A TECHNIQUE OF PANELS CUTTING FOR MODIFICATION OF HULL GEOMETRY HYDRODYNAMIC MODELS

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SUMMARY

A panel cutting technique is developed for automatic modification of an initial mesh of a ship hull used for hydrodynamic computations leading to improved meshes for the prediction of wave induced vertical load effects. The technique can provide a model with divided panels in any defined position regardless of the initial discretization of the body. The applications of the provided technique include panel distinction and division in predetermined positions, generation of finer mesh based on the initial coarser model of meshes and improvement of vertical load prediction in predetermined positions. The method is applied for case studies of a barge, shuttle tanker and frigate to depict various applications. Finally, the hydrostatic and hydrodynamic vertical shear forces are calculated for two models of initial and modified panels of well-known frigate 5415. The results are compared for the sections alongside the ship and accuracy of load integration is shown for predetermined sections.

1. INTRODUCTION

The various types of panel methods are traditionally one of the main methods to evaluate the motions of the floating bodies and the imposed loads to marine structures due to waves. The mesh format usually is used to the discretization of the structures in the domain in contact with the fluid. In a common approach, the meshes are formed by distributing of quadrilateral polygons, denoted as panels, on the body surface. Those panels define the positions of source points, which are distributed on the wetted body surface. Then, the velocity potential at any point in the fluid domain is calculated by integrating the velocity potentials of the distributed source points using the boundary integral equation (Faltinsen 1990). Thus, the panels are not required to have a connection in hanging nodes for the measurement of the pressure on the body by a linear panel method. On the other hand, the panel number and their arrangement, especially the cosine spacing, affect the accuracy of the solution (Lee and Newman 2004). Thus, the construction of the body model using high-quality panels results in the distribution of the sources in the actual coordinates on the body surface, especially in curved areas such as the bulbous bow. The resulting improvement of predicted motion is discussed in Jafaryeganeh *et al.* (2015) by changing the quality of the panels.

The proper distribution of panels on the body surface can be used for the applications that require the geometrical properties such as volume, the centre of buoyancy, sectional distribution of buoyancy and wetted area calculation. One of the major applications of those models is the prediction of the imposed loads on the ship structures, where the mentioned quantities are evaluated from the provided model of panels.

The panel can be distributed by analytical formulas for the bodies that can be represented by the analytical equations. Uzunoglu and Guedes Soares (2018) categorized the surface of such bodies in two groups of radius-based and face-based and presented distribution approaches based on the driven formula for various samples of the mentioned geometries. They provide the model of panels for ship hull using the table of offset directly, though, the approach cannot represent the actual shape of the ship hull, especially in the curved areas.

Usually, a semi-manual approach applies to the generation of the panels on the ship shapes bodies. The method includes two steps: first, the model of the body surface is provided by B-Spline surfaces (e.g., NURBS surfaces) from the table offset or body lines, then, the surface can be discretized with panels (e.g Ventura and Guedes Soares, 1998). A variety of modelling software provides the facility of performing each mentioned steps, such as Rhinoceros and CAESES. One of the advantages of the method is the ability to provide fit panels on the faired surfaces, however, a variation of the provided panels need to change of the base surfaces and regenerate the panels based on the modified surfaces. The process is time consuming even for an expert user of the tools.

For modification of generated panels, Rodrigues and Guedes Soares (2014) applied an approach for regenerating the panels of the floating body according to the form of the free surface. The approach identifies the body panels that have intersections with the profile of wave, then a recursive process was applied to replace the intersecting panels with smaller quadrature panels. The process continues until reaching the predetermined length for the regenerated quadrature panels. Thus, the floating body can be presented by non-uniform panels, i.e., a series of small panels replace the initial panels that have intersections with the free surface, the other panels remain unchanged for presenting the part of the body that do not have an intersection with the free surface. The number of regenerated panels may increase significantly due to keeping the quadrature shape of the panels. Another approach for modification of panels is cutting panel, which has the advantage of minimum increment of panel number, so, the method prevents the unnecessary increment of the run-time of programs based on the ranking source panel methods. In this regard, Choi *et al.* (2011) developed a technique of cutting panels to consider the change of the non-linear effect of the free surface, trim and draft for a ship hull. However, their approach applies only a single non-vertical cut for each panel to generate the profile of free surface based on the initially provided panels. Thus, the method cannot be used to improve the quality of panels after the initial discretization, because, modification of panels quality may require multiple cuts for some panels in specific positions.

This study focuses on the method for vertical cutting of panels regardless of the number of intersections with the cutting planes due to respond the need for the modification of initial panels. The multiple cut approach can be applied for facilitating the convergence tests, where the size of all panels can be reduced simultaneously (Lee 1995). The vertical cutting is required specifically to separate the panels at the predetermined boundaries. For example, one of the applications of the regenerated panels is modelling the flooding compartment, either by changing the type of compartment panels from source to dipole for simulation of the damaged ship motion (Kong and Faltinsen 2010), or by removing the compartment panels to use lost buoyancy approach for predicting the induced load to the damaged ship (Parunov *et al.* 2015). Another application of the regenerated panels is the improvement of the accuracy of load prediction alongside the ship by applying the exact integration to each section (Jafaryeganeh *et al.* 2016).In this work, a panel cutting technique was developed to divide initially generated panels at predetermined longitudinal positions. However, the presented method is compatible with any direction of cutting planes. Initially, the cutting algorithm was presented based on the categorization of panels' positions relative to the cutting planes. Then, three applications of the method were described for different types of floating bodies, with special attention to the improvement of integration accuracy for prediction of the static and dynamic longitudinal loads. In particular, the vertical shear force was calculated for two type of initial and divided panels and the results were compared to each other.

2. PROBLEM DEFINITION

The semi-manual method is used to generate the initial panel discretization of the bodies. Initially, the model of the hull is generated in the Rhinoceros, Figure 1 presents a sample of provided NURBS surfaces based on the body lines for the well-known frigate 5415. Afterwards, the hull surface is discretized by the panels regardless of the quality and size.

Although, a variety of tools provide the facility of generating the required shape and sizes of panels based on a specific surface (e.g., "panelling tools" in Rhinoceros), modification of size and shapes of panels requires an exhaustive procedure, especially when the edge of panels need to coincide in a series of specified boundaries. Because base-surfaces need to be remodelled between two required boundaries, then the panels discretize each surface separately and finally are connected manually. Figure 2 shows a sample of six cutting planes, which are parallel to the *YZ* axis of the specified coordinate. The procedure of providing separate surfaces is costly in the aspect of time even for such few numbers of cutting planes. Thus, an automatic procedure is developed to regenerate the divided panels based on an arbitrary initial discretization.

Figure 1.Hull model of the frigate 5415.

