Effects of Weather and Ocean on Ship Traffic in the eastern Seto Inland Sea

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Waves, currents, and winds are important factors for safe and economic ship navigation, especially in coastal areas where ship density is relatively higher and the topography is more complicated. In this research, the eastern Seto Inland Sea, also known as the Harima Nada area, was selected for conducting numerical ship navigation. Ship traffic information was given from AIS, and WRF, SWAN, and POM models were used to produce numerical simulations of wind, waves, and currents, respectively.

The high-resolution weather and ocean information was then used to conduct numerical ship navigation. To verify their accuracy, results simulating the weather and ocean were compared with actual observation data. The findings showed that the estimation of a ship’s position using the proposed numerical navigation simulation method was effective in helping a ship navigate safely and economically.

Key words: weather and ocean, AIS, numerical simulation, optimum route

1. INTRODUCTION

The Harima Nada area is known as a busy navigational area of both large merchant ships and small fishing ships coming from the Osaka Bay and western Seto Inland Sea.

Surrounded by mountainous landscape with islands inside, this area can be easily affected by high-speed winds as well as wind-induced waves, making ships navigate in a rough ocean state. Besides, constricted by the water depth, large merchant ships with deep drafts have few routing choices, which may also increase the risk of ship accidents.

Therefore, to avoid ship accidents in such a busy
and dangerous area, accurate route planning is of great importance. To make an optimal route plan, it is necessary to have weather and ocean information regarding wind, waves, and currents. In our study, modern simulation models are utilized to generate high-resolution weather and ocean information, which may be provided to ships to avoid accidents and save navigational cost such as fuel and time.

2. VESSEL TRAFFIC DISTRIBUTION IN THE HARIMA NADA AREA

Harima Nada lies between Awaji Shima to the east and Shodo Shima to the west, with general depths of 20.1 m to 40 m, except in the west entrance to Akashi Strait, where there are shoals with depths of less than 10.1 m. The recommended route through the Nakai, shown in Fig.1, runs from the west entrance to Akashi Kaikyo, to the east entrance of Bisan Seto, with a least depth of 23 m through the Harima Nada and a distance of about 65 km. The south shore is steep-to, with a few scattered rocks, but on the north side there are a number of islands, rocks, and shoals. 1)

The congested traffic distribution of vessels on one day obtained from the AIS (Automatic Identification System) is given in Fig.1. As shown in this figure, there were approximately 2000 AIS-equipped vessels navigating in the Harima Nada area on September 11, 2013. Considering small fishing ships that have no AIS, we can say that the Harima Nada area has a higher ship density.

3. MODEL SIMULATION OF WEATHER AND OCEAN

(1) Wind Simulation
In this paper, a wind simulation was carried out by WRF-ARW 3.3.1. 2) GFS-FNL data were used for boundary information. 3)

The simulation period was from September 2, 00:00 UTC, to September 8, 00:00 UTC, of 2004. The starting time was about 5 days before the studied period of numerical ship navigation. As shown in Fig.2, three areas for nesting were calculated in each case to simulate winds more accurately. The vertical grid is 28 from the top pressure to the ground pressure. Detailed information about the various parameters is shown in Table 1.

Table 1. Conditions of calculation by WRF

<table>
<thead>
<tr>
<th></th>
<th>d01</th>
<th>d02</th>
<th>d03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>100x98x28</td>
<td>88x88x28</td>
<td>76x73x28</td>
</tr>
<tr>
<td>Mesh size</td>
<td>9 (km)</td>
<td>3 (km)</td>
<td>1 (km)</td>
</tr>
<tr>
<td>Time step</td>
<td>60 (s)</td>
<td>20 (s)</td>
<td>6.6 (s)</td>
</tr>
</tbody>
</table>

Fig. 2 WRF simulation domains
As shown in Fig. 3, a strong southern wind blew when the typhoon was closest to the Harima Nada area. The black dashed lines are the boundary of landscapes around. The calculated wind velocity is compared with the observation data of Iejima Island from the JMA (Japan Meteorological Agency) in Fig. 4.

(2) Current Simulation
The Princeton Ocean Model (POM) was used to simulate the current affected by this typhoon. The grid divisions in the x and y directions are the regular mesh of 500 m, while the vertical direction utilizes the sigma coordinate system, which contains 5 levels from the sea surface (0) to the bottom (-1). The calculation time interval is 2 seconds.

