Influence of geometric detail in component modeling

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Abstract

In any computational approach it is necessary to idealize the structure modeled to some extent. In much of the work completed to date using boundary element methods to model shipboard impressed current cathodic protection systems (ICCP) propellers have been idealized as solid disks. While this simplified geometry may capture the shadowing nature of the component it may not capture essential features of the near hull potential field in the vicinity of the propeller. Earlier work utilized the disk representation of propellers as a required compromise between modeling and problem size limitations. Recent advances in computing power coupled with advances in solid modeling programs have resulted in the ability to readily create complex geometries without significant concerns related to mesh size. In this work three different representations of propellers are evaluated. The hull geometry studied is that of the US Navy CVN aircraft carrier class. This hull class has 4 propellers. Two methods of representing details of propeller geometry are examined. In one case the propeller is modeled in detail including individual blades. In the second detailed approach a propeller is modeled as a solid that is shaped to simulate the complex geometry of a rotating assembly. Calculated potential fields for these two advanced geometric representations are compared with results based on the solid disk representation.

Keywords: impressed current cathodic protection, mesh refinement, boundary element, corrosion control.
1 Introduction

Computational modeling is often approached as a mixture of science and art. Mesh refinement studies and error estimations have presented more of the science to the general technical population. However there is still very much a feel of an art to the determination of what features should be included in a computational model and what features can be left out without sacrificing accuracy in the resulting calculations. In the case of systems that are subject to synergistic response based on a complex combination of factors, it is imperative that analysts must be aware of the potential impact of the inclusion or exclusion of what may seem on the surface to be minor features. In the past the decision to represent a structure as an idealized streamlined geometry ignoring what may well be key, but minor, features was often based on issues of feasibility. It simply was not possible to create or to run in a reasonable time more detailed models. Another issue that the analyst also has to struggle with is how accurately do the calculated results have to be. This is directly dependent on what uses will be made of the results. Variations between two different designs can be determined with relatively simplistic models that capture the primary features. Detailed designs that require understanding of minor variations in stress, temperature, voltage or other calculated fields require more details.

Initial work on impressed current cathodic protection (ICCP) systems for marine structures, including shipboard systems, was focused on determining overall system performance. Introductory work by Stromman et al [1], Adey and Niku [2] and Zamani [3] emphasized the feasibility of the application of boundary element methods to these types of systems. More detailed performance investigation lead to work that examined material and boundary condition assumptions. Advances in the confidence of the community in the application of boundary element methods to shipboard ICCP system calculations has led to questions that require more and more detailed models. In addition advances in control systems and increased complexity of the next generation ICCP system has increased the need for accurate prediction of system performance under many different operating conditions.

The focus of this paper is the development of more detailed representation of the propeller of a ship hull model. The impact on calculated results due to the inclusion of different propeller representations is discussed. It is noted that the mesh sizes of the boundary element models do significantly increase with the addition of bladed and other more detailed representations for the propeller assembly. Key to being able to create and successfully evaluate more detailed and therefore more geometrically realistic models are the advances made in computational speed and memory with associated reduction in computational costs in the past few years. It was simply impossible to create these sizes of meshes until very recently. Since the resources are now available at reasonable costs it is incumbent upon the analyst to determine if the past methods are sufficient for the levels of accuracy now required of the calculated results.
2 Ship geometry and BE modeling

The ship hull chosen for study is the U. S. Navy aircraft carrier hull class. There has been significant work done with a computational model previously created of this hull class. The boundary element mesh is of the underwater portion of the hull. A symmetric model is created so that half of the ship is modeled. Symmetry conditions are used to represent the water surface. The computational model of the U. S. Navy aircraft carrier hull class has been previously validated by comparison with physical scale modeling experimental results [4]. It has become a boundary element model that has been used for parametric studies of boundary and material conditions [4-6]. All computational models were created in or imported into MSC Patran [7]. Boundary element meshes were then translated using a custom program developed at the Naval Research Laboratory (NRL) to create input files for the commercial boundary element program BEASY [8]. The BEASY cathodic protection solver was used. The results are post-processed using another custom program developed at NRL that extracts and translates pertinent data. Contour plots are then generated using the program Tecplot [9].

There are three different propeller assembly geometries considered. The first is the disk with equivalent area that was used in the original modeling of the aircraft carrier hull class. A pseudo attachment strut is used as seen in Figure 1 and no propeller shaft is included in the model. This representation was chosen in the original work due to mesh and memory limitations. Results agreed well for global responses and point values at the lower tip of the propeller for static conditions. There were differences noted in experimental and computational results for dynamic maximum damage conditions. These were attributed to material characteristics such as film formation and mixed potential response that are not accounted for in the material polarization response used [4].

