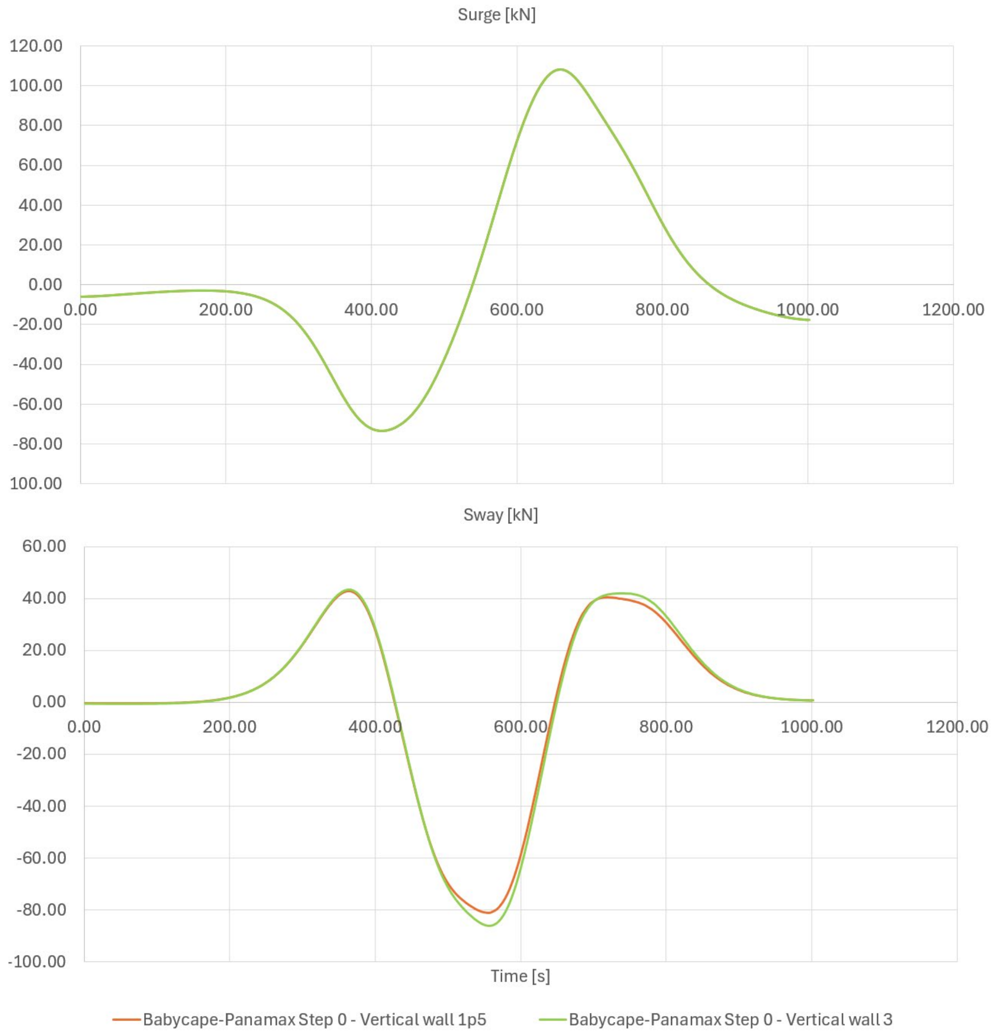

Figure 11. Passing surge and sway forces for the model Step 0 – Vertical wall with a panel size of 1.5 m and 3 m

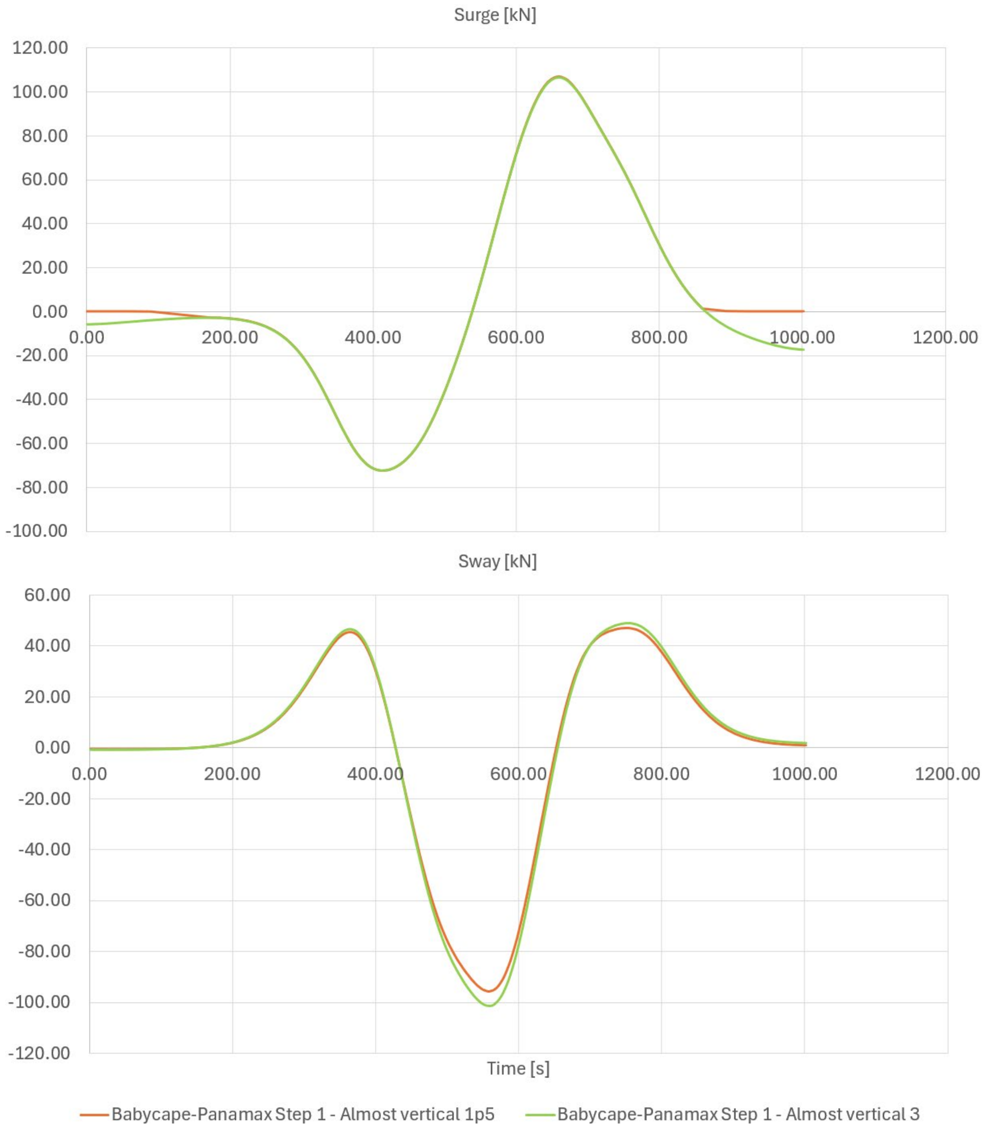

Figure 12. Passing surge and sway forces for the model Step 1 – Almost vertical with a panel size of 1.5 m and 3