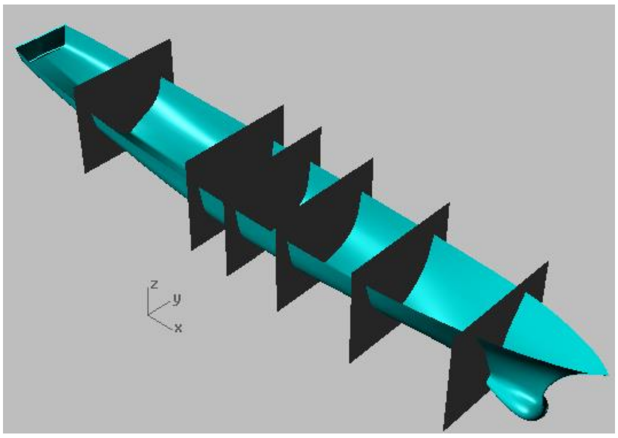

Figure 2. Dividing the hull of frigate 5415 by transverse cutting sections along the ship length

3. METHOD OF PANEL CUTTING

The panel types were identified based on the number of intersections with the cutting planes, then the *starting vertex* was determined for each panel. Finally, the modified panels were generated based on the case of cutting.

3.1 IDENTIFICATION OF PANEL TYPES

The initial panels were generated and the number and positions of the cutting planes were determined initially. The initial panels describe the body surface regardless of the quality of the provided panels and the position of the cutting plane, i.e., no special consideration is needed for the initial generation.

The position of cutting planes are specified according to the requirement of the problem, i.e., the positions and number of cutting panels depend on the application that is expected from the modified panels. Whereas the cutting plane can be determined at any position, some of the panels are between two consecutive cutting planes without any intersection. Those panels were separated from the panels that require modification and their properties were kept constant for the regeneration of new panels. So, the remaining panels have at least one intersection with the cutting planes. Consequently, the number of cutting planes were determined for each of the intersecting panels, because the approach of dividing the panels are depended on the number of cutting planes.

Figure 3 shows the process of identification of panel types and the number of intersecting cutting planes.

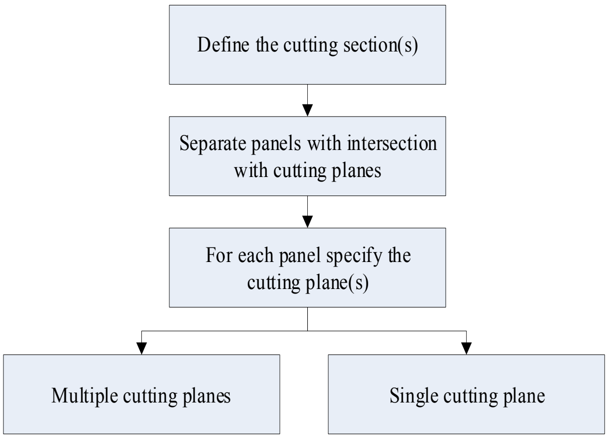

Figure 3. Determination the type of panels and number of cut for the panels that have intersection(s) with cutting plane(s)

3.2 DEFINITION OF THE "STARTING VERTEX"

Each panel is defined by *(x, y, z)* Cartesian coordinate of four vertices of the quadrilateral polygon relative to the origin of the coordinate system. However, the panels can be substituted by triangle shapes by coinciding the coordinates of two vertices. The order of panels that represent the floating body is unimportant, however, the order of vertices in each panel follow counter clockwise direction when the panel is viewed from the fluid domain.

Each of the four vertices of panels can be used for introducing the panels' vertices with the counter clockwise direction. One of the vertices was defined as starting vertex in the current approach, The concept of starting vertex was used to specify the positions of the panel edges related to cutting planes and consequently, the intersections can be determined by the definition of line segment for panel edges based of the starting point, also, it can be used as base-point to regenerate the new panels.

The definition of starting vertex was based on the position of the intersecting plane relative to the panel, where the plane was considered as a boundary that separates the panel vertices. Thus, a corner of panels is a starting vertex:

- If it is the only vertex that is separated by the cutting plane, these cases are shown in Figure 4 and Figure 5, where the starting point is indicated by "*a*".
- If it is not the only vertex that is separated by the cutting plane. The starting vertex is the vertex that is located right before the cutting plane, while the position of the next vertex, following the counterclockwise direction, is right after the cutting plan. This case is depicted in Figure 6 where the starting point is indicated by "*a*". The condition can be examined by the following equation for any cutting plane that is parallel to the *YZ* axis :

$$X_i \le X_{CP} \text{ and } X_{i+1} \ge X_{CP}$$

where *i=1,2,3,4* presents the indices for the vertices of the panel, X_i presents the *x*-position of the panel vertices, and X_{CP} is the *x*-position of the cutting plane

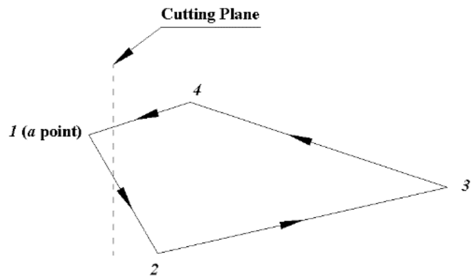

Figure 4. Identification of the starting point (*a*), case *I*

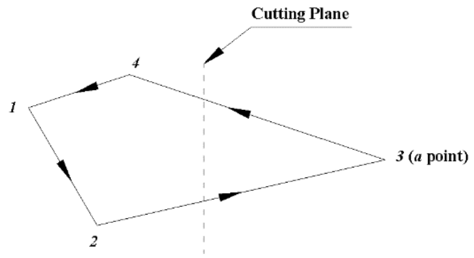

Figure 5. Identification of the starting point (*a*), case *II*

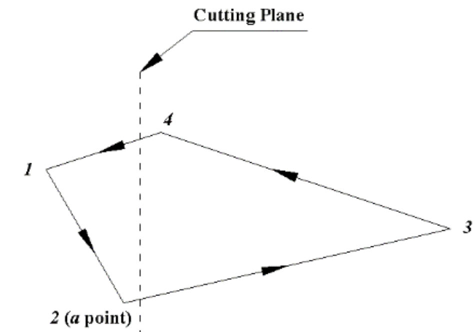

Figure 6. Identification of the starting point (*a*), case *III*

3.3 SINGLE CUTTING PLANE

Figure 7 shows the process of cutting panels for a single cutting plane. First, the starting vertex was determined by the described method and then the vertices of the panel were resorted based on the starting point. The number of new generated panels depended on the categorized cases of cutting.

