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USING A TRIANGULATION TECHNIQUE FOR IMPROVING THE RESOLUTION IN ICEBERG SHAPE DATA

Abdillah Suyuthi [1]
[1]DNV GL, Høvik, Norway

ABSTRACT
Methods for estimating iceberg impact loads often rely on a representation of the iceberg shape. The accuracy of such a method will then depend on the vertical resolution of iceberg shape data. The shape data usually consist of a set of coordinates representing the iceberg wall, ordered as contours that connect vertices at equal level. Unfortunately, the available data usually has a coarse vertical resolution. The present paper describes the triangulation method, which refines the vertical resolution of the shape data effectively. The method is able to handle non-convex contours and is able to handle refinement for multiple contours at the same level. Therefore, the method allows the splash zone and sail parts of the iceberg, which is usually quite complex due to both non-convex shape and multiple contours, to be refined properly. An example on how improved resolution is obtained to a quite complex iceberg shape is also presented.

INTRODUCTION
For iceberg actions against offshore structures, ISO 19906:2010(E) mentions in clause A.8.2.4.7.3 that the impact load can be calculated using closed-form analytical solutions or numerical models. Both methods require that the instantaneous impact load be expressed as a function of penetration depth. The impact load can then be calculated based on the impact pressure and contact area. The impact pressure may follow a pressure-area relationship, which describes the strength properties of iceberg. The contact area depends on the structure shape, iceberg shape, and the penetration depth. When estimating the impact load, the contact area is an important parameter.

An accurate estimation of the contact area tends to be governed mainly by the iceberg shape. The iceberg shape data usually consist of a set of coordinates representing the iceberg surface ordered as contours, which connect vertices at equal level. Canadian Program of Energy Research and Development (PERD) iceberg shapes and geometry database is an example of iceberg shape data that is arranged in such a way; see Canatec et al. (1999). Unfortunately, the available data usually has a coarse resolution vertically, which could result in inaccurate contact area estimation. Therefore, a method to improve the resolution in iceberg shape data was developed.

The present paper focuses on the effort of improving the resolution in iceberg shape data by means of a triangulation technique. There indeed exist other methods for this purpose, such as level set analysis (Mukherjee and Ray, 2012), gradient controlled partial differential equation (Chai et al., 1998), straight-skeleton method (Felkel and Obdrzalek, 1998; Barequet et el., 2003), piecewise-linear interpolation (Barequet and Sharir, 1996), contour metamorphosis approach (Nilsson et al., 2005), and others. The triangulation technique is selected due to its workability and simplicity.

PROCEDURE OF THE TRIANGULATION TECHNIQUE

The process starts from the input data, i.e. 3D profile of the iceberg. The 3D profile data can be obtained from full-scale measurement. It is usually in the form of a collection of point coordinates (for example the one provided in PERD iceberg shapes and geometry database), which represents the iceberg surface. It is usually arranged as polygon(s) for the same level (the same z-coordinate value). Unfortunately, often the points in the polygon are not regularly arranged. Regularly spaced points in the polygon are necessary to ensure the triangulation runs well. Therefore, the original polygon(s) in each level needs to be modified (re-partitioned) prior the implementation of the triangulation technique in order to obtain regular points arrangement.

The resolution improvement using the triangulation technique is done by the slice-wise approach. The term "slice" here refers to vertices at two consecutive X-Y planes (the lower and upper ones), where vertices on each plane form a polygon (or more). An example of a "slice" of an iceberg 3D-profile is presented in Figure 1. More polygons at intermediate horizontal planes are generated for each slice. All newly generated polygons at the intermediate horizontal planes are then combined with the original planes in order to form a refined set of contours, which indicates the whole surface of the iceberg.