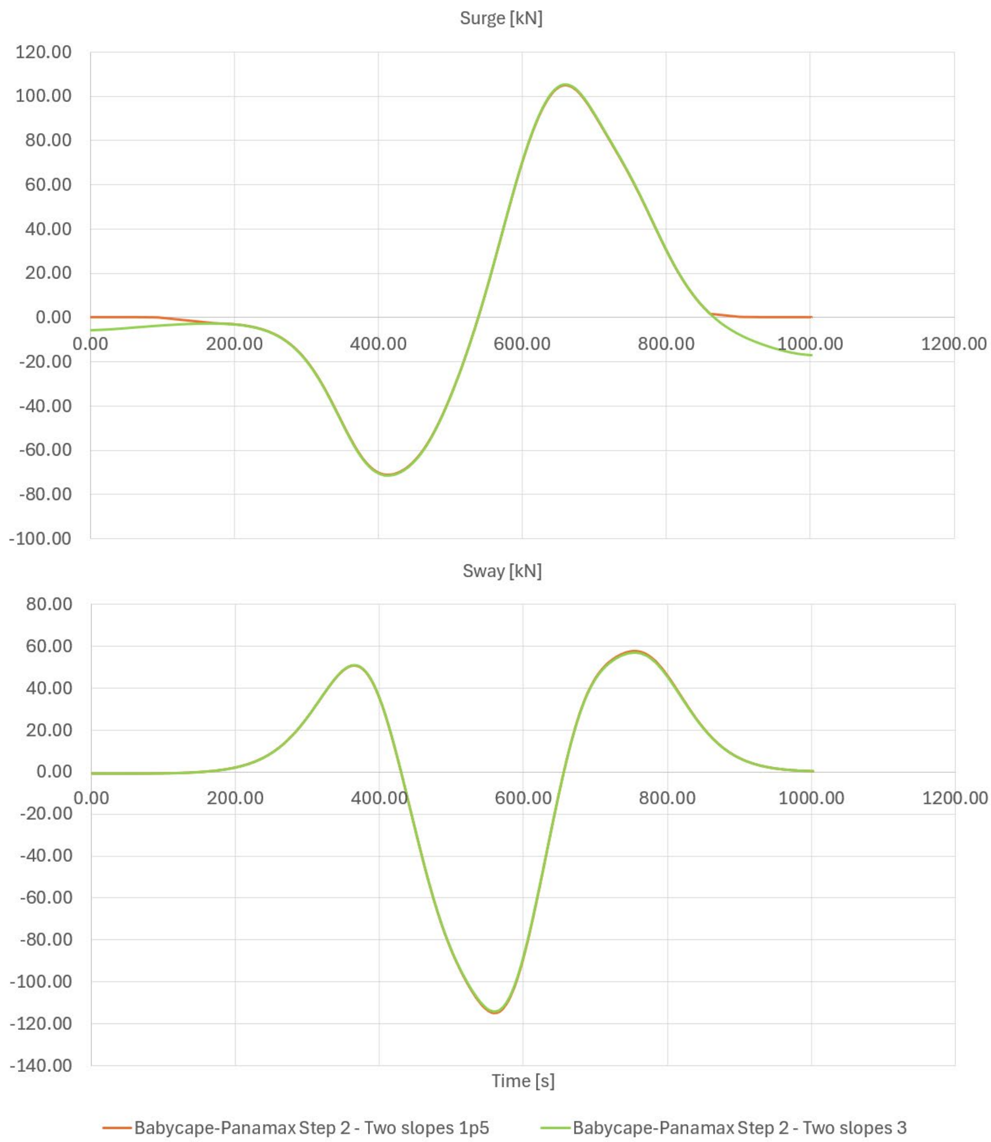

Figure 13. Passing surge and sway forces for the model Step 2 – Two slopes with a panel size of 1.5 m and 3

5.2 (b) Closed quay Vs Open water

The qualitative check of results included also a comparison of forces for a ship moored at a jetty (open water model) and at a vertical quay 2 m distance from the moored vessel. The Step 0 model results were compared with open water in order to better understand the effect of the defined quay wall. The resulting passing surge and sway forces are presented in Figure 14. Open water results presents higher sway forces, while surge increases due to the effect of the Step 0 quay. This is the expected qualitative behavior of models.

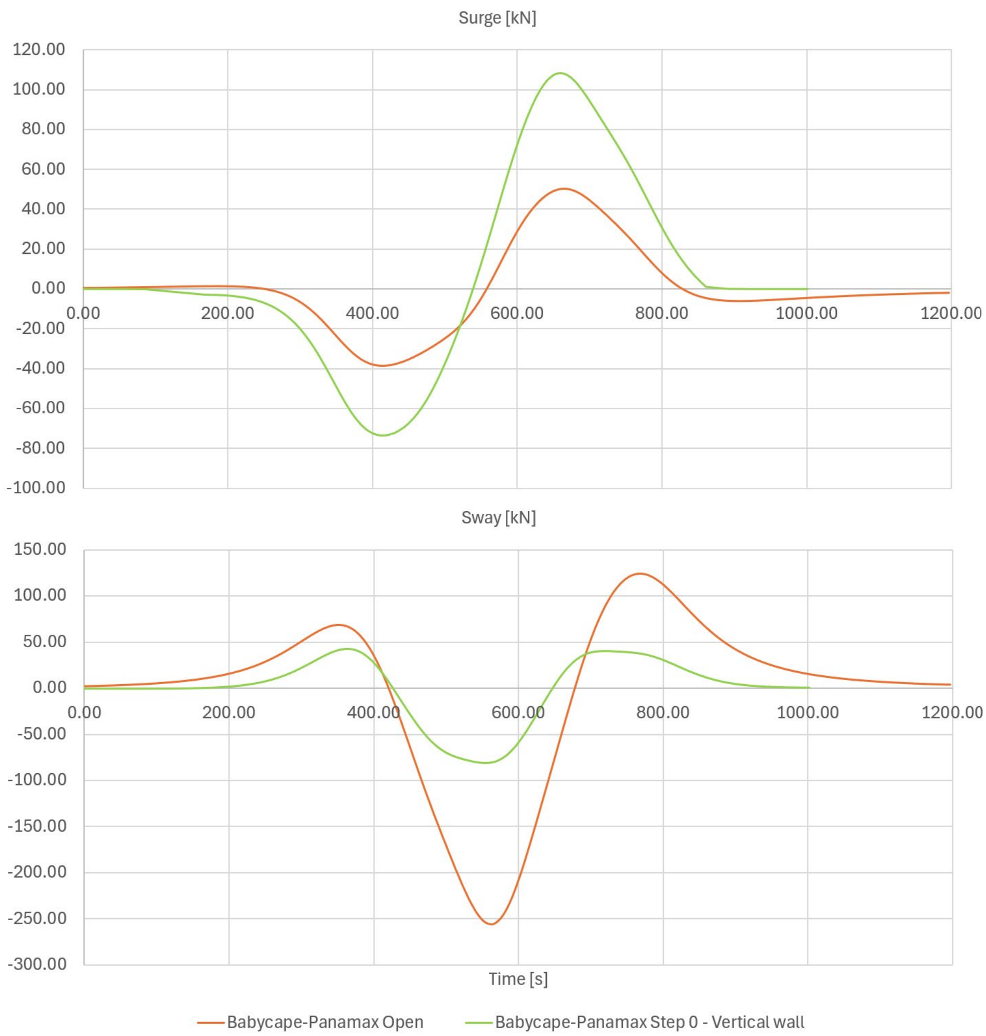

Figure 14. Passing surge and sway force for the Baby cape moored and Panamax passing with an open quay and Step 0 model

5.2 (c) Shift in the longitudinal position

In order to confirm that the position of the vessel with respect to the location of the whirl chambers did not have any effect on the results, one simulation was performed with the moored vessel shifted 3.5 m in the longitudinal position. The possible inaccuracies in results might originate from the relative shifts of panels of the moored vessel model and the quay wall model.