Figure 8 presents the divided panels for the identified *case I* and *case II*, where three new panels are generated based on the initial panel. The intersecting edges of the panel were determined using the position of cutting plane and the vertices of the panel relative to the starting vertex. Thus, the intersecting coordinate of cutting plane and panel edges were determined, as below:

$$y_{s_1} = y_2 + (y_3 - y_2) \times (\frac{x_s - x_2}{x_3 - x_2})$$

$$z_{s_1} = z_2 + (z_3 - z_2) \times (\frac{x_s - x_2}{x_3 - x_2})$$

$$y_{s_2} = y_1 + (y_4 - y_1) \times (\frac{x_s - x_1}{x_4 - x_1})$$

$$z_{s_2} = z_4 + (z_4 - z_1) \times (\frac{x_s - x_1}{x_4 - x_1})$$

where x_s is the longitudinal position of cutting plane, y_{s_i} and z_{s_i} *;i=1,2* are transverse and vertical position of the intersection points and x_j, y_j, z_j *;j=1,2,3,4* are the vertices coordinates after resorting based on the starting vertex.

A line segment was defined using the intersection coordinates and the mid-point of the line segment was used for the generation of two quadrilateral panels (P_2 and P_3). Besides, the panel (P_1) was generated with a triangular shape by coinciding the fourth vertex on the position of starting vertex.

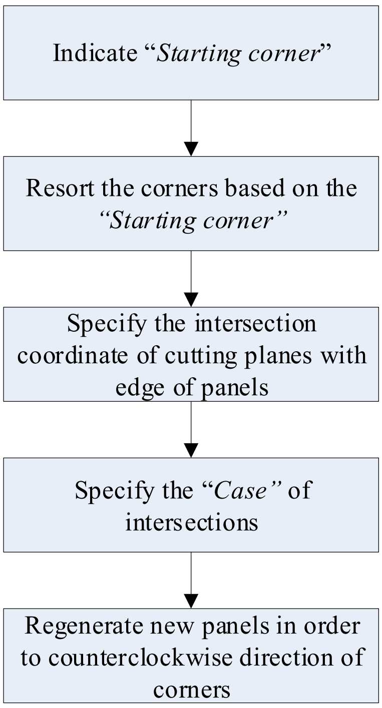

Figure 7. The process of dividing panels, where has an intersection with cutting plane

Figure 9 presents the divided panels for the identified *case III*, where two new panels are generated based on the initial panel. A similar method of *case I* and *case II* was used for the identification of intersecting edges and definition of the line segment. The panels (P_1 and P_2) are generated with quadrilateral shape using the endpoints of the line segment, which is defined by the intersection of the cutting plane and the panel.

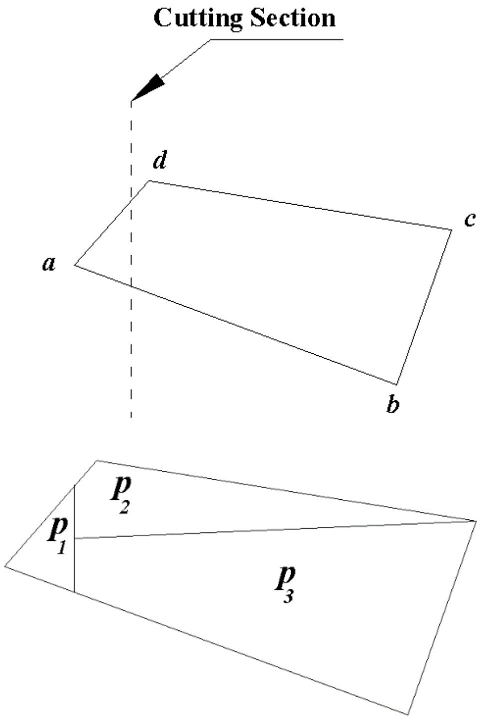

Figure 8. Generation of three divided panels for the single cutting plane (case *I* and case *II*)

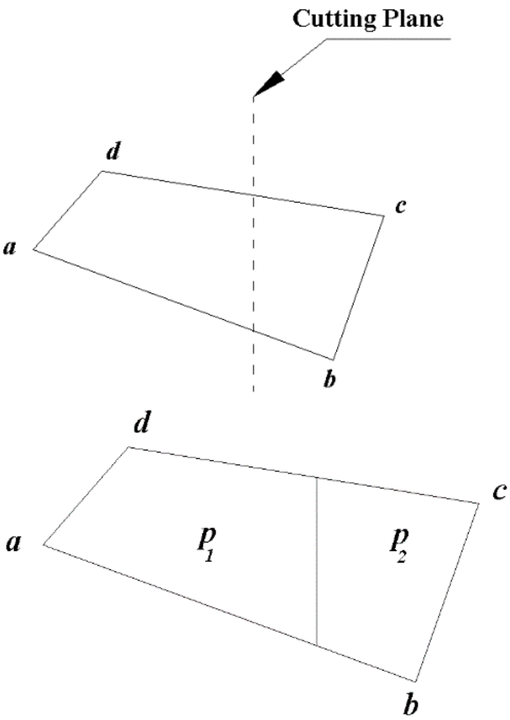

Figure 9. Generation of two divided panels for the single cutting plane (case *III*)

3.4 MULTIPLE CUTTING PLANES

If multiple cutting planes intersect with a panel (Figure 11), the new panels were generated by following steps :

- Identification of the "*starting vertex*": the method is similar to a single cutting plane, however, only the first cutting plane ($C.P._1$) was used for determining the position of the panel vertices relative to cutting planes.
- Resorting the panel vertices based on the starting vertex (*point a*)
- Determining the intersecting points of edges with the cutting planes: the panel edges were selected in a sequence from the starting vertex with counter-clockwise direction, then, the intersections of cutting planes with the selected edge were determined with an order from starting point with counter-clockwise direction. The below matrix includes all positions of the intersecting points (*I.P.*), which is shown in Figure 12.

$$\left[I.P_1 \quad I.P_2 \quad \cdots \quad I.P_n \quad I.P_{n+1} \cdots \quad I.P_{2n} \right]$$

where *n* is the number of cutting planes for the panel.

- Generate the divided panels: the order of panel generation is from the starting vertex (*point a*) to the vertex (*point c*) with a maximum distance from starting one, as is depicted in the order of cutting plane in Figure 11. For each cutting section, the case of the panel cut was identified among the four possible cases as depicted in Figure 13 to Figure 16. Then, the new panel was generated and removed from the initial panel. The process continued to the last member of the intersecting matrix (Figure 10).