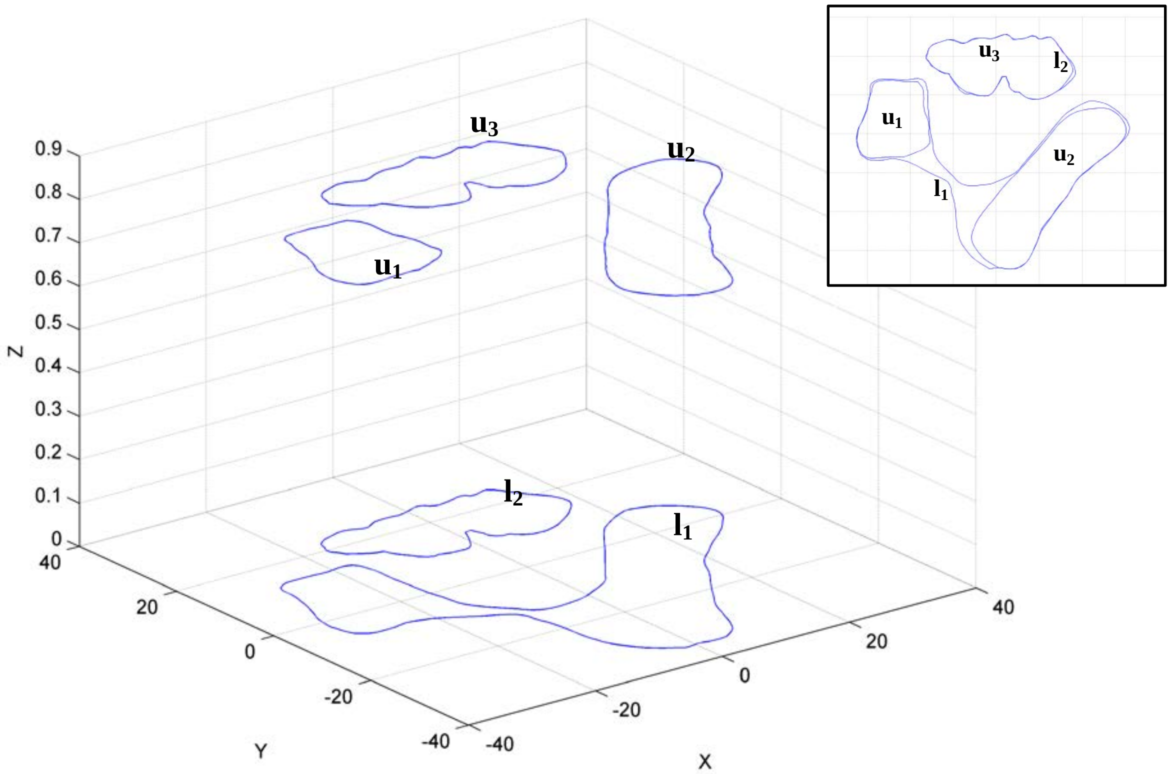


Figure 1. An example of a "slice". The lower and upper contours consist of two and three polygons, respectively. Note the Z-axis is not scaled for clarity. The inset shows the polygons seen from above.

The procedure to improve the resolution in iceberg shape data can be outlined as follows:

1. Select a slice (which consists of the lower and upper contours), see Figure 1.
2. Create the triangulation, see Figure 2.
3. Use the “legs” of the triangles as interpolation line.
4. Divide the interpolation line at intended Z-level and create new vertices.
5. Select the vertices at the same new intermediate horizontal plane.
6. Re-arrange the selected vertices, connect them, and create a new polygon, see Figure 3.
7. A new intermediate contour is created and finally an improved resolution shape data is achieved, see Figure 4.

If a contour at a particular level (or both levels, i.e. the lower and upper ones) consists of more than one polygon and only if those polygons overlap, then the above procedure is repeated for each pair of polygons. An example is given in Figure 1. Here, a slice consists of two polygons (l_1, l_2) at the lower level and three polygons (u_1, u_2, u_3) at the upper level. As indicated at the inset in Figure 1, that there are two groups of overlapping polygons. First, polygon l_1 overlaps with polygons u_1 and u_2. Second, polygon l_2 overlaps with polygon u_3. Thus, the polygon pairs are (l_1, u_1) and (l_1, u_2) for the first group and polygon pair (l_2, u_3) for the second group.