The passing surge and sway forces are presented in Figure 15, showing no noteworthy differences in the results. Therefore, it is safe to place the moored vessel at any location along the whirl chambers.

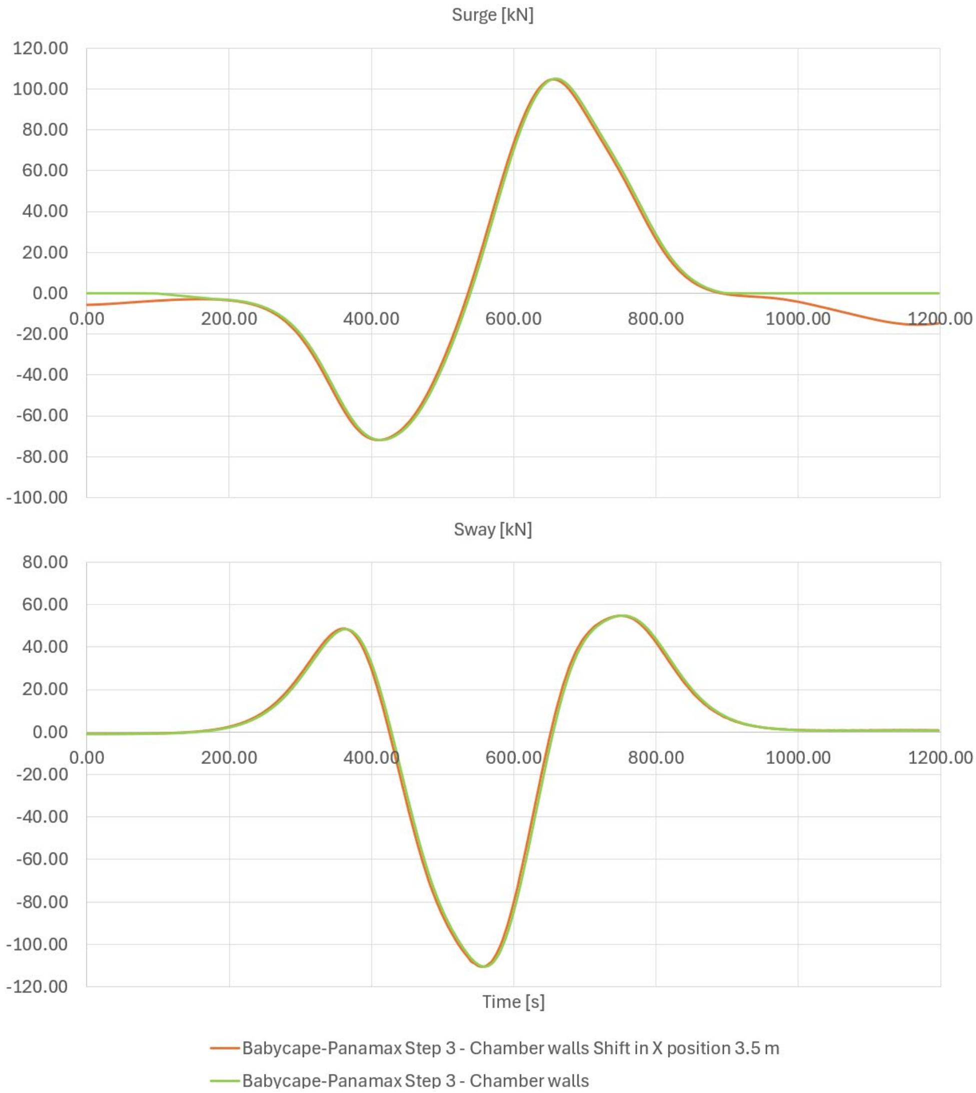

Figure 15. Passing surge and sway force for the Baby cape moored and Panamax passing with Step 3 model and the moored vessel shifted 3.5m in the longitudinal position

5.2 (d) Moored vessel

The strengths of sources modelling the sailing ship depend on the vessel speed and its geometry, as well as on the strengths of sources on panels modelling the geometry of the channel and berth (and the moored vessel). Therefore the resulting forces acting on it can be seen whether the channel model length and the extent of the berth panel model are correctly chosen to minimize their influence on the forces on the moored ship (because the latter depend on the strength of the sources on the sailing ship). The observation of the forces on the sailing ship serves to determine the effect of whirl chambers geometry on the strength of sources on the sailing ship (so, indirectly, on the forces on the moored ship), and on the extent the whirl chambers need to be modelled, considering the position of the sailing ship when the forces on moored ships become non-zero.

Following this concept, the forces acting on the passing vessel have been checked with and without moored vessel to verify whether the complex panel model at berth in Step 3 can be limited to the (extended) length of the moored vessel.

By observing the earlier presented time histories of the forces acting on the moored vessel we see that they are non-zero in time segments between 200s and 1000s, so the model edge effects do not visibly influence them.

The variations of surge forces on the sailing ship, presented in Figure 16, show that in case of no moored ship the forces on the sailing ship depend only on the channel blockage factor (the channel becomes narrower), not on details of the whirl chambers. When there is a moored ship, then the forces on the sailing vessel indicate when the sailing ship begins to “feel” the moored ship presence, thus indicating the necessary extent of modelling of quay wall sloped and whirl chambers (here it is about 400m).

The sway force on the sailing ship (lower plate of Figure 16) confirms that the details of the whirl chambers do not influence the forces on the sailing ship (case with no moored ship). The addition of the moored ship shows that its presence changes the forces on the sailing ship in time segment between 200s and 1000s. This confirms that the length of the whole channel model is sufficient.

These observations show that the whirl chambers have little effect on the sailing ship, confirming the hypothesis that their effect is specific to the near-field model of the moored ship and the berth. Therefore, the length of the whirl chamber model needs to be larger than the moored ship length but does not need to extend over the whole berth length, so it is why the berth model can be simplified when far from the moored ship.