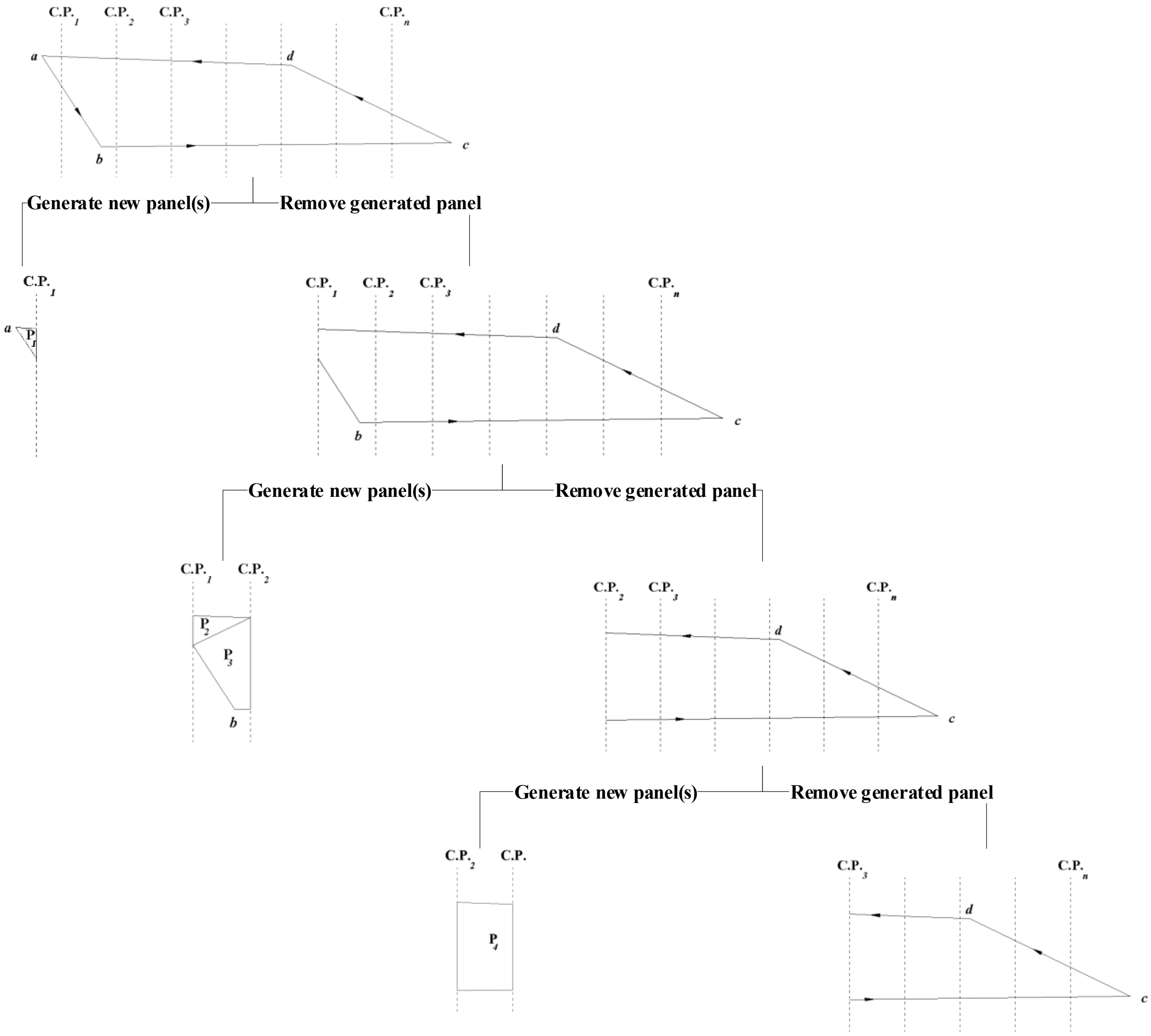

Figure 10. Schematic view of generating new panels, where multiple cutting planes intersect with one panel

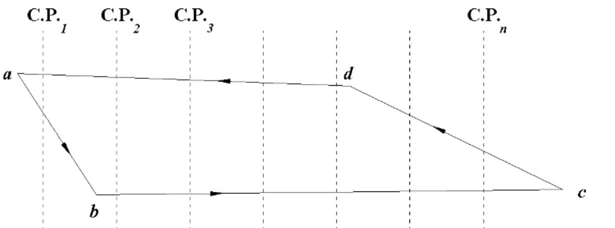

Figure 11. Intersecting of multiple cutting planes with a panel

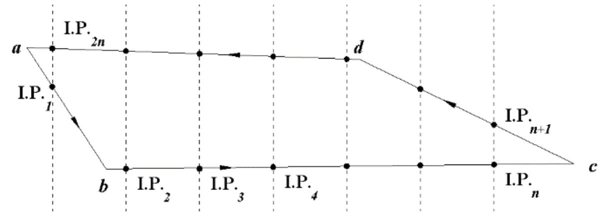

Figure 12. Determining the intersecting point of multiple cutting planes with the panel edges

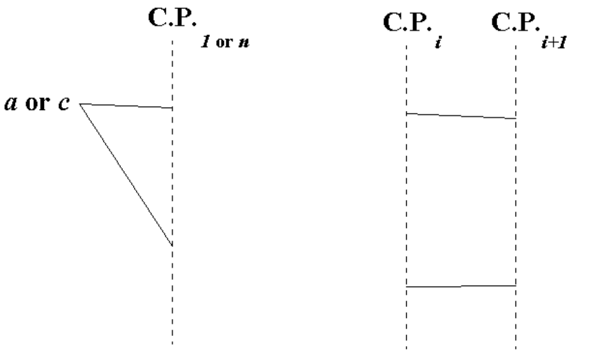

Figure 13. The case of panel cut, where multiple cutting planes intersect with a panel (*case I*)

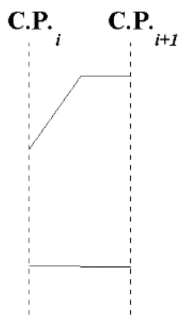

Figure 14. The case of panel cut, where multiple cutting planes intersect with a panel (*case II*)

4. APPLICATIONS

Two types of applications were demonstrated: 1) regeneration of the panels as the input of hydrodynamic prediction program, 2) subdividing the original panels to analyse the distributed pressure on the ship hull. Three case studies are used for the provided method of cutting panels parallel to the YZ axis. However, the applications of the cutting method are not limited to the mentioned direction. The process can be used for any direction of cutting planes by transforming the coordinates. For instance, the panels can be cut by a horizontal plane to demonstrate the underwater part of floating body. For those cases, a quality control of panels is required by simply applying a constraint for regenerated panels, such as the limitation for aspect ratio, area and centroid distances of subdivide panels relative to the original panels. Once the constraints are not passed the cutting process is stopped, and the original panel is used. However, the presented applications focused on the vertical cutting planes in this study.

