Examination of *Guidelines for Determining Minimum Propulsion Power* in the Light of Model Experiment

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Interim Guidelines (MEPC.1/Circ. 850)

Level 1

Minimum power lines as a function of deadweight, based on existing ship data.

Level 2

Simplified assessment of installed power to be sufficient for:

- Keeping a certain speed in head wind and waves;
- And maintaining a course in wind and waves from any other direction.
Problems to be tackled for level 2 requirement

• Experimental validation of the state-of-the-art technology for this purpose is available?
• A ship complying with the current level 2 is really safe?
Plan of research

• Model experiment for a Panamax bulk carrier in head wind and waves
  ⇒ completed so that reported here!

• Model experiment for a Panamax bulk carrier in bow wind and waves
  ⇒ to be executed this month

• Model experiment for a car carrier in head and bow wind and waves
  ⇒ to be executed this May
## Panamax bulk carrier

1/61.18 scaled model with super structures

<table>
<thead>
<tr>
<th></th>
<th>ship</th>
<th>model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{bp}$ (m)</td>
<td>178.0</td>
<td>2.9091</td>
</tr>
<tr>
<td>$L_{WL}$ (m)</td>
<td>181.0</td>
<td>2.9591</td>
</tr>
<tr>
<td>$B$ (m)</td>
<td>32.26</td>
<td>0.5273</td>
</tr>
<tr>
<td>$D$ (m)</td>
<td>21.14</td>
<td>0.3455</td>
</tr>
<tr>
<td>$d$ (m)</td>
<td>11.57</td>
<td>0.1891</td>
</tr>
<tr>
<td>DWT (ton)</td>
<td>47500</td>
<td></td>
</tr>
<tr>
<td>MCR (KW)</td>
<td>7930</td>
<td></td>
</tr>
<tr>
<td>$D_p$ (m)</td>
<td>5.51</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Level 2 requirement for the ship

- Minimum navigation speed: $V_{\text{nav}} = 4\text{kt}$
- Minimum course-keeping speed: $V_{\text{ck}} = 4.56\text{kt}$
- Significant wave height: $H_s = 4\text{m}$
- Peak wave period: $T_p = 7.0$ to $15.0$ s
- Mean wind velocity $V_w = 15.7\text{m/s}$
Conditions for model experiment

• Irregular head waves with the ITTC spectrum (1978)
• Constant head wind
• Relation between wave height and wind velocity is based on the WMO reference data

<table>
<thead>
<tr>
<th>Beaufort.No.</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{1/3}$ $(m)$</td>
<td>3</td>
<td>4</td>
<td>5.5</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>$U_{wind}$ $(m/s)$</td>
<td>12.35</td>
<td>15.55</td>
<td>19</td>
<td>22.65</td>
<td>26.5</td>
</tr>
</tbody>
</table>
Experimental procedure

- Auto pilot for head wind and wave condition
- By changing specified propeller RPM, condition for zero ship forward speed is to be identified as a function of the Beaufort number.

zero forward speed ⇒

- no scale effect in ship resistance and propeller wake
- unlimited time for exposure
Experimental facility

• Seakeeping & manoeuvring basin of National Research Institute of Fisheries Engineering (60m x 25 m x 3.2m)
• 80 segmented wave maker with wave absorbing beach
• 108 wind fans attached to a X-Y towing carriage
Wind blowers

- wind fan
- honeycomb filters
- contraction nozzle
Wind blowers
Uniformity of wind velocity

Graph showing the dimensionless wind velocity as a function of distance from the center of the measuring frame. The graph compares different heights: h=195mm, h=380mm, and h=525mm. The x-axis represents the distance in meters, and the y-axis represents the dimensionless wind velocity.
Scale effect of wind force

![Graph showing the relationship between Reynolds number and drag coefficient. The graph illustrates a curve that increases with increasing Reynolds number, indicating the scale effect of wind force.](image-url)
Scale effect of wind force

If the body has sharp edges not aligned with the flow, separation will generally occur at these edges irrespective of the Reynolds number …… For a bluff body at large Reynolds numbers the drag coefficient is insensitive to Reynolds number except insofar as this affects the point of separation. (Newman, “Marine Hydrodynamics” 1977)
Measured Items

- Ship motions (roll, pitch, yaw) : optical gyroscope
- Ship motions (surge, sway, heave): total station system (consisting of optical theodolite and prism)
- Propeller RPM and rudder angle
- Propeller thrust and torque
- Rudder normal force
- Wind velocity: hot - wire anemometer
- Wave elevation: servo-needle wave height meter
experiment