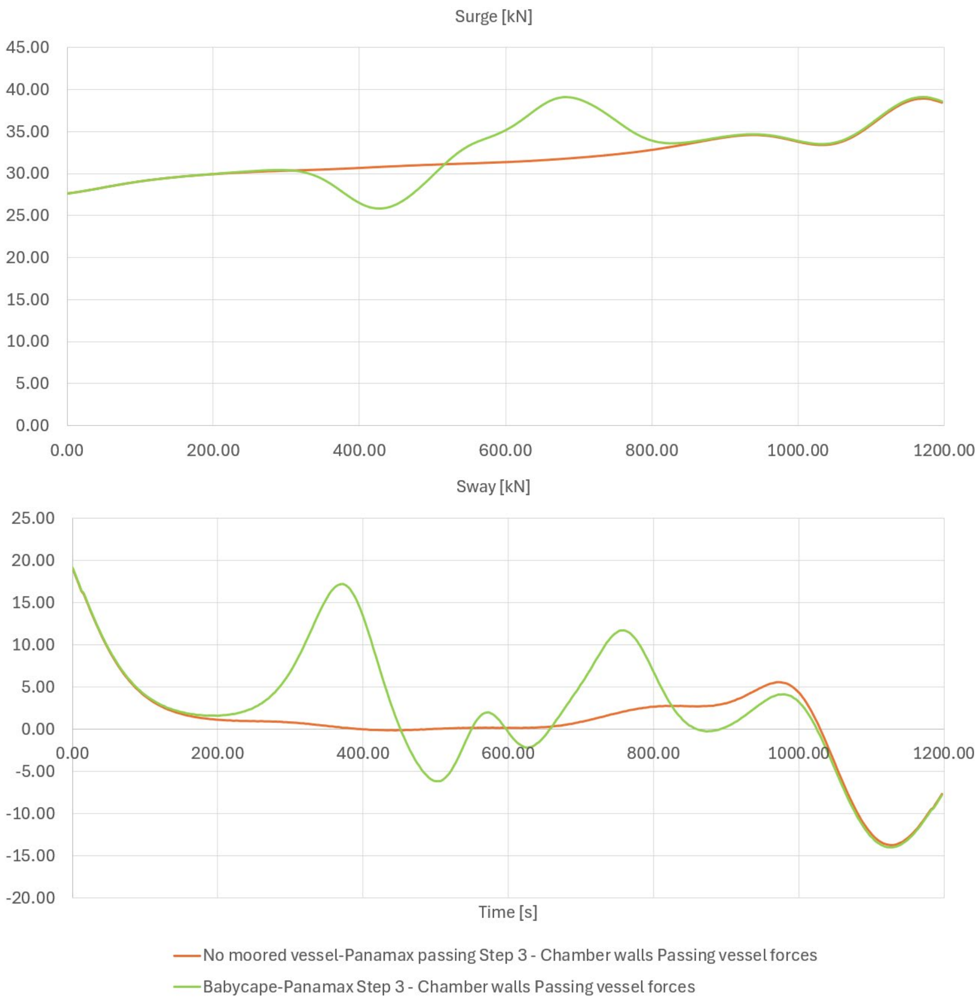

Figure 16. Passing surge and sway forces in the passing ship with Step 3 model for the Panamax passing with and without moored vessel

5.2 (e) Bank slope (opposite side of the channel)

The effect of the opposite bank slope on the results was also checked in order to simplify the model, as presented in Figure 17. The effect of removing the bank slope in sway forces is not relevant and in surge it slightly reduces the forces. Therefore, it is concluded that the bank slope should be included in the model, but it can be modelled with bigger panel size due to the reduced effect in the final results (the bank slopes panels are placed in large distance from the panels on the sailing ship).

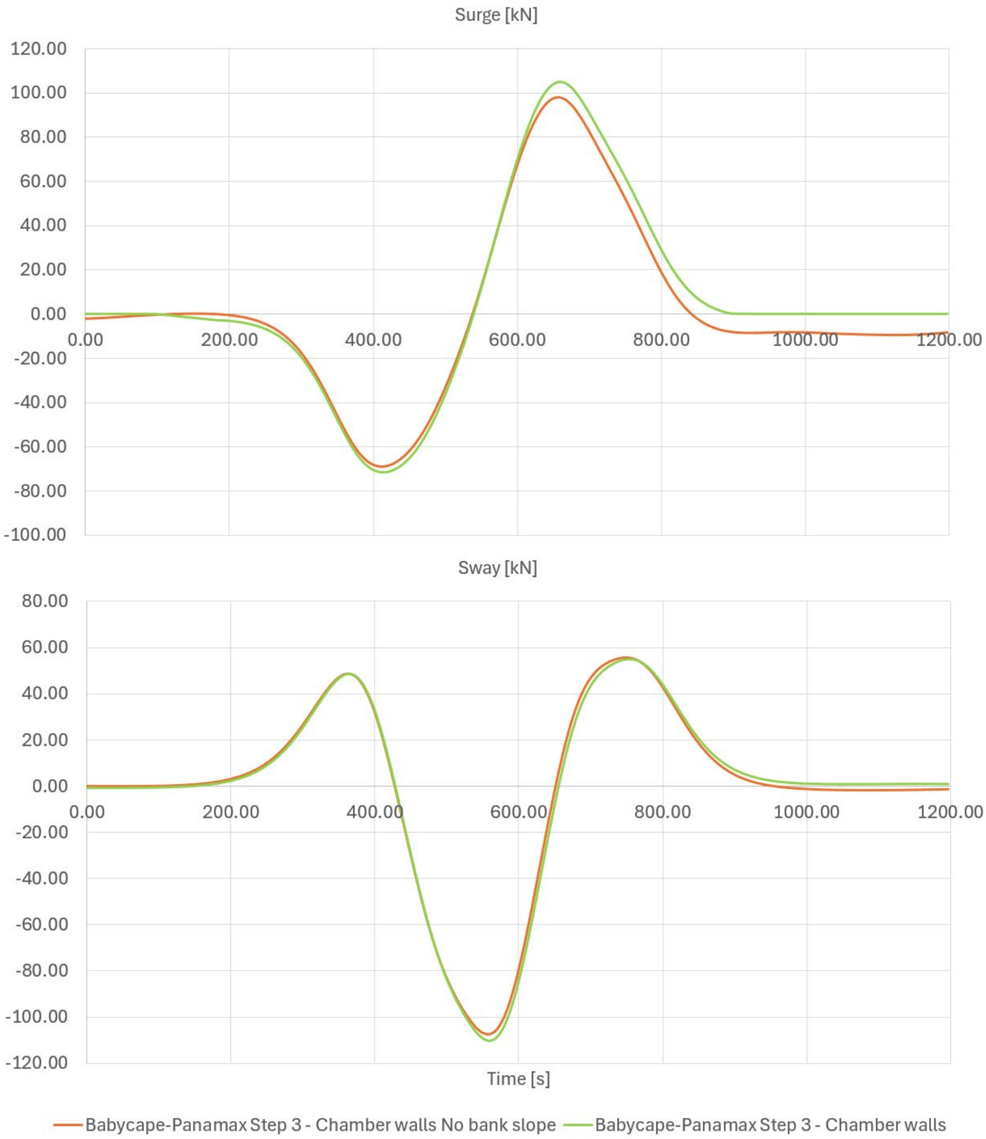

Figure 17. Passing surge and sway forces with Step 3 model with and without bank slope

5.2 (f) Step-wise models

The final model test with the different models was tested for Scenario 1. Figure 18 and Figure 19 show the surge and sway force signal variability for the different ROPES panel models built, from Step 0 to Step 3.

The vertical wall and almost vertical wall result in the highest surge forces compared to the cases with the chamber slopes and the whirl chambers. This is because surge forces increase when there is less water volume between the vessel side and the quay wall.

On the contrary, when the water volume between the moored vessel side and the quay walls increases, the sway forces also tend to increase. The highest sway force is obtained for the chamber slope scenario (Step 2) followed by the case with the chamber walls (Step 3), which creates higher blockage in the longitudinal flow and slightly reduces the volume between vessel side and quay/chamber walls.