The velocity distributions of the surface tidal currents when the low pressure was closest are shown in Fig. 5. The sea level height between the observation and the POM calculation in Komatsu Island is compared in Fig. 6. The obvious influence of the typhoon on the tidal current can be found.
(3) Wave Simulation

SWAN (Simulating Waves Nearshore) was used as a numerical model for simulating waves.\(^3\), \(^7\), \(^8\), \(^9\)

The numerical simulation of wind-induced high waves was carried out using the SWAN model. The mesh size is about 0.5 km horizontally, and the calculated time step is 5 seconds. The distribution of significant wave height is shown in Fig. 7.

Given a wind speed of 25 m/s and a fetch of 80 km when the low pressure was closest, the significant wave height and period calculated by the Wilson formula are about 4.0 meters and 6.0 seconds, respectively, which agree with the model results of 3.4 meters and 6.1 seconds.

4. EFFECT OF WEATHER AND OCEAN ON SHIP NAVIGATION

(1) Mathematical Model Group

The MMG (Mathematical Model Group) model is the division of all hydrodynamic forces and moments working on the vessel’s hull, rudder, propeller, and other categories, as well as the analysis of their interaction.\(^10\), \(^11\)

Two coordinate systems are used in ship maneuverability research: space fixed and body fixed. In the latter, G-x,y,z, moves together with the ship and is used in the MMG model. As shown in Fig. 8, G is the ship’s center of gravity, the x-axis is the direction the ship is heading, the y-axis is perpendicular to the x-axis on the right-hand side, and the z-axis runs vertically downward through G.

Therefore, the equation of the ship’s motion in the body-fixed coordinate system adopted in the MMG is written as:

\[
\begin{align*}
(m + m_x)u - (m + m_y)v &= X \\
(m + m_y)v + (m + m_x)w &= Y \\
(I_{zz} + J_{zz})r &= N
\end{align*}
\]

where \(m\) is the mass, \(m_x\) and \(m_y\) are added masses, \(u\) and \(v\) are components of the velocity in the directions of the x-axis and the y-axis, respectively, and \(r\) is the angular acceleration; \(I_{zz}\) and \(J_{zz}\) are the moment of inertia and the added moment of inertia around \(G\), respectively; \(X\) and \(Y\) are hydrodynamic forces, and \(N\) is the moment around the z-axis.
According to the MMG model, the hydrodynamic forces and the moment in the above equation can be written as:

\[
\begin{aligned}
X &= X_H + X_P + X_W + X_T + X_A + X_E \\
Y &= Y_H + Y_P + Y_W + Y_T + Y_A + Y_E \\
N &= N_H + N_P + N_T + N_A + N_W + N_E,
\end{aligned}
\]

where the subscripts \( H, P, T, A, W, \) and \( E \) denote the hydrodynamic force or moment induced by the hull, the propeller, the rudder, the thruster, the air, the wave, and the external forces, respectively.

Hydrodynamic forces caused by wind, waves, and currents are defined in (3), (4), and (5), respectively:

\[
\begin{aligned}
X_A &= \frac{\rho A}{2} V_A^2 A_T C_{XA}(\theta_A) \\
Y_A &= \frac{\rho A}{2} V_A^2 A_L C_{YA}(\theta_A), \\
N_A &= \frac{\rho A}{2} V_A^2 L A_L C_{NA}(\theta_A),
\end{aligned}
\]

where \( \rho_A \) is the density of the air, \( \theta_A \) is the relative wind direction, \( V_A \) is the relative wind velocity, and \( A_L \) and \( A_T \) are the frontal projected area and lateral projected area, respectively. \( C_{XA}, C_{YA}, \) and \( C_{NA} \) are the coefficients. In this paper, these coefficients were estimated by the method of Fujiwara et al. as:

\[
\begin{aligned}
X_W &= \rho g h^2 B^2 / L \bar{C}_{XW}(U, T, \nu, \varphi - \varphi_0) \\
Y_W &= \rho g h^2 B^2 / L \bar{C}_{YW}(\omega_0, \varphi - \varphi_0) \\
N_W &= \rho g h^2 B^2 / L \bar{C}_{NW}(\omega_0, \varphi - \varphi_0),
\end{aligned}
\]

where \( \rho \) is the density of seawater, \( g \) is the acceleration of gravity, \( h \) is the amplitude of significant wave height, \( B \) is the ship’s breadth, and \( L \) is the length of the ship. \( \bar{C}_{XW}, \bar{C}_{YW}, \) and \( \bar{C}_{NW} \) are averages of short-term estimated coefficients.