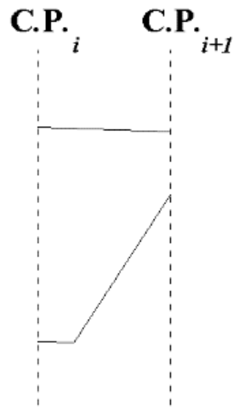

Figure 15. The case of panel cut, where multiple cutting planes intersect with a panel (*case III*)

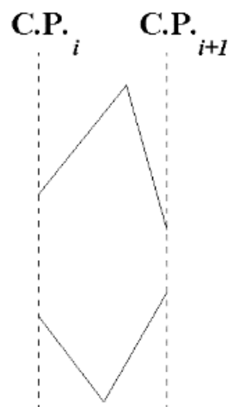

Figure 16. The case of panel cut, where multiple cutting planes intersect with a panel (*case IV*)

4.1 PANEL CUTTING IN SPECIFIC POSITIONS

The cutting method can be applied for special cases of panel discretization, where the panels need to be divided into predetermined positions. In particular, this application refers to the requirement of the modification of the panels' type at specific positions. For instance, if a specific part of the floating body needs to be defined as thin elements, while, there is no distinction between panels that present the source and dipole. So the cutting method provides the required panels in specified boundaries based on an arbitrary initial discretization.

Figure 17 presents an initial discretization of panels for a barge, the longitudinal positions of transverse bulkheads are specified for a compartment in the mid part of the barge. The panel type of the specified compartments required to be modified from the source to the dipole, thus, the panels between the transverse bulkheads need to be distinct with the other panels. The cutting technique provides the facility of panel modification without repeating the manual discretization of the body surface.

The bulkhead positions are defined as cutting planes, which are shown in two views of perspective and front. New panels are generated after applying the modification technique. Figure 18 shows the perspective and front views for the new panels, where panels of the specified compartment are generated separately. The intersecting panels with the cutting planes are divided and connected to the panels of transverse bulkheads in the position of the transverse bulkheads. While some of the panels that do not have an intersection with cutting planes remain the same as the initial discretised ones.

4.2 FINER DISCRETIZATION BASED ON INITIAL COARSER PANELS

The cutting technique also can be applied in the study of panels' size, where the sizes of panels need to be modified considering the geometry of the ship's hull to observe the effects on the seakeeping of vessels (Jafaryeganeh *et al.* 2015). For this application, the initial panels can be discretized with the coarser size, then the modification technique provides the facility of generation of models with finer discretization. The panel sizes can be reduced in a convergence study to observe their effect on the calculated hydrodynamic properties. For this purpose, some sets of cutting planes were defined to reduce the sizes of the original meshes uniformly. Thus, the average size of panels can be obtained without a manual effort to regenerate uniform panel for the convergence study.

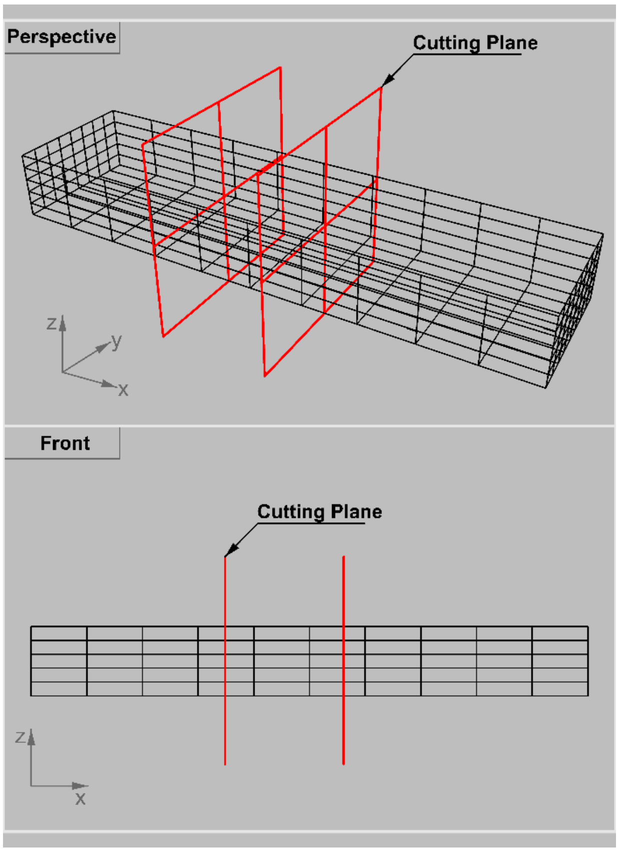

Figure 17. Initial discretised panels for a barge and determined cutting planes

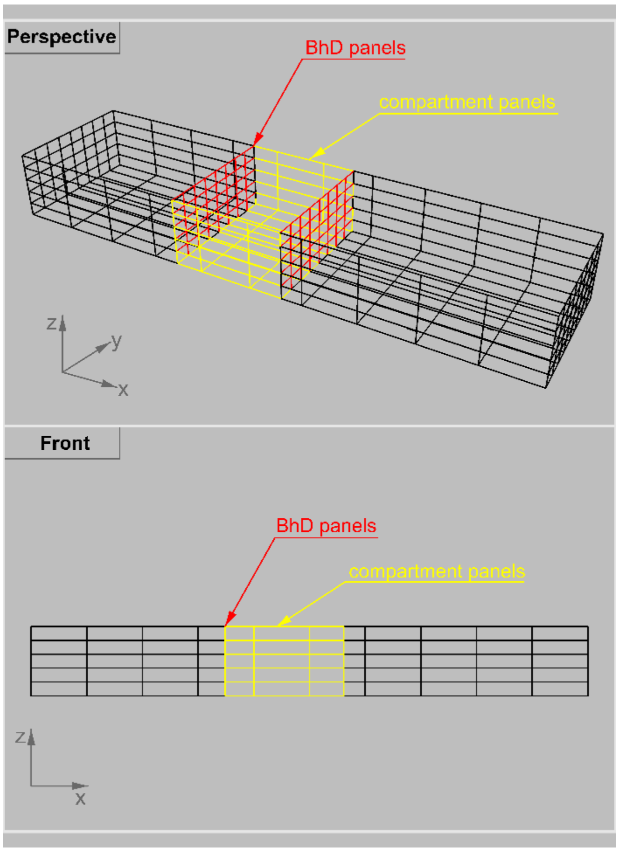

Figure 18. New panels generated by dividing the initial panels in the cutting planes position