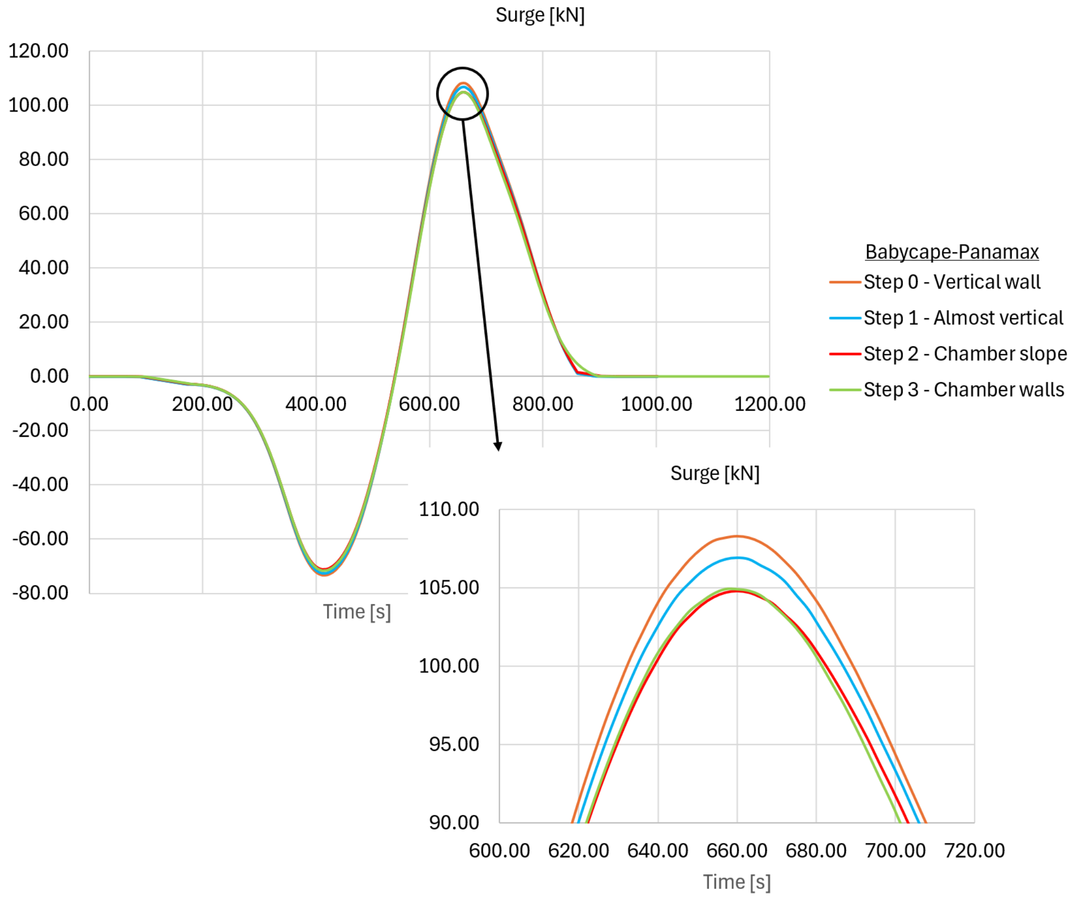

Figure 18. Passing surge motions for the different ROPES panel models Step 0 to Step 3 (top figure). Zoom to the peak in surge force (bottom figure)

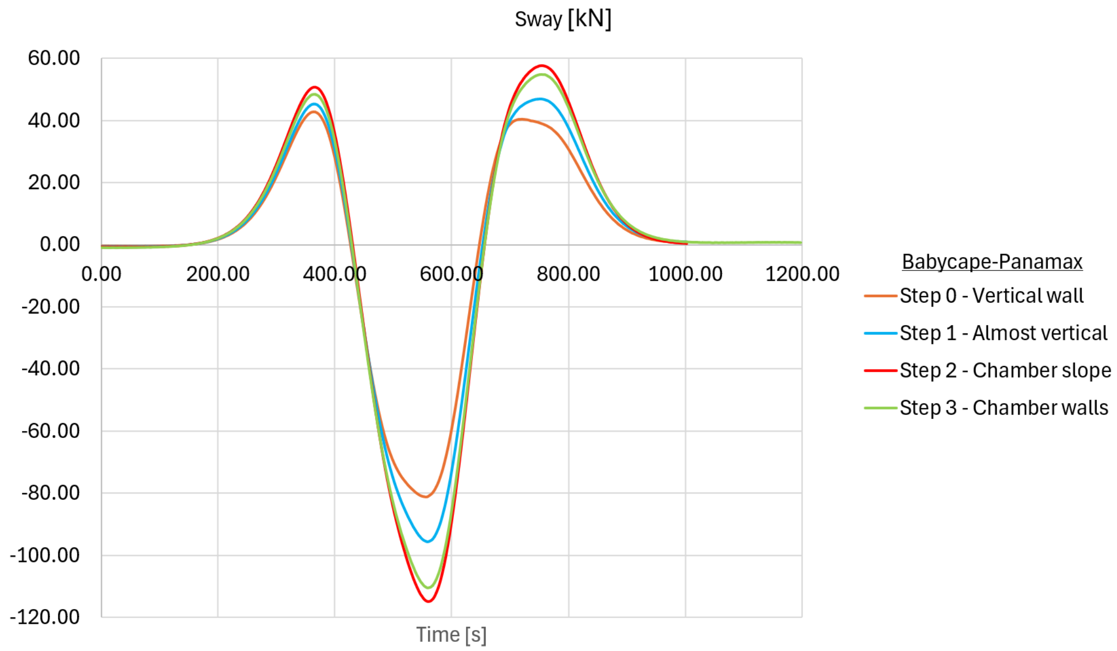

Figure 19. Passing sway forces for the different ROPES panel models Step 0 to Step 3

5.2 (g) Passing ship

The model was also validated with different passing ship size, Baby cape size moored and Baby cape size passing. The results are presented in Figure 20, showing a 70% and 40% increase in the surge and sway forces respectively.

This behavior is expected: a larger passing ship size (volume and the blockage factor due to increased midship area) increases the peak forces, and the larger passing ship length increases the length of passing force signal. Also, the qualitative behavior of passing ship forces is similar, which is expected considering that the data for the numerical models are just scaled.

