Development of a bow appendage to reduce added resistance in head waves for a PCC

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1. Introduction

In this paper, an appendage for reducing the added resistance in waves for a pure car carrier, PCC, is developed. In the previous papers of the authors 1)-4), blunt bow ships running in low speed were the targets of the studies on reduction of the added resistance in waves. However, a PCC runs in medium speed, and has a slender hull, a sharp bow shape near water line, a hard bow flare and a flat bow nose above water surface to keep wide car space. Therefore characteristics of the added resistance of such a PCC may be completely different from those of blunt ships studied in our previous research works 1)-3).

2. Development of appropriate appendages

At first, model tests in head regular waves of a PCC model is carried out to investigate the reflected waves and spray at the bow. The model used for the experiments is a 1/77 scale model of a PCC which can carry 6000 cars, and her principal particulars are shown in Table 1 and a photo. of her is shown in Fig. 1. In the experiment, no sail is attached although three sails are attached to the model shown in Fig. 1. The flat hull part of the bow face above the hard flare may cause large added resistance due to incident head waves when the waves are high.

Table 1 Principal particulars of the model ship.

<table>
<thead>
<tr>
<th></th>
<th>Full scale</th>
<th>1/77 model</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_{pp} [m]</td>
<td>192</td>
<td>2.5</td>
</tr>
<tr>
<td>B [m]</td>
<td>32.26</td>
<td>0.42</td>
</tr>
<tr>
<td>d [m]</td>
<td>9</td>
<td>0.12</td>
</tr>
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</table>

A photo. of water surface around the bow of the model running at Fn=0.237 in regular head waves of λ/L_{pp}=0.4 and H_{w}=80mm is shown in Fig. 2. The photo, which was taken at the moment when an incident wave hits the bow horizontally, shows that a thin and wide spray covers over the flat bow face above calm water level. A high stagnation pressure generated by hitting of the waves may create the spray. Therefore reduction of the stagnation pressure on the bow part decreases the added resistance due to waves.

Fig. 2 Dynamic swell-up and spray at the bow in head waves ; Fn=0.237, λ/L_{pp}=0.4, H_{w}=40mm.

3. Experimental condition

To reduce the stagnation pressure acting on the bow due to hitting of waves, some kinds appendages, NOSES 2, 3 and 5, shown in Fig. 3 are developed and are attached as shown in Fig. 4.

The experimental condition is shown in Table 2. Froude number Fn is 0.237 and wave heights are 0mm, 50mm, 80mm, 90mm.
Table 2 Experimental condition.

<table>
<thead>
<tr>
<th>λ/L=0.4</th>
<th>F_r=0.237</th>
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<tbody>
<tr>
<td>H_w[mm]</td>
<td>0</td>
</tr>
<tr>
<td>without appendage</td>
<td>○</td>
</tr>
<tr>
<td>NOSE2</td>
<td>○</td>
</tr>
<tr>
<td>NOSE3</td>
<td>○</td>
</tr>
<tr>
<td>NOSE5</td>
<td>○</td>
</tr>
<tr>
<td>NOSE5 lower</td>
<td>○</td>
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</tbody>
</table>

Fig. 3 Model ship with the appendage.

Fig. 4 Schematic views of NOSEs.

4. Experimental results

Measured results of the resistance \( R_W \) acting on the model with these appendages are shown in Fig. 5, and the added resistances in waves are calculated by subtracting the measured resistance in calm water from the measured ones in waves in Fig.6. It can be confirmed that only slight reduction of the added resistance at \( H_w=50 \text{mm} \) is shown in these figures. In Fig. 7, photos of spray at the bow without appendage and with NOSE 5 are shown. Compared with the spray of the non-nose model shown in the left photograph of the figure, the spray shown in the right photograph suggests that the spray height at the center decreases but the spray at the sides increases. The fact may mean that the appendage squeezes the thin spray to both sides but does not work to reduce the stagnation pressure which generates the spray. In other words, the appendage may not be located at the stagnation area generated by hitting of the incident head waves.

Then, the location of NOSE 5’ is lowered by 20mm as shown in Fig. 8. The measured resistances for the nose are shown in Figs. 9 and 10. We can see that the effects of the reduction of the added resistance of the both cases are almost same.

Fig. 5Measured resistance acting on the ship with different NOSEs in regular head waves.

Fig. 6 Obtained added resistance in waves with different NOSEs in regular head waves.

Fig. 7 Observed images without NOSE (left) and with NOSE5’ (right). Red lines show outer boundary of spray which is in maximum.

Fig. 8 Change of location of NOSE5’.
Fig. 9 Effect of location of NOSE5 on resistance acting on the ship in regular head waves.

Fig. 10 Obtained added resistance acting on the ship with NOSE5 in different locations.

A wider appendage named as NOSE 6 is also developed as shown in Figs. 11 and tested. No improved result is obtained by the appendages as shown in Figs. 12 and 13. On the basis of these results, it may be concluded that similar appendages which were developed for full ships like bulk carriers and tankers by the authors 1)–4) are not appropriate for a slender ship like PCC.

Fig. 11 Frontal views of NOSE5’ (left) and wider NOSE6 (right).

Lastly, a very slender or narrow appendage is developed for the PCC as shown in Fig. 14. The cross section of the appendage is a triangle and attached at lower location of the flat bow of the PCC. To investigate the effect of cross section shape, an appendage with a round cross section as shown in Fig. 15 is also tested.

Measured resistances in waves for these appendages, NOSE-triangle and NOSE-round, are shown in Figs. 16 and 17. The results demonstrate that larger reductions of the added resistance due to waves are obtained by the appendages with a triangle section.

The reduction ratios of the added resistance in percentage by the appendages are shown in Fig. 18. The ratio is defined as,

\[
\text{Reduction ratio} = 100 - \left( \frac{100 \times R_{\text{NOSE}}}{R_{\text{W/o NOSE}}} \right)
\]

The maximum reduction ratio by the slender appendage with a triangle section reaches by 50% at \( H_w = 20 \text{mm} \). As wave height increases, the reduction ratio decreases as shown in Fig. 18.
Fig. 14 The photograph of the bow.

Fig. 15 Cross section of slender NOSEs.

Fig. 16 Measured resistance acting on the ship with slender NOSEs in head waves.

Fig. 17 Obtained added resistance in waves with slender NOSEs in head waves.

5. Conclusions
An appendage to reduce the added resistance due to waves is developed for a medium speed PCC. Following conclusions are obtained.
1) Appendages developed for blunt bow ships do not work for a slender hull like a PCC.
2) A specially designed slender appendage can reduce the added resistance of the PCC due to head waves up to by 50% in moderate wave height.
3) The reduction rate of the appendage decreases with increasing wave height of incident waves.

References
1) Y. Ikeda, S. Ibata, Y. Aoyama, Ngo Van He: Development of an appendage to reduce the added resistance in waves for a large blunt ship using CFD, JASNAOE, 2013.10
3) K. Mizutani, S. Ibata, Y. Aoyama, Y. Ikeda, H. V. Ngo: A Role of Spray on the Added Resistance acting on a Blunt-Bow Ship in Head Waves, ISOPE, 2015.6
4) Y. Aoyama: Development of an appendage to reduce the added resistance in waves for a large ship, Master thesis of Osaka Prefecture University, 2016.3