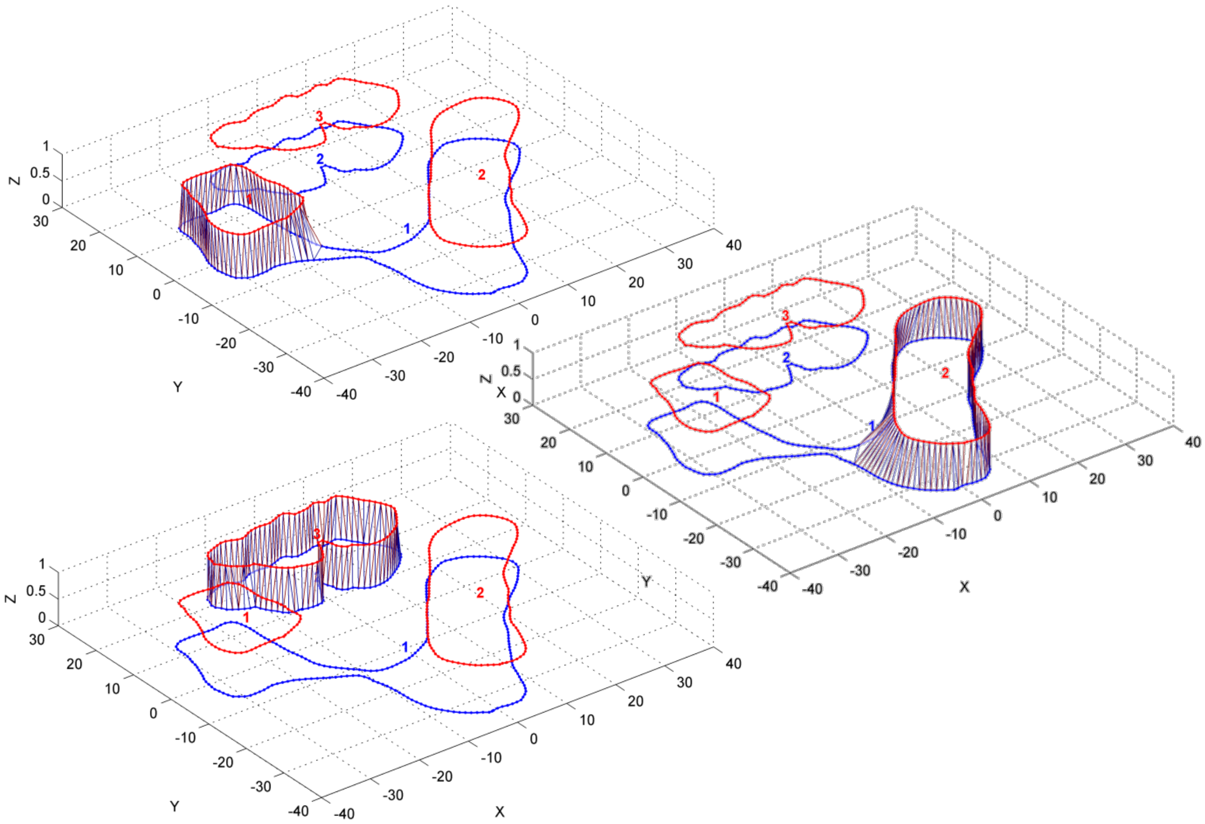


Figure 2. Triangulation of each pair of polygons. Note the Z-axis is not scaled for clarity.

When a group consists of more than one pair of overlapping polygons, then extra consideration is necessary. This is especially true when one or more newly created intermediate polygons of a particular pair intersecting with other intermediate polygons at the same level. If it is the case, then the intersected polygons must be combined into a single polygon. An example is given in Figure 6. The blue and red polygons are the lower and upper polygons, respectively. The shaded polygons are the intermediate polygons, which evolve from (a) to (i) with decreasing Z-level. In Figure 6.(e)-(i), we observe that the intermediate polygons are intersecting each other for contours #e-#i. The intersection points are detected; and then the overlapping bounded areas (marked by darker color) are deleted; and finally both polygons are combined. The result is presented in Figure 6.

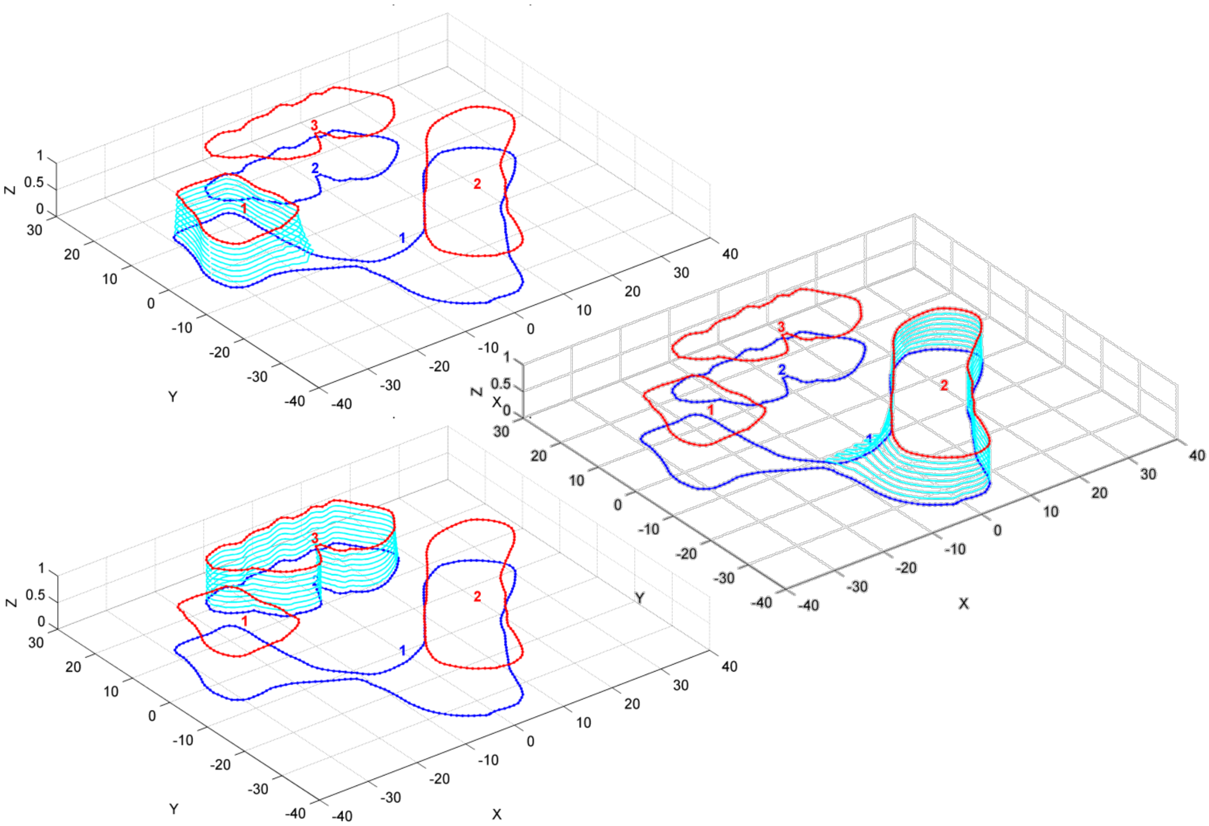


Figure 3. Intermediate polygons are generated for each pair of polygons.