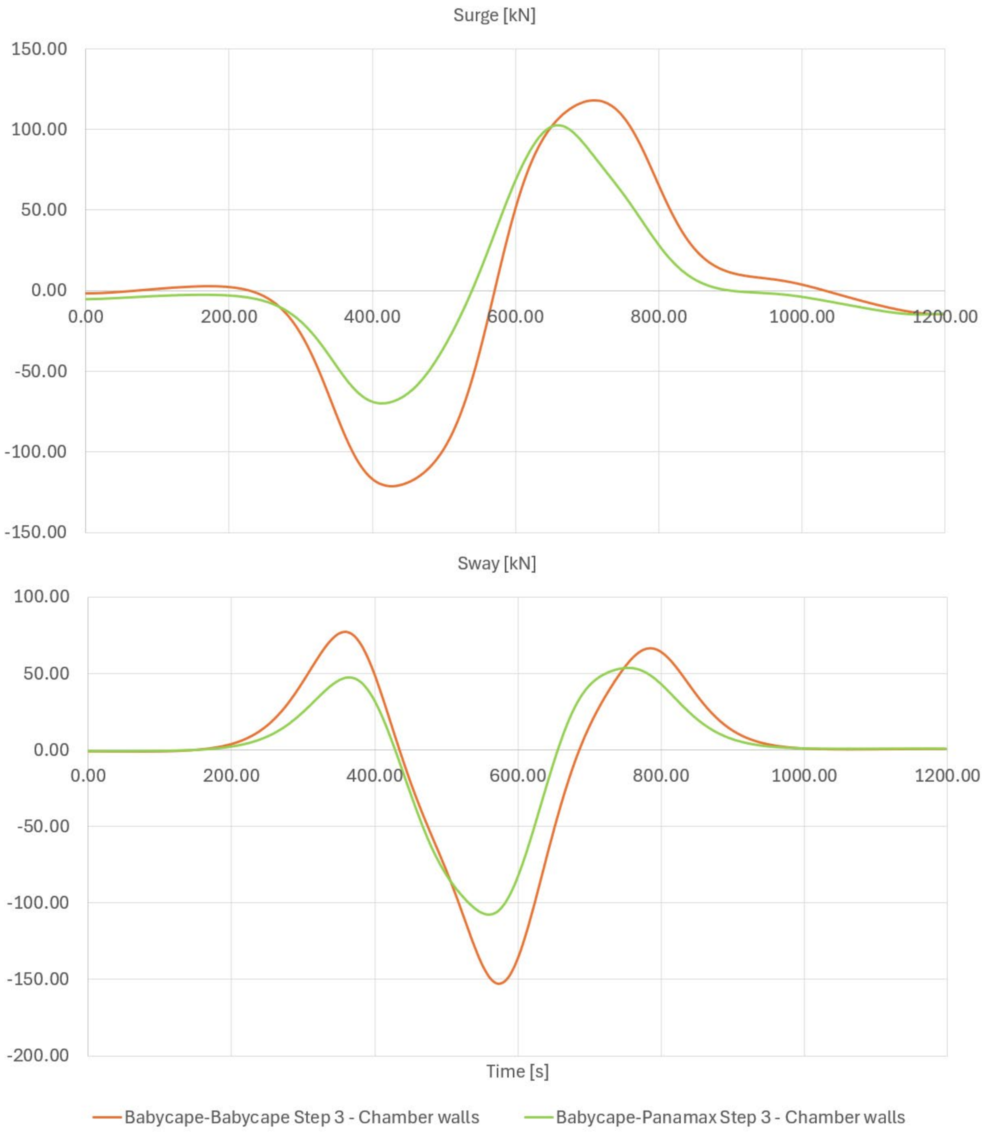

Figure 20. Passing surge and sway forces with Step 3 model for a Panamax and Baby cape size vessel passing

5.3 UNEXPECTED BEHAVIOR OF THE NUMERICAL MODEL

5.3 (a) Effect of the water depth

During the analysis it was observed how sensitive the ROPES model is to changes in the water depth, leading to incorrect results. Unexpected passing ship forces (large peaks and qualitatively different behavior) were noted in a quay model with panels. The initial water depth simulated was 13.25 m, which lead to the results presented in Figure 21. The peak forces are unexplainably high and the qualitative behavior of forces is not as expected for passing ship forces.

Sensitivity checks with the selected vessels and analytical quay were performed to investigate what causes these unexpected forces. The quay wall was modelled in the simplest way, using either large panels on vertical quay wall or the analytical quay. Then the water depth was also varied. When the water depth was modified to 13.3 m and 13.35 m, the model resulted in reasonable passing ship forces, as presented in Figure 22. Therefore, it is very critical to perform initial sensitivity runs with the different parameters before running the final simulation program.

These observed results can be thus attributed to internal implementations in ROPES, not to the specifics of the vessel and/or quay models. Any numerical model may have some implementation deficiencies and it is important to check the results and to detect such cases, if they occur.

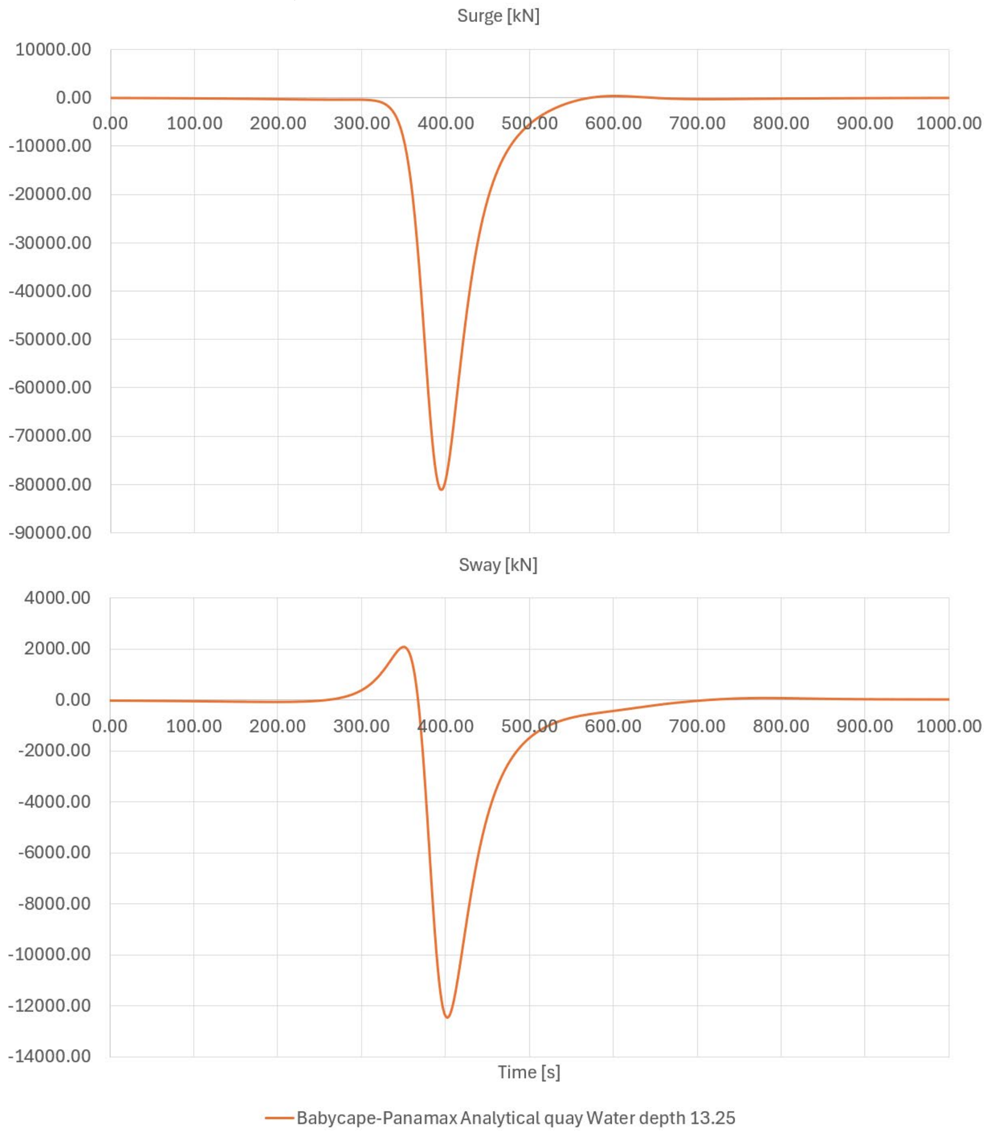

Figure 21. Passing surge and sway force for the Baby cape moored and Panamax passing with an analytical quay and water depth 13.25