\[
\begin{aligned}
X_H &= 1/2 \rho d U^2 \left( X_{uvv} \nu^2 + X_{rr} \nu^2 + X_{uvv} r^2 + X_{rr} r^2 \right) - R \\
Y_H &= 1/2 \rho d U^2 \left( Y_{uvv} \nu^2 + Y_{rr} \nu^2 + Y_{uvv} r^2 + Y_{rr} r^2 \right) \\
N_H &= 1/2 \rho d U^2 \left( N_{uvv} \nu^2 + N_{rr} \nu^2 + N_{uvv} r^2 + N_{rr} r^2 \right),
\end{aligned}
\]

where \( \rho \) is the density of air and seawater, \( d \) is the draft, \( U \) is the ship’s speed, \( v' = v / U \), \( r' = rL / U \), and \( R \) is the resistance of the hull. The other parameters, such as \( X_{uvv} \) and \( X_{rr} \), are various coefficients.

(2) Ship simulation

The MMG simulations were based on the characteristics of a container ship, SR108, with detailed information shown in Table 2 and Fig.9. Numerical navigation was carried out in a fixed propeller revolution of 23 kn in still water.

Table 2. Principal properties of the SR108

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (W.L)</td>
<td>178.21 m</td>
</tr>
<tr>
<td>Beam (M.L.D)</td>
<td>25.40 m</td>
</tr>
<tr>
<td>Draught (M.L.D)</td>
<td>9.50 m</td>
</tr>
<tr>
<td>LCG relative to midships</td>
<td>-2.48 m</td>
</tr>
<tr>
<td>Block coefficient</td>
<td>0.572</td>
</tr>
<tr>
<td>Displaced volume</td>
<td>24,801 ton</td>
</tr>
<tr>
<td>Wetted surface</td>
<td>5,499 m²</td>
</tr>
<tr>
<td>Diameter of propeller</td>
<td>6.507 m</td>
</tr>
<tr>
<td>Ratio of propeller pitch</td>
<td>0.7348</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>32.46 m²</td>
</tr>
</tbody>
</table>

Fig.9 Body plan of the ship model

Considering the recommended route in the Harima Nada area, a straight heading direction was used for about one hour of course 068. In all cases, autopilot was utilized. The weather and ocean data was input to the MMG model in a temporal and spatial resolution of every 1 hour and 0.5 km, respectively.

The ship’s track with the combined effects of the wind, tidal current, and waves as compared with the set course is shown in Fig.10. The drift angle and distance difference can be 1.92 degree and 1.56 km,
respectively. A contribution of each factor, such as wind, wave or current, to result can be found in Table 3. Therefore, to sail on the recommended route affected by such weather and ocean state, a set course of 66.08 should be applied.

| Current | +0.32 degree | +0.24 km |
| Wind    | +1.61 degree | +2.51 km |
| Wave    | -0.01 degree | -1.19 km |

**Table 3. Effects of each single factor**

![Numerical simulation results of ship navigation](image)

**REFERENCES**


**5. CONCLUSION**

In this study, several simulations were performed for a numerical navigation of an ocean-going ship in coastal areas, in an attempt to evaluate the effectiveness of different models for simulating weather and optimal route planning. The conclusions are as follows:

1) Combining the numerical models of the WRF, SWAN, and POM models, effective high-resolution data of wind, waves, and currents can be generated.
2) The ship-maneuvering model (MMG) can calculate ship motion as affected by weather and ocean.
3) Calculated data can be applied for optimal route planning, and the influence of wind, waves, and currents on an ocean-going vessels was found to be great.
4) The ship navigation, what has become effective by making use of high accuracy oceanographic data.

It is possible to select an optimal route using a numerical simulation if information on the wind, waves, and tidal currents can be forecasted accurately in advance.