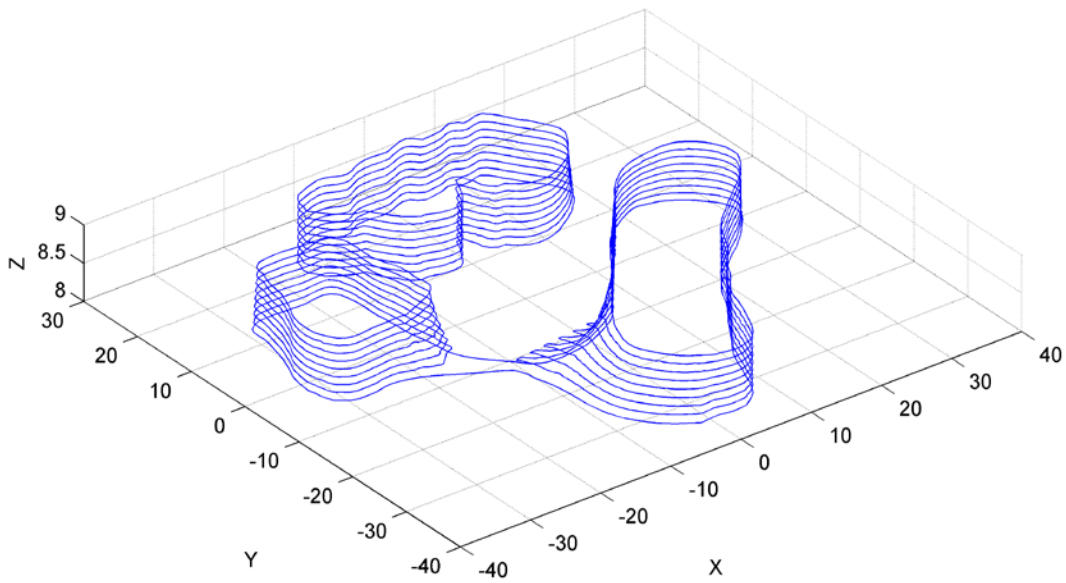


Figure 4. A new set of intermediate contours is created and finally the resolution shape data is improved.