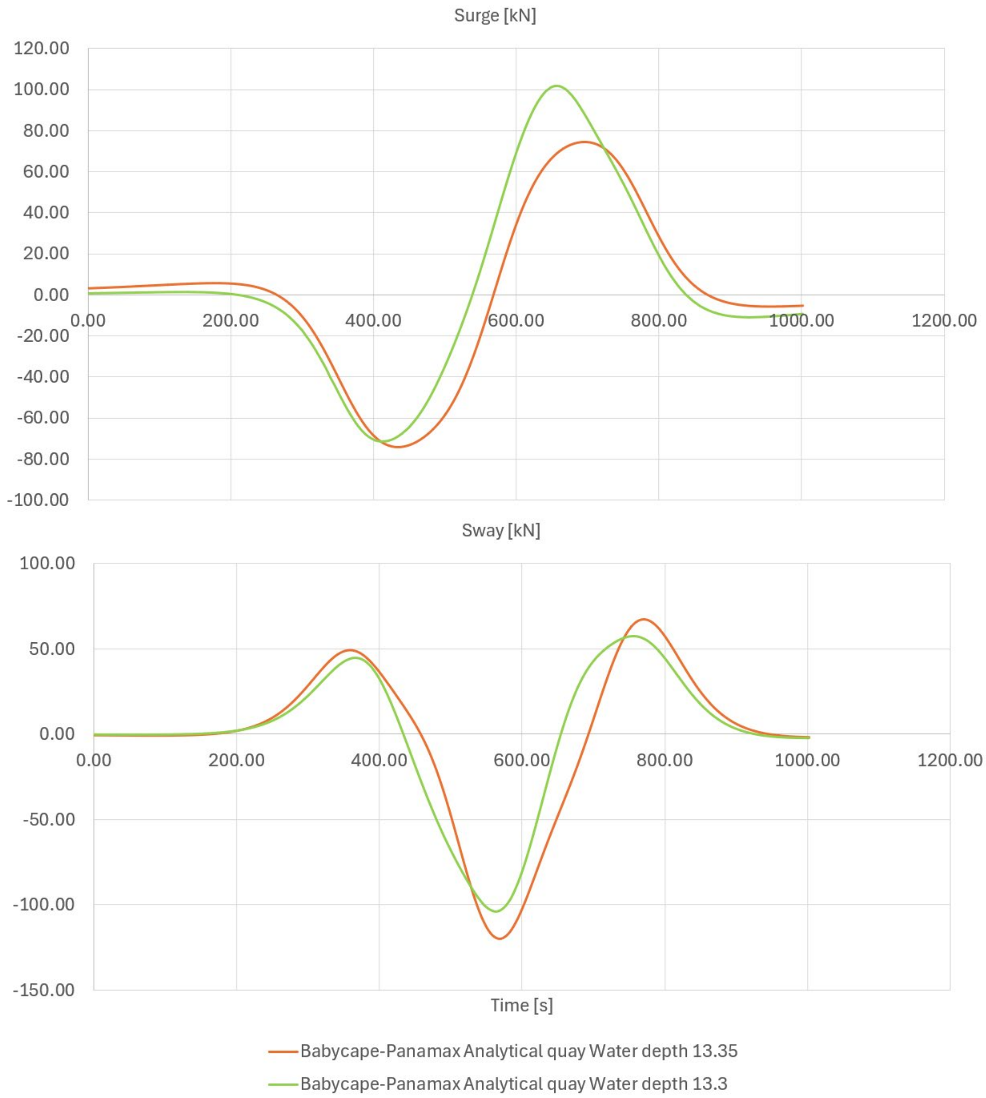

Figure 22. Passing surge and sway force for the Baby cape moored and Panamax passing with an analytical quay and water depth 13.3 m and 13.35 m

5.3 (b) Different hull shapes

Pasing ship scenarios were simulated for different passing and moored ship sizes. For one of the cases, the Post Panamax moored and passing vessels, an unexpected behavior was found in the sway forces, see Figure 25. This was unexplainable, since other combinations of vessels also used the tanker hull model from ROPES library, with its panels, and produced qualitatively similar behavior. ROPES tanker hull shape scaled for the Post Panamax is presented in Figure 23.

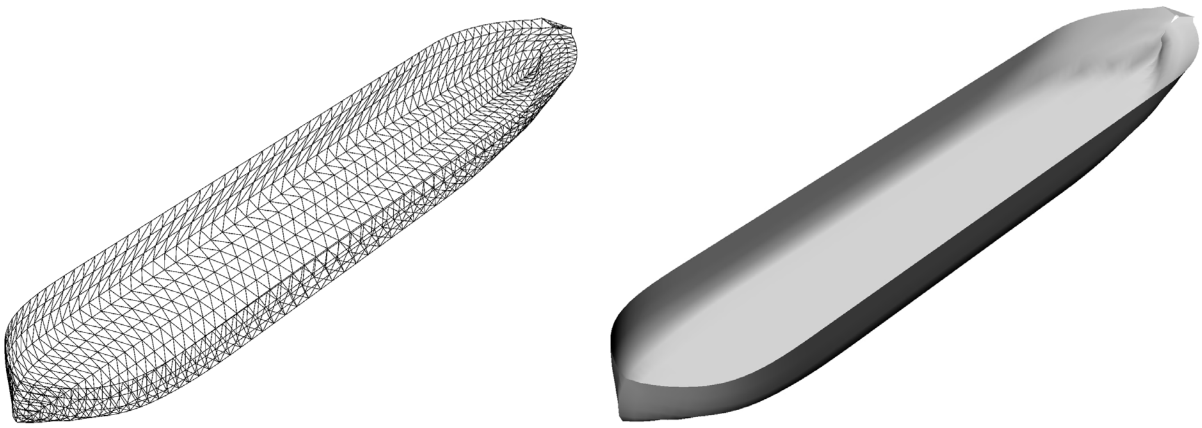

Figure 23. ROPES library tanker hull shape scaled for the Post Panamax

In order to correct this, it was necessary to select a different hull shape for the moored vessel, so a different panel model; while modeling principal dimensions and the block coefficient (hull volume) of Post Panamax vessels. After the change of the Post Panamax moored vessel hull panel model to LNG one, also from ROPES library, the results were qualitatively similar to results for other bulker vessels sizes, obtained with the tanker model. ROPES LNGC hull shape scaled for the Post Panamax is presented in Figure 24.