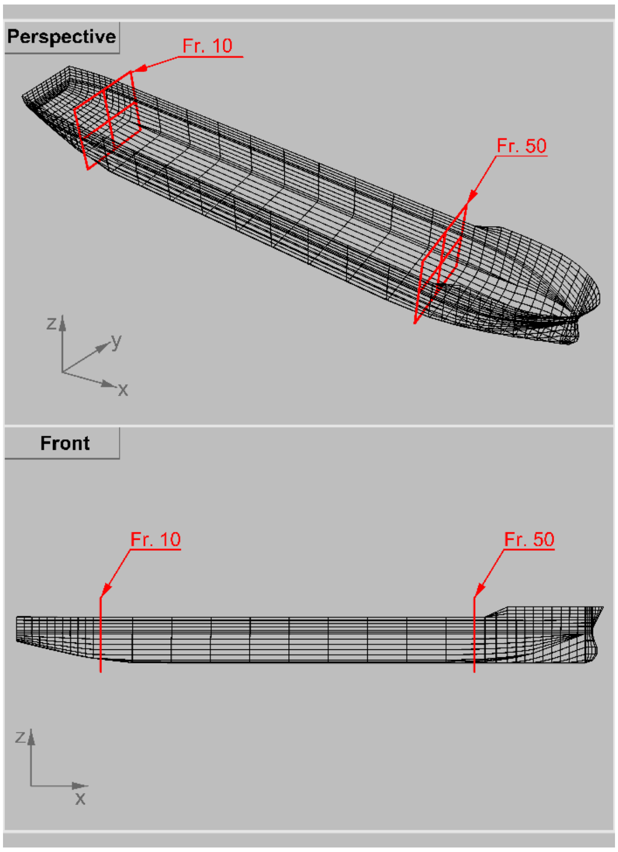

Figure 19. Initial discretised panels for a Shuttle tanker with coarser sizes between two specified frames

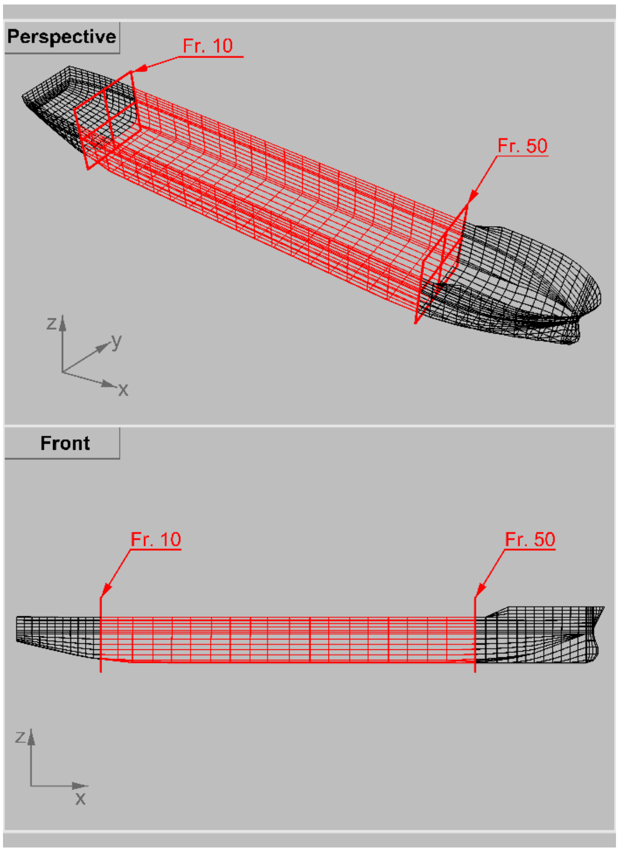

Figure 20. Modified panels by refining the initial panels between two specified frames

Figure 19 presents an initial panel discretization for a shuttle tanker, the model has coarser panels in the specified part between the frames of 10 to 50. A series of cutting planes are defined between two specified positions to generate the finer panels with homogenous sizes. Figure 20 shows a model of finer panels, which are modified by the cutting technique. The size of panels can be reduced in a recursive process to reach the optimum value from the aspect of the accuracy of the calculated results and run-time for hydrodynamic calculations.

4.3 IMPROVEMENT OF THE PREDICTED VERTICAL SHEAR FORCES

Initially, the formulation was described for vertical hydrostatic and hydrodynamic loads effect on the ship hull, in particular, the vertical shear force, then the application of the cutting technique for prediction of shear force is described by comparison of results for two types of panel discretization of a case study.

Below formulation presents the hydrostatic vertical bending moment (V_5^S) and shear force (V_3^S) at a transverse section with the longitudinal position of X:

$$V_5^S(X) = \int_0^X V_3^S(x)dx$$

$$V_3^S(X) = \int_0^X f(x)dx$$

$$f(x) = B(x) - w(x)$$

where, f, B and w are the net load, buoyancy and weight of the ship at the longitudinal position of x respectively.

The ship hull is assumed as a free-free beam box, i.e., shear-free and moment-free at two ends of the hull. The dynamic vertical shear force (V_3^D) at a cross section (X) is calculated by the difference between the inertia force (I_3) and the sum of the external forces acting on the hull section (Salvesen *et al*. 1970) as below:

$$V_3^D(X) = I_3(X) - \left(R_3(X) + H_3(X)\right)$$

where I_3 is the inertia force, R_3 is the restoring force and H_3 is the sum of the exciting force and hydrodynamic responses, including the diffraction and radiation effects in a potential fluid. Similarly, the vertical bending moment (V_5^D) at a cross section (X) is calculated as below:

$$V_5^D(X) = I_5(X) - \left(R_5(X) + H_5(X)\right)$$

where I_5 is the moment of inertia, R_5 is the restoring moment and H_5 is the sum of the exciting moments and hydrodynamic responses for the pitch motion more detail of formulation can be found in Papanikolaou and Schellin (1992) for the three-dimensional linear panel method.

The net load, shear force and bending moment of each section are functions of the distance of the specified section from the origin (A.P.). Thus, the prediction approach includes three main steps as follow:

- A series of arbitrary sections are defined alongside the ship's length.
- The sectional loads are calculated by accumulation of the load of the panels that are located between two consecutive sections.
- The total loads are calculated by the integration of the sectional loads alongside the ship.

The advantages of such panel discretization for load prediction is shown by comparing the results of two initial and modified panels. Figure 21 shows an initial discretization of panels for the well-known model of frigate 5415. Although, the initial coarser panels for the model have the proper size for the hydrodynamic pressure evaluation according to DNV (2010). They are not discretized based on the predefined distance of sections i.e., the panels mostly cross the predefined longitudinal position of the sections. Figure 22 presents the modified panels, which are divided by parallel cutting planes along the ship length. The number of sections is 142, which are defined from aft to the fore with an equal distance of 1m.

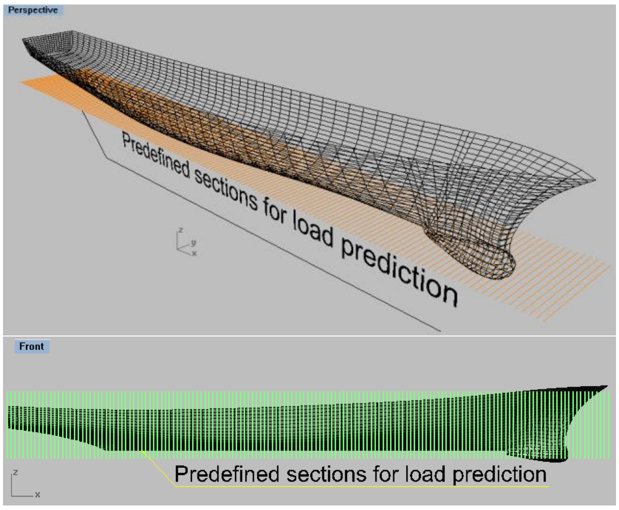

Figure 21. Initial discretised panels for frigate 5415

So, if the panel edges coincide with the predetermined longitudinal positions of the transverse sections, i.e., the discretised panels only located between two consecutive sections, then, the integration only included those panels that are located between the A.P and the specified positions of each section. Consequently, the loads can be predicted for a specific section accurately.