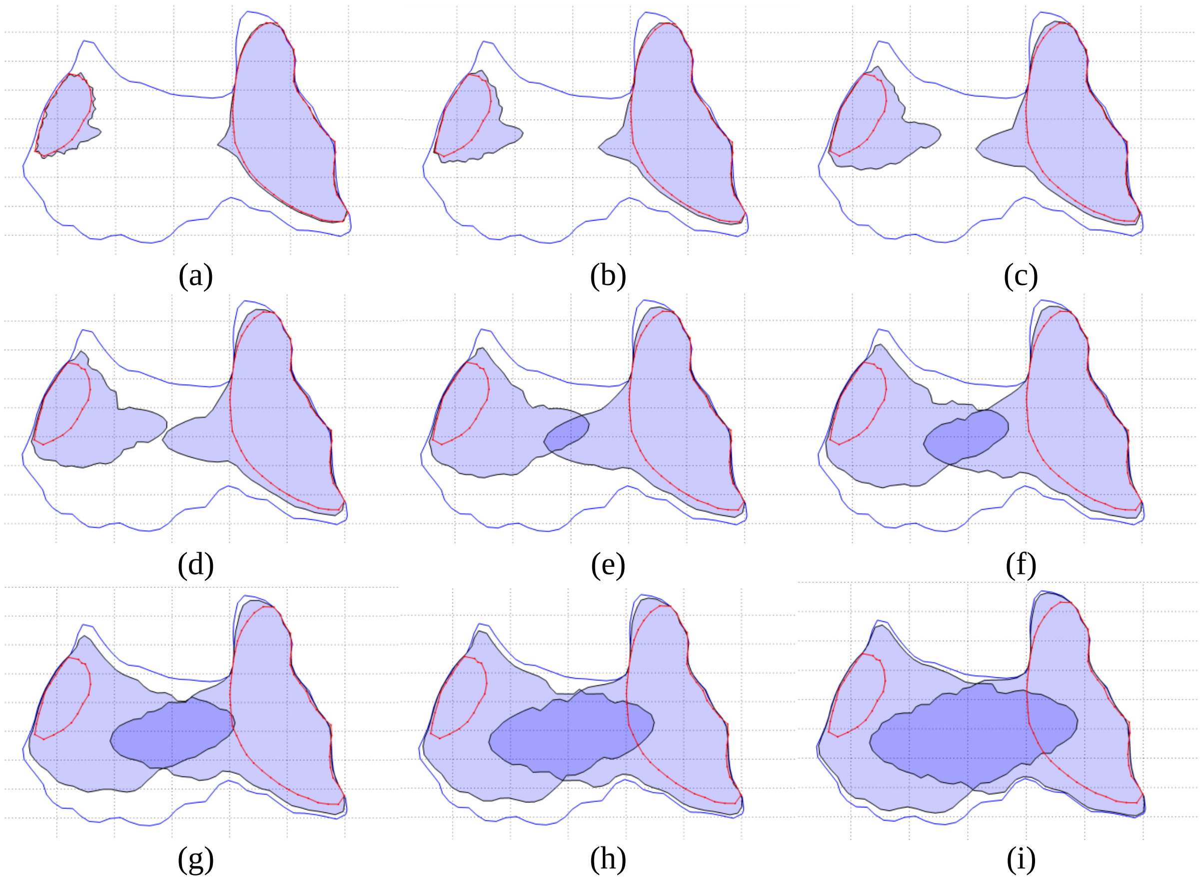


Figure 5. An example case when one or more newly created intermediate polygons of a particular pair intersects with other intermediate polygons at the same level.

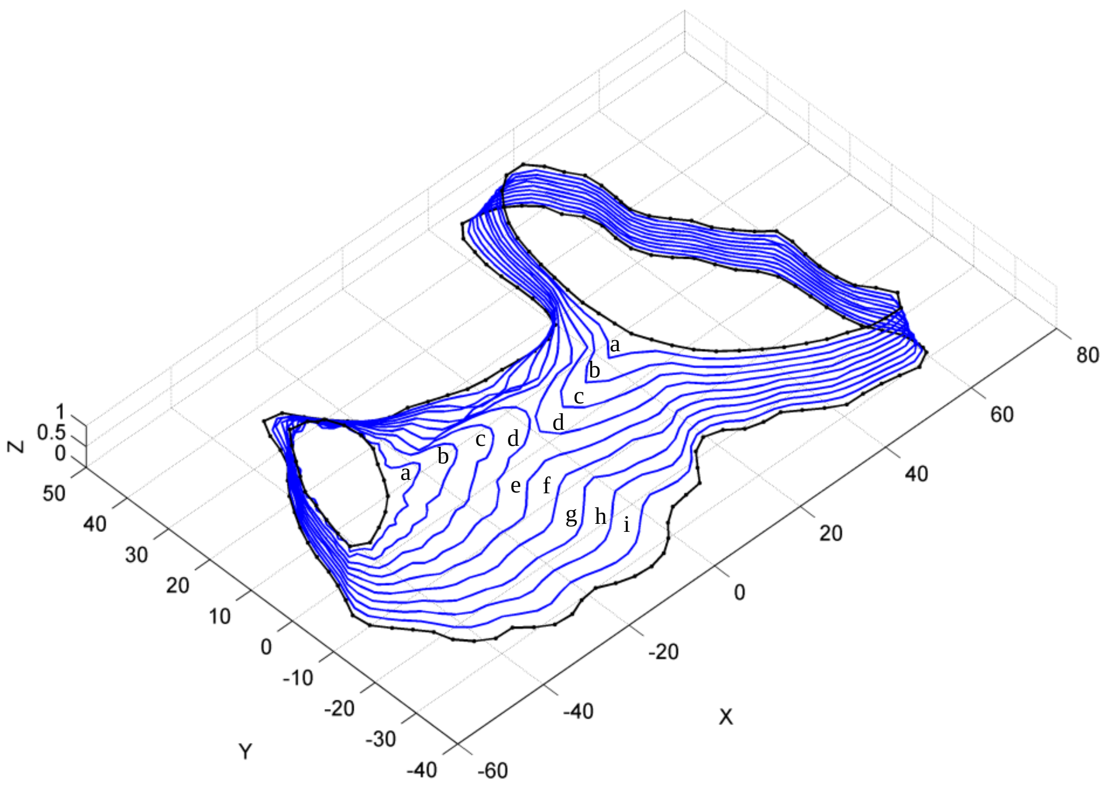


Figure 6. The result of the intermediate polygons that are intersecting each other.

DISCUSSION

The triangulation technique presented here assumes a linear transition between the lower and the upper planes, which is limited to a single triangle plane. Linearity assumption is quite natural due to the slice-wise approach, which only involves two planes at a time. Moreover, linear transition oriented in 3D-space, which is governed by the triangle legs, could be meant non-linear transition. This can be understood if we slice the refined iceberg shape vertically at an arbitrary X or Y values, see Figure 7. The non-linearity transition is even clearer when the top-most and bottom-most planes are absent, see Figure 7(b)-(d). The projected view of the refined iceberg shape also shows that the transition between the original upper and lower planes is not linear, see Figure 8.