Beaufort No8  \( H_s = 5.5 \text{m} \quad V_w = 19 \text{m/s} \)

Moving forward  70.3 rpm

resting

Moving backward  57.5 rpm

Displacement in X axis (m)

\( \begin{align*}
\text{Time (sec)} & \\
0 & 50 & 100 & 150 & 200 & 250 \\
\end{align*} \)

Displacement in X axis (m)

\( \begin{align*}
\text{Time (sec)} & \\
0 & 50 & 100 & 150 & 200 & 250 \\
\end{align*} \)

Displacement in X axis (m)

\( \begin{align*}
\text{Time (sec)} & \\
0 & 50 & 100 & 150 & 200 & 250 \\
\end{align*} \)
Numerical calculation - Equilibrium in surge direction -

Identify the propeller RPM for resting

Wave drift force (Maruo’s theory with the Kochin function of Ogilvie-Tuck’s slender body theory) Calculated by Yasukawa

Wind force (Fujiwara’s empirical formula)

Propeller T & Q (POT test) By Yasukawa
Comparison at 0 kt

Slightly conservative prediction but discrepancy increases with increasing wave height.
Calculation with 4kt for equilibrium in surge

Added wave resistance (Maruo’s theory with the Kochin function of Ogilvie-Tuck’s slender body theory) Calculated by Yasukawa

Wind force (Fujiwara’s empirical formula for relative wind velocity)

Ship Resistance, Propeller T & Q (model test with scale effect) By Yasukawa
Comparison at 4 kt

![Graph comparing Plimit, estimation(U=4kt), estimation(U=0kt), experiment, and level 2 requirement vs. significant wave height (m).]
Course-keeping with forward velocity

1. Equilibria of surge-sway-yaw-roll model by solving nonlinear equation

- Added wave resistance (Maruo’s theory)
  Cal by Yasukawa

- Wave-induced steady sway force and yaw moment (3D panel method with zero speed)
  Cal by Yasukawa

- Low speed manoeuvring forces and moment (Yoshimura’s cross-flow model)
  Exp by Yoshimura
Course-keeping with forward velocity

2. Locally linear stability analysis of the equilibria by calculating eigenvalues of the Jacobean matrix

If all real parts of eigenvalues are negative, the equilibrium is stable.
Model to be solved

\[(m + m_x)\dot{u} - (m + m_y)vr = X_H + X_P + X_R + X_A + X_W\]

\[(m + m_y)\dot{v} + (m + m_x)ur - m_y l_y \ddot{\phi} = Y_H + Y_R + Y_A + Y_W\]

\[(I_z + J_z)\ddot{\chi} = N_H + N_R + N_A + N_w\]

\[(I_x + J_x)\ddot{\phi} - m_y l_y \dot{v} - m_x l_x ur + 2\mu \dot{\phi} + \beta |\dot{\phi}| + mgGM\phi = K_H + K_P + K_A + K_w\]

\[T_E \dot{\delta} + \delta = -K_P (\psi - \psi_c) - K_P T_D \dot{\phi}\]
Estimated results

Beaufort.No. 8  $H_s=5.5\text{m} \quad V_w=19\text{m/s}, \quad V_s=4\text{kt}, \quad K_P=3, \quad T_D=10\text{s}$

The ship can keep a straight course under the Beaufort No.8
Estimated results for 4kt

Beaufort No. 8

Beaufort No. 10
The ship can keep a course with 4kt under the Beaufort No.8 for any bow wind and wave direction and can keep a position in head wind and waves under the Beaufort No. 10.
Conclusions

• The model experiment demonstrates state-of-the-art technology could provide slightly conservative prediction for a critical situation in severe head wind and waves.

• A Panamax bulk carrier complying with the current level 2 requirement can keep a straight course with 4 kt for any bow wind and wave direction under the Beaufort No. 8 and can keep a position even under the Beaufort No. 10.
Acknowledgements

• This research is supported by ClassNK.
• It is executed under the umbrella of the strategic research committee of the Japan Society of Naval Architects and Ocean Engineers (JASNAOE).
• We thank Professors Yasukawa, Yoshimura and Kashiwagi, Drs. Tsujimoto and Miyake for kindly providing valuable data as well as Mr. Saito from MLIT for essential information.