The application of such discretization was discussed in Jafaryeganeh *et al*. (2016), where the results of predicted loads by the panel method are compared with the strip theory method for each section along the ship length. Also, Jafaryeganeh and Guedes Soares (2018) applied the cutting technique for modelling the flooded compartment and predicting the wave loads for the damaged ships, where the result are compared with two methods of added weight and lost buoyancy.

The advantages of such panel discretization for load prediction is shown by comparing the results of two initial and modified panels. Figure 21 shows an initial discretization of panels for the well-known model of frigate 5415. The initial coarser panels for the model have the proper size for the hydrodynamic pressure evaluation according to DNV (2010). Thus, these panels were used to evaluate the hydrodynamic pressure by a three-dimensional panel code, where the run-time is compensated due to the small number of panels. However, the panels are not discretized based on the predefined distance of sections i.e., the panels mostly cross the predefined longitudinal position of the sections. The load predictions need the properties of the panel within the sectional distances to be calculated. So, the vertical cutting technique is applied to cut the original meshes into predetermined sections. The area of new panels and predicted pressure of initial panels were used to load prediction.

Figure 22 presents the modified panels, which are divided by parallel cutting planes along the ship length. The number of sections is 142, which are defined from aft to the fore with an equal distance of 1m.

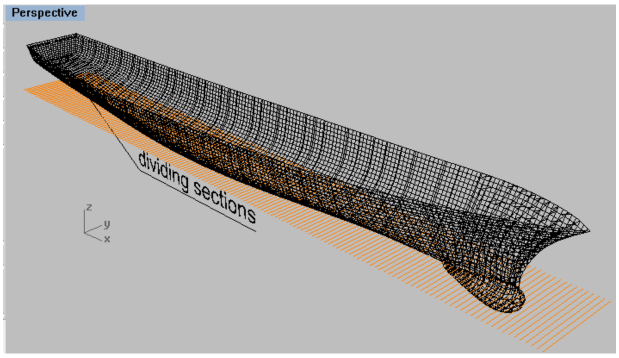

Figure 22. New generated panels for frigate 5415 by cutting at the position of parallel YZ planes with equal distance of 1m

The static and dynamic loads are predicted in the predefined section with 1 m distance along the ship length. Figure 23 shows the weight and buoyancy distribution for the initial coarser panels in the predetermined sections. The calculated buoyancy does not lead to a smooth curve relative to the *x*-position of the sections. Moreover, a large variation can be seen in the fluctuation points of the calculate buoyancy. These extreme cases happen when the sectional distances and lengths of coarser panels are of the same order. Thus, some of the predetermined consecutive sections do not include any panels centre. Consequently, the sectional buoyancy does not account for those sections, because the sectional buoyancy is calculated by the summation of the hydrostatic pressure on the centre of panels that are limited between the predetermined sectional distances. Figure 24 shows the weight and buoyancy distribution for the cut panels in the predetermined sections, the buoyancy distribution is calculated exactly and resulted in a function with a smooth curve relative to the *x*-position of the sections.

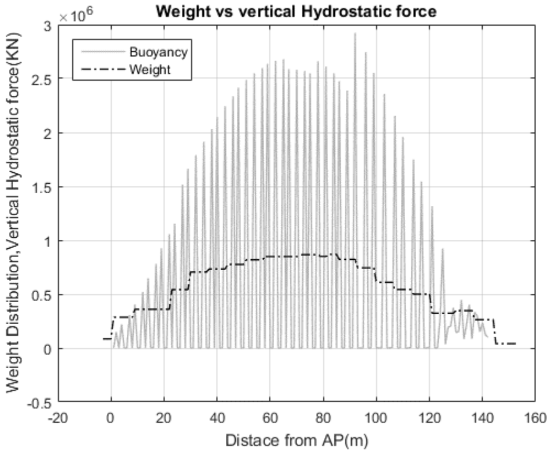

Figure 23. Weight and buoyancy distribution (initial coarser panels)

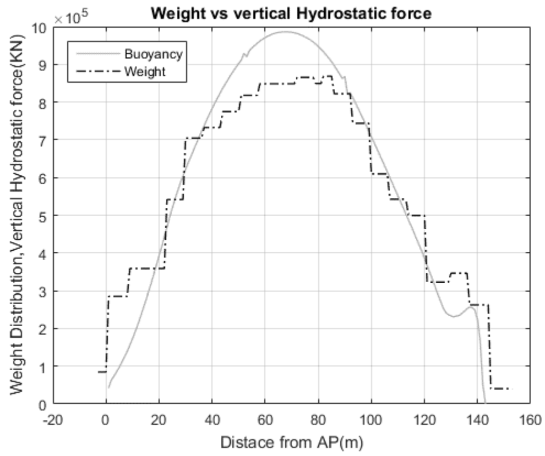

Figure 24. Weight and buoyancy distribution (modified panels)

Figure 25 presents the result of vertical hydrostatic shear force for initial coarser panels, the irregular fluctuation can be seen in the values of hydrostatic shear force. Because the integration of the imposed loads includes those panels that are not located exactly in the *YZ*-plane of sections. Figure 26 presents the results for the divided panels in the longitudinal positions of predefined sections. The shear force is calculated similar to the described process for the coarser panels, however, only those panels are included in the integration that is completely located right before the specified sections, i.e., all the panels are defined only between two consecutive sections. Thus, the accurate values of the vertical shear force for each frame result in a smooth curve relative to the ship length. The same trend can be seen in a comparison of the vertical dynamic shear force of initial coarser panels and the divided panels, the results are shown in Figure 27 and Figure 28 respectively. The induced wave shear force is predicted relative to the ship length for a head wave and 0.7 Rad/s frequency.