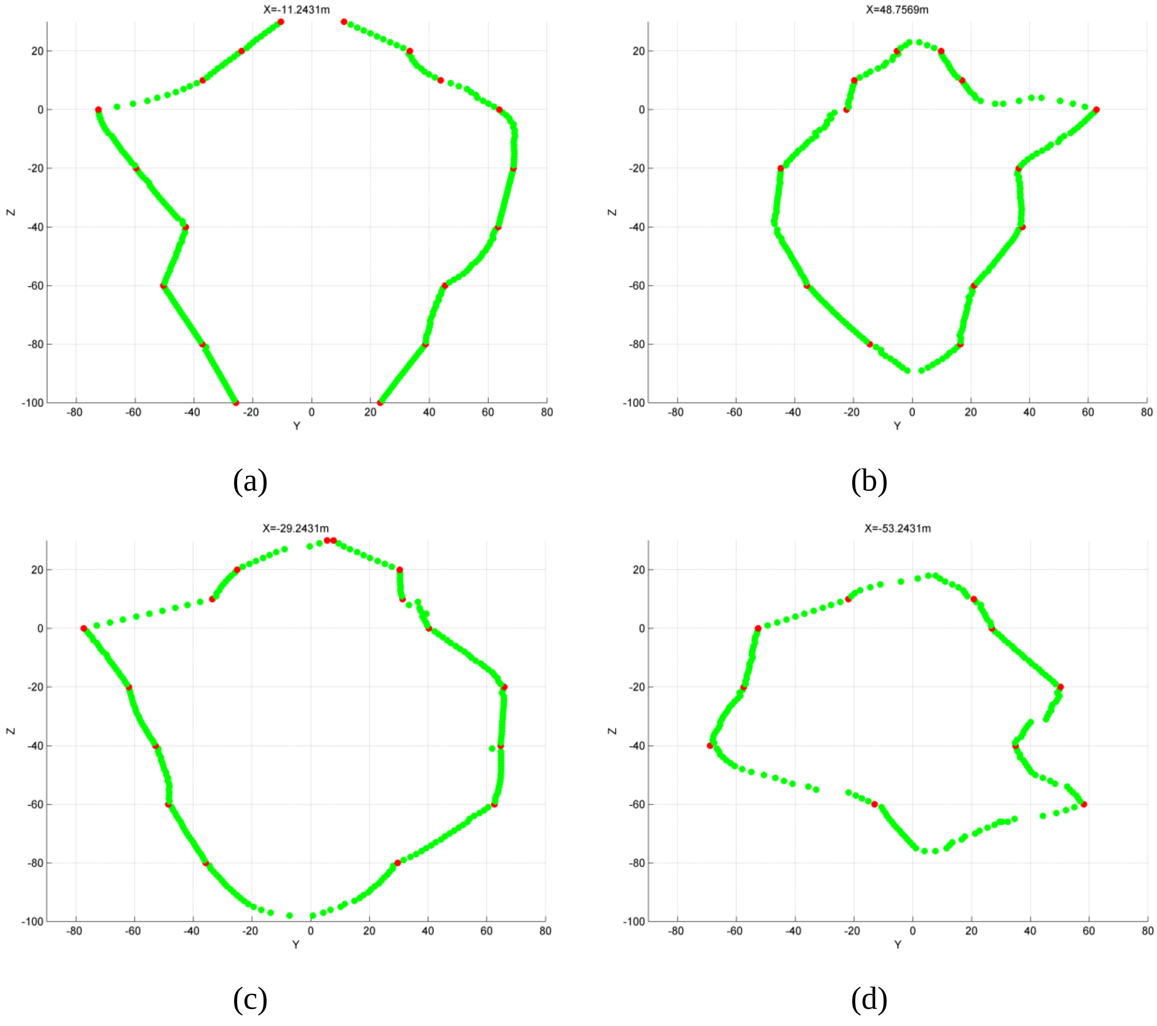
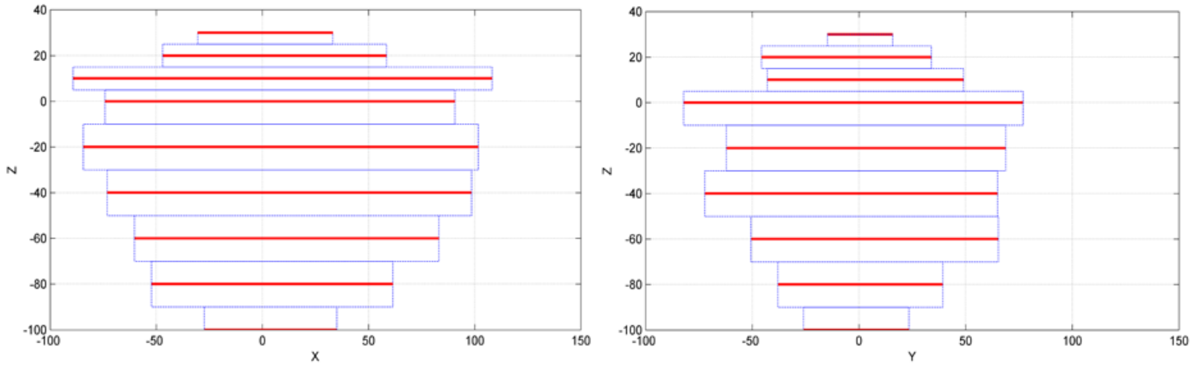