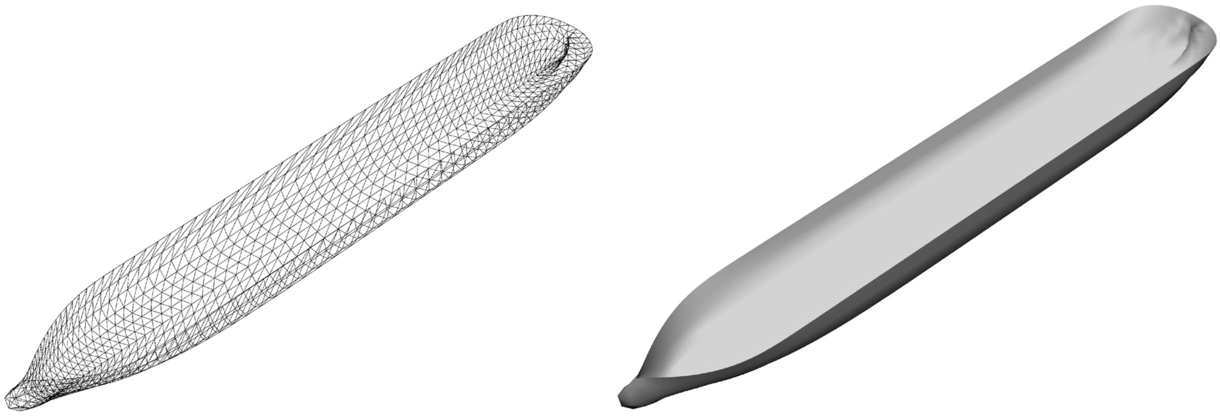

Figure 24. ROPES library LNGC hull shape scaled for the Post Panamax

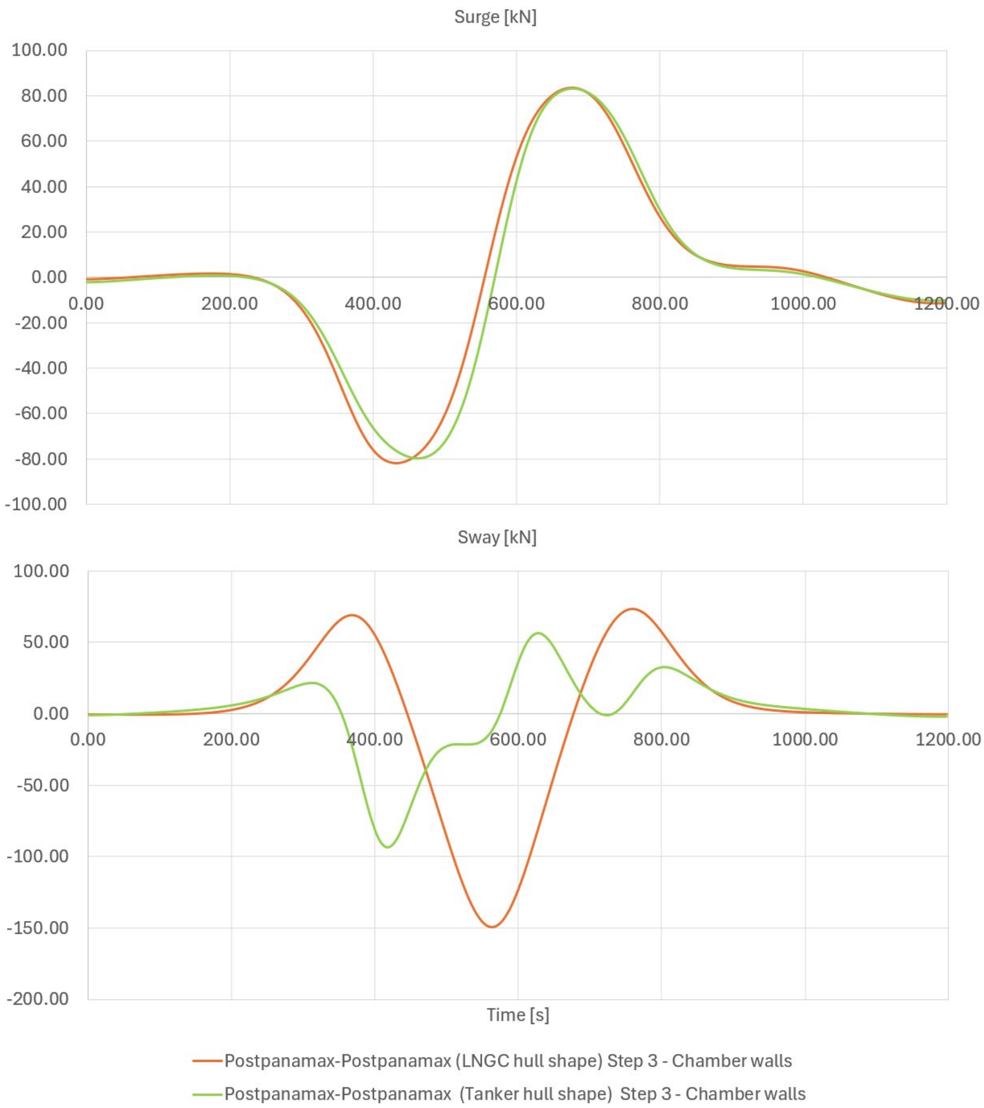

Figure 25. Passing surge and sway force for the Post Panamax moored and Post Panamax passing for Step 3 model considering different hull shapes for the moored vessel

The scaling inside the ROPES to obtain a desired hull volume consists of stretching/squeezing of the cylindrical part of the hull and doing the reverse for the bow and stern part; the number of panels do not change. The scaling of vessel dimensions results in expanding / contracting of panels sides. These two actions are improbable to result in the observed unusual behavior of forces in case of PostPanamaxes. Based on authors' experience with panel models (SHIP-PASSING) it is rather combination of integration method and relative positions of panels of various models (ship and quay wall).

6 CONCLUSIONS

The following conclusions can be formulated.

- The peak forces due to passing ships vary relatively little when comparing quay with whirl chambers and continuous vertical quay. However, these differences in peak forces may have effect on the final vessel responses, thus for the limiting speed of sailing vessel
- The forces due to passing ships at the complex quay behave as expected (less surge due to blocking of longitudinal flow, more sway because of increased volume between the quay and ship side)
- Full complex quay model (particularly, implementing of lateral baffles between chambers) may be implemented over a limited length of the quay, slightly larger than the length of moored ship. The remaining parts of the quay may be modelled with a simpler model that captures remaining features of the flow (sloped quay sides responsible for the increased volume of the space between ship hull side and the quay wall)
- The peak forces are sensitive to panel sizes on the quay next to the ship side; the decrease of panel size decreases the peak of forces
- ROPES, being example of panel method potential flow solver, can be used for calculation of passing ship forces acting on a ship moored along a complex quay.
- ROPES is suitable for fast development of geometrical models and produces the results (forces) fast, thus allowing for step-wise development of complex models, controlling the quality of models and allowing for testing of sensitivities to variations of these models.

The following recommendations can be formulated:

- Develop the final complex model through a sequence of simpler models, capturing important features and allowing to observe the resulting changes in forces. This approach gives a confidence in obtained results and allows to detect and assess irregularities that may occur
- Perform sensitivity checks of model parameters, like panel size, water depth and passing ship draught, distance of the moored ship to the quay side and along the quay side
- Check for the behavior of obtained forces whether this behavior qualitatively conforms to the expected one,
- Check for unexplainable results (both the qualitative behavior of forces and the values of peak forces) and whether the numerical implementation of the models produces stable results.

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