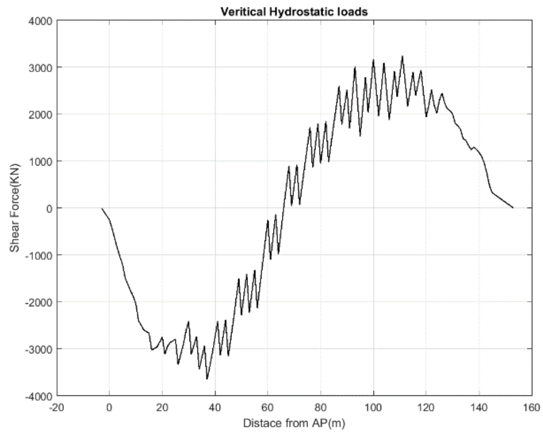

Figure 25. Hydrostatic shear force presentation for coarser panels in the position of frames with 1 m distance

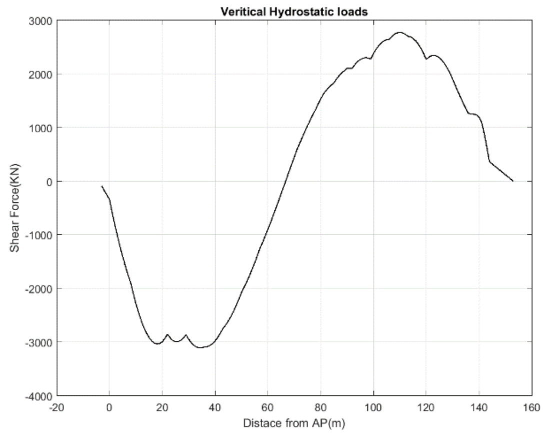

Figure 26. Hydrostatic shear force presentation for divided panels in the position of frames with 1 m distance

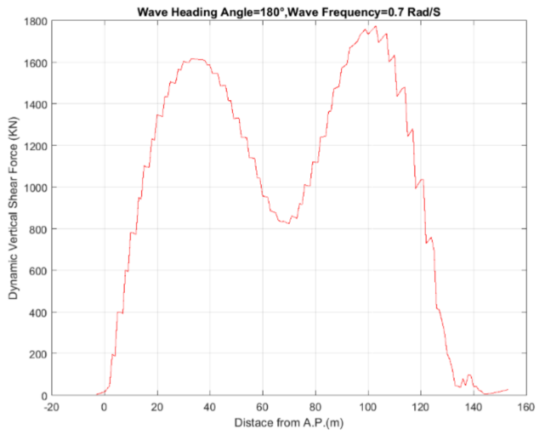

Figure 27. Dynamic vertical shear force for head waves with a frequency of 0.7 Rad/S relative to ship length (initial coarser panels)

The calculation of loads is a sample of application of cutting technique, especially for the buoyancy distribution and shear force, where the difference between the initial panels and the cut panels is significant. While the bending moments do not show such a significant difference between the initial panels and the cut panels.

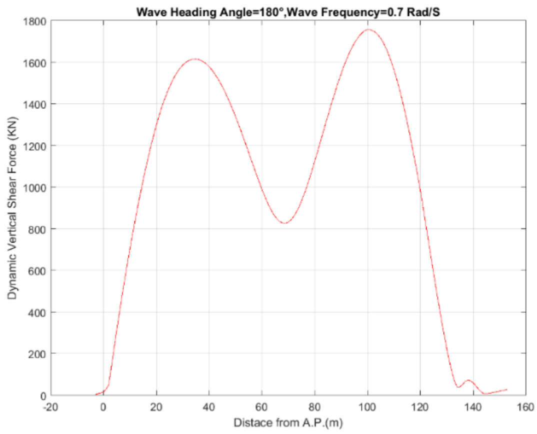

Figure 28. Dynamic vertical shear force for head waves with a frequency of 0.7 Rad/S relative to ship length (modified panels)

Figure 29 and Figure 30 shows the comparison of the predicted static and dynamic bending moment, respectively. Both initial and cut panels result in a similar prediction with a smooth curve relative to the *x*-position of the predefined sections. Because, the bending moment is the integration of the shear force, the fluctuations of the shear force function are reduced during the integration process. The reason can be explained by an example of an integration method. For example, if the "trapezoidal method" is applied for the integration of shear forces relative to the ship length, the variation of shear force is accumulated for two consecutive sections and finally, the average values of these two integrands are taken into account.

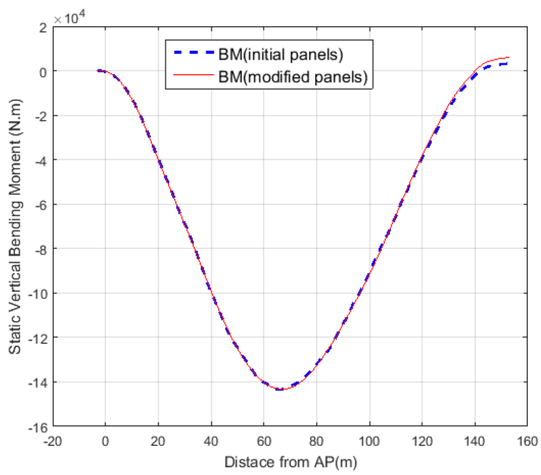

Figure 29. Comparison of static vertical bending moment for initial and modified panels relative to the ship length

So, the integration process moderates the variations of the two values of shear force for two consecutive sections. Similarly, The trend can be seen by comparison of the value of the fluctuations of buoyancy distribution (Figure 23) with the value of the fluctuations of the static shear force (Figure 25). The shear force is calculated by the integration of net load, so, the integration moderates the fluctuations of the buoyancy distribution. However, the integration of net load does not result in the complete elimination of fluctuations of shear force. So, the cutting technique is required to exact prediction of the shear force relative to the length of the ship.

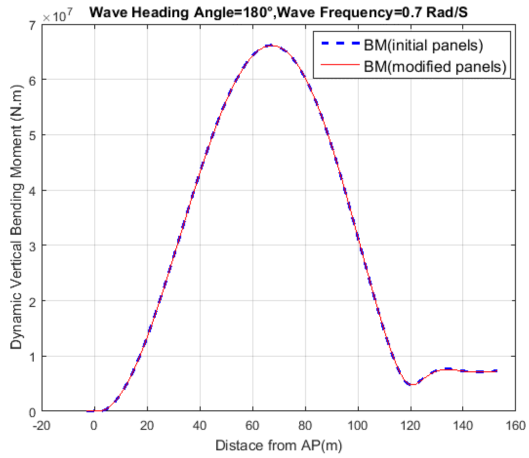

Figure 30. Comparison of dynamic vertical bending moment for initial and modified panels relative to the ship length for head waves with a frequency of 0.7 Rad/S

5. CONCLUSION

A technique has been presented for dividing quadrilateral panels, which are used to the discretization of the ship hull. The new panels can be generated considering distinct boundaries with the other panels at any predefined positions, however, the initial panels can be discretised arbitrary. Consequently, the presented method leads to reduce the time and effort for the manual discretization of the ship hull.

The applications of the provided technique have been described for vertical cutting planes, where the need for generating new panels are responded based on initial ones. The applications include a requirement for changing the type of panels in specific positions, generating finer discretization based on coarser panels, and improvement of the predicted vertical shear force for specific sections along the ship length. However, the uses of the technique are not limited to the mentioned applications, as it can be applied for any requirement of panel cutting in the hull discretization.

6. ACKNOWLEDGEMENT

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