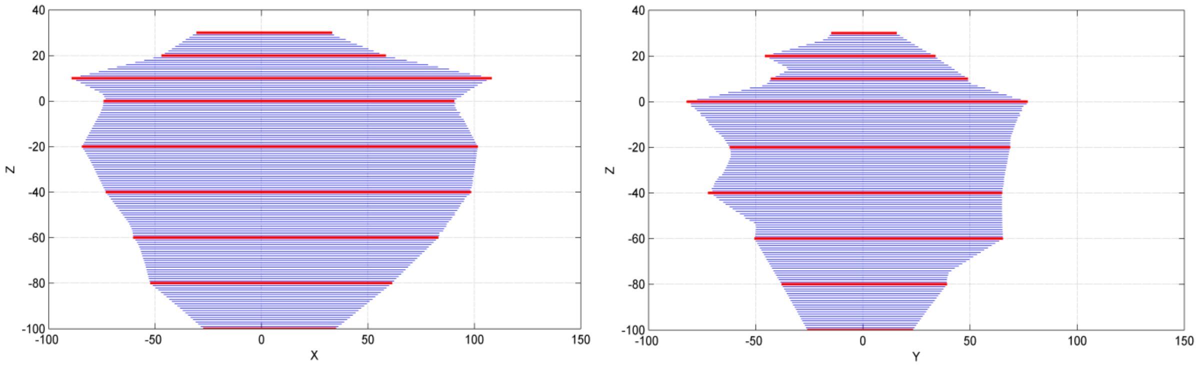
Figure 7. Section view of the refined iceberg shape at various X values. NB: the red dot represents the original contour.

The estimation of iceberg impact load based on pressure-area approach requires the assumption of the iceberg shape. One may employ the original shape data (which may have course resolution) as an option, see Figure 8(a). Alternatively, one may employ the refined shape, which has finer resolution as another option, see Figure 8(b). It should be clear that the second option, by using the refined iceberg shape, as shown in Figure 8(b) looks more realistic. Since there is no more information available regarding the iceberg shape in between the two planes, any approximated transition planes (either linear or non-linear) that do not alter the original planes should be valid.

It is understood that the most "appropriate" shape refinement method should be able to track the geometry change of the iceberg throughout its life. This involves the geometry changes due to all physical processes during the iceberg formation, relief formation processes due to wave, wind, and currents actions, thermal effects, as well as due to scouring with seabed. However, that is beyond the scope of the present paper.



(a) Projected view of the original iceberg shape.



(b) Projected view of the refined iceberg shape.

Figure 8. Projected view of the original and refined iceberg shapes at X-Z and Y-Z planes. NB: the red line represents the original contour.

In order to illustrate the application of the present method, the same iceberg shape as presented in Figure 8 is used as case study. The iceberg is moved along X-axis (negative to positive) against infinite vertical wall. The step of penetration depth is $\Delta\delta$=0.1m. On each step, the following values are calculated:

1. Contact area, A.
2. Impact force, $F = P \times A$, where P is ice pressure and taken as constant 1.0Mpa.
3. Collision energy, $E = F \times \Delta\delta$.
4. Cumulative of collision energy, $E_{cum} = \Sigma E$.

Accordingly, we may expect that the contour at Z=10m will be crushed first and then the contour at Z=-20m. The development of contact area at various penetration depths is shown as example in Figure 9. The calculation result of A, F, and E_{cum} is presented in Figure 10. If the kinetic energy that needs to be spent during collision is 160 MJ, then the corresponding iceberg impact load is 67.3MN and 126.4MN based on the original and refined iceberg shapes, respectively. For this particular example, the refined iceberg shape gives the impact load almost twice as given by the original shape. However, if the kinetic energy that needs to be spent during collision is 400 MJ, then it seems the refined iceberg shape gives lower impact load as compared to the one given by the original shape. Therefore, it is difficult to conclude which option gives more conservative result. Large number of iceberg shape (and orientation relative to the vertical wall) may be needed to clarify the conservative and non-conservative issue, which could be a subject of further study.