![Figure 1: Disk representation of propeller.](image)

The second propeller assembly geometry considered is a detailed bladed model (Figure 2a). This model is shown with the modeled truncated portion of the propeller shaft; not shown are the attachment struts. The bladed geometry allows for the protective current to flow through the gaps between blades. It provides a geometrically realistic representative of the propeller at rest or at slow revolution speeds. The addition of the bladed propeller increases the mesh size from 1884 elements to 3793 elements as shown in Table 1.
Table 1: Mesh information for 3 different propeller geometries.

<table>
<thead>
<tr>
<th></th>
<th>Disk Propellers Static Conditions</th>
<th>Disk Propellers Dynamic Conditions</th>
<th>Real Propellers Static Conditions</th>
<th>Rotating Propellers Dynamic Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Elements</td>
<td>1884</td>
<td>1884</td>
<td>3793</td>
<td>3760</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>7996</td>
<td>7996</td>
<td>16,199</td>
<td>15,898</td>
</tr>
</tbody>
</table>

Runs time increase from less than a half hour to just over two hours clock time. This is deemed acceptable. It should be noted that the larger run times are equivalent to or less than those required in earlier work for the aircraft carrier model with disk representations for propellers. The decrease in clock run time over the years for the same boundary element mesh has been due to advances in computational power and processor speed. The current analyses were performed using a Sun Ultra workstation running Solaris 8 (450 MHz SPARC processor, 4GB memory). BEASY was run serially.

The third propeller assembly geometry considered is a stylized representation of a fast spinning propeller assembly. The ‘donut’ shape propeller is shown in Figure 2b. This model is shown with the attachment struts. These struts were also included in the model with the bladed propeller. This propeller assembly was created to represent the profile created by the high-speed response of the bladed propeller. The disk propeller can be used to represent this same condition however the ‘donut’ shape of this model provides a representation of the convoluted surface created by the propellers as they spin at high speeds. The spinning propeller assembly resulted in a total mesh size of 3760 and run times equivalent to the bladed assembly model.

Figure 2: Detailed propeller models. (a) Bladed model for static analysis and (b) ‘Donut’ shaped model for fast spinning propeller for dynamic analysis.
3 Results

In all cases maximum design damage conditions were considered. Maximum damage consists of 15% of the wetted surface area defined as bare metal in a pattern defined by Naval Sea Systems Command. The propeller geometries were matched with the appropriate design conditions. Results for the disk propeller representation were calculated for static and dynamic conditions. Results for the bladed representation were calculated for static conditions. Results for the rotating bladed representation were calculated for dynamic conditions. The same anode input values were used for both static cases. The same anode input values were used for both dynamic cases.

Figure 3: Potential contours for propellers. (a) Disk representation. (b) Bladed propeller for static analysis. (c) ‘Donut’ shaped propeller for dynamic analysis. Inboard propeller (propeller 2).
Computational results were compared. The intent is not to determine if one representation better approximates the experimental response but what is the influence of the additional detailing on the calculated results. All calculated results were derived using the same version of the computational code. Results of interest are the potential at key locations and potential contours. Locations of interest for point potential values are the lower tip of each propeller, the lower edge of the rudder, the bilge keel corner, the keel corner and reference cell locations. Reference cells located forward, mid-section and aft are used to control the ICCP system. Reference cell 3 is the aft control point and is the most likely to be affected by the changes in propeller geometry.

First consideration will be given to the potential fields on the propellers themselves. As can be seen in Figure 3 (a-c) the absolute range of potential does not vary however there are changes in the profiles on the propellers. Figure 3 is for the inboard propeller (propeller 2). Little information can be gained from the disk model as to the protected state of the propellers.

In examining the on-board potentials on the hull in the aft region significant changes in the profiles are observed as shown in Figure 4 (a-b). These variations are due solely to the use of a bladed propeller model instead of the disk representation. The bladed representation allows for increased current flow to the aft section of the hull. Essentially the disk geometry intensifies the shadowing effect of the propellers.