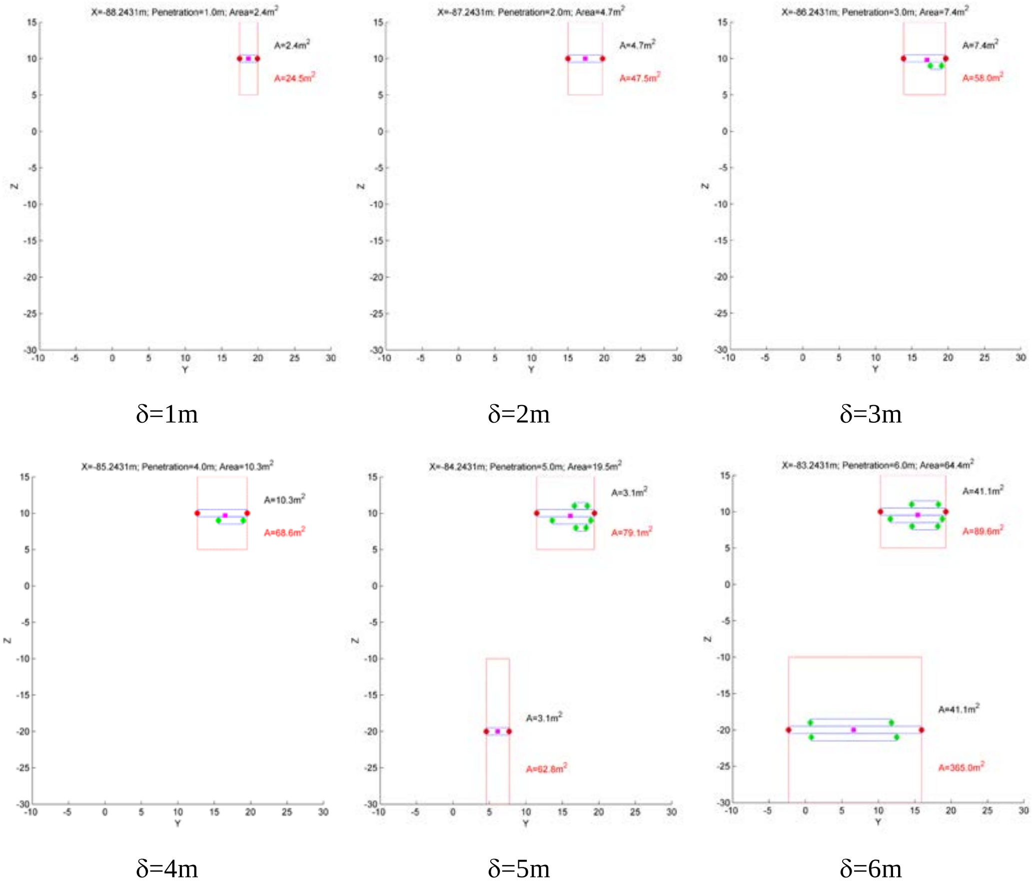


Figure 9. Contact area development at various penetration depths. The blue and red lines represent the contact area based on the refined and original iceberg shapes, respectively.

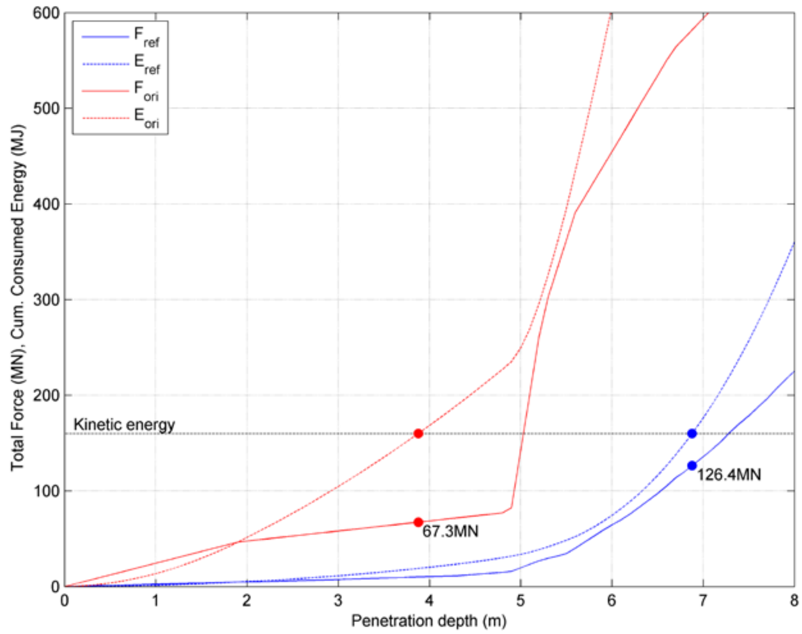


Figure 10. Iceberg impact load and cumulative collision energy as function of penetration depth.

CONCLUSION

A method to improve the vertical resolution of iceberg shape data, by means of the triangulation technique, has been outlined. The presented examples demonstrate that the proposed approach is able to handle non-convex contours and is able to handle refinement for multiple contours at the same level. The case study shows discrepancy of iceberg impact load resulted from the application of different iceberg shape assumptions (coarse resolution versus refined shapes). However, it is not yet clear which shape assumption gives result that is more conservative.

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