Figure 4: Hull on-board potential contours for (a) Bladed propeller and (b) Disk propeller representation.
Finally we will discuss the potential point values at key locations. Table 2 shows point values associated with key locations of interest shown in Figure 5. Reference cells are located fore, mid-hull and aft. Reference cell 3 is the aft reference cell. Anode input values are identical for each set of runs; static runs used the same anode values and dynamic runs used the same anode values. Whether the potential at point locations increases or decreases with the use of a more detailed model is dependent on geometric location. What is important to note is that the reference cell readings for the static conditions are increased with the more detailed geometric meshes. Reference cell readings for dynamic conditions show the opposite trend. The more detailed model results in reduced values. Reference cell readings are the feedback value that drives the ICCP system response. These are critical values in the system design. This is important in understanding the differences between predicted ICCP system performance and actual in field performance.

Figure 5: Geometric feature location used for point value comparisons.

4 Summary

This work examines the influence that the level of detail of attachments, specifically the propellers, has on calculated results. Advances in computational speed and affordability have made the use of highly detailed models possible on an as needed basis. In many instances these models were not possible in the past. Memory as well as financial considerations prevented the use of detailed representations.
Table 2: Potential values at defined points (Figure 3).

<table>
<thead>
<tr>
<th>Potential (V)</th>
<th>Point</th>
<th>Disk Propellers Static Conditions</th>
<th>Bladed Propellers Static Conditions</th>
<th>Disk Propellers Dynamic Conditions</th>
<th>Rotating Propellers Dynamic Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Tip of Propeller 1</td>
<td>A</td>
<td>0.773</td>
<td>0.801</td>
<td>0.812</td>
<td>0.726</td>
</tr>
<tr>
<td>Lower Tip of Propeller 2</td>
<td>B</td>
<td>0.786</td>
<td>0.810</td>
<td>0.851</td>
<td>0.737</td>
</tr>
<tr>
<td>End of Rudder</td>
<td>C</td>
<td>0.929</td>
<td>0.951</td>
<td>0.859</td>
<td>0.783</td>
</tr>
<tr>
<td>Bilge Keel Corner</td>
<td>D</td>
<td>0.866</td>
<td>0.897</td>
<td>0.938</td>
<td>0.930</td>
</tr>
<tr>
<td>Keel Corner</td>
<td>E</td>
<td>0.934</td>
<td>0.981</td>
<td>0.896</td>
<td>0.876</td>
</tr>
<tr>
<td>Reference Cell 1</td>
<td></td>
<td>0.862</td>
<td>0.890</td>
<td>0.852</td>
<td>0.845</td>
</tr>
<tr>
<td>Reference Cell 2</td>
<td></td>
<td>0.865</td>
<td>0.892</td>
<td>0.940</td>
<td>0.932</td>
</tr>
<tr>
<td>Reference Cell 3</td>
<td></td>
<td>0.862</td>
<td>0.903</td>
<td>0.804</td>
<td>0.795</td>
</tr>
</tbody>
</table>

In the work three different propeller representations are considered. Two of the representations provide more geometric details. One propeller representation is a disk geometry that has long been used in boundary element modeling of shipboard ICCP systems. The bladed propeller and disk propeller are compared for static conditions. The spinning propeller, or ‘donut’ model is compared with the disk propeller for dynamic conditions. Input anode values are maintained constant between the two different geometries for each flow condition. There are significant differences in propeller and hull on-board potential profiles. Whether potential values are increased or decreased is dependent on their geometric location. The disk geometry intensifies the shadowing effect of the propeller assembly. The bladed representation allows protection current flow through the propeller. The changes in potential field patterns has significant implications for the control and performance predictions of ICCP systems based on the location of reference cells. If the reference cell is located in a region that experiences increased shadowing due to the disk representation then calculated performance will be different from actual performance.

There are additional costs, in time and money, associated with the more detailed geometries. Therefore the analyst must consider the end use of the analysis in her decision on how detailed the model must be. Costs should be
evaluated based on the analysis requirements. None of the detailed geometries presented here are such that they cannot be generated or run within a reasonable length of time. The increases in computer time reported in this work should be considered worse case since no mesh refinement or optimization studies were performed. In fact the authors feel that the ‘donut’ spinning propeller mesh is overly dense.

In general, the more detailed the level of design the more detailed the computational model should be. Much can be learned about how different systems perform using a relatively simple model. However, for such critical design decisions such as reference cell placement a more detailed model should be used.

This work should not be seen as a criticism of earlier work but an enhancement to the understanding of what is possible with computational modeling. Past work has provided important information on system performance. In some respects an increased confidence in the methodology requires the analyst to constantly strive to improve accuracy. This study examines one method to obtain this goal.

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References