On the Development of an Information Service System for Navigational Safety of Seagoing Vessels

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Abstract

This study aims to develop the information service system of navigational safety for seagoing vessels. It has been successful in developing the intended system which has made possible to provide the following functions and capabilities:

• immediate computation of the dynamic motions of a ship against the present and future weather conditions;

• evaluation of the integrated seakeeping performance of a ship on a real time basis and providing the navigators with the navigational information on the spot enabling them to take the most appropriate countermeasures; and

• supporting the navigators in the selection of a safe sailing route by providing the integrated seakeeping performance.

1. Introduction

Ship operators navigating in rough seas should take grip with the extent of navigational safety and take measures according to the condition of ship itself, weather and sea in order to secure safe and economic operation of the ship.

This study aims at developing navigation safety information system through internet for the purpose of preventing sea casualties in rough seas and economic operation of the ship. First of all, a ship's operator should key in the following information:

• current weather information of the area in which the ship is navigating,

• the future information of the area in which the ship shall navigate,

• the ship's principal dimension and the condition of the body of the ship through internet network.

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Based on this information, navigation safety information system evaluates, in real time, the degree of navigation safety by calculating the response of ship's motion in the current position and the future estimated position. The evaluated information is provided to the ship through internet network to take some appropriate measures by the operators, and furthermore another evaluation on the basis of weather forecasting will be done and allow the operators to choose safer route.

2. The structure of navigation information system

2.1 Internet network for providing information

Some information about the current weather information of the area in which the ship is navigating, the future information of the area in which › shall navigate, the ship's principal dimension and the condition of the body of the ship should be typed in, in real time, through internet network. The information is processed by the system, which is not available on board the ship, and is fed back into the ship through internet network which also takes place in real time.

The overall configuration of the system is depicted in Fig.1.

The flow of the data processing system which gets real-time data from a ship and evaluates the degree of the navigation safety is illustrated in Fig. 2.

The picture frame of input and output is given as Fig. 3 and Fig. 4. The input information is the current weather information of the area in which the ship is navigating, the future information of the area in which the ship shall navigate, the ship's principal dimension and the condition of the body of the ship through i ətwork. The output informations a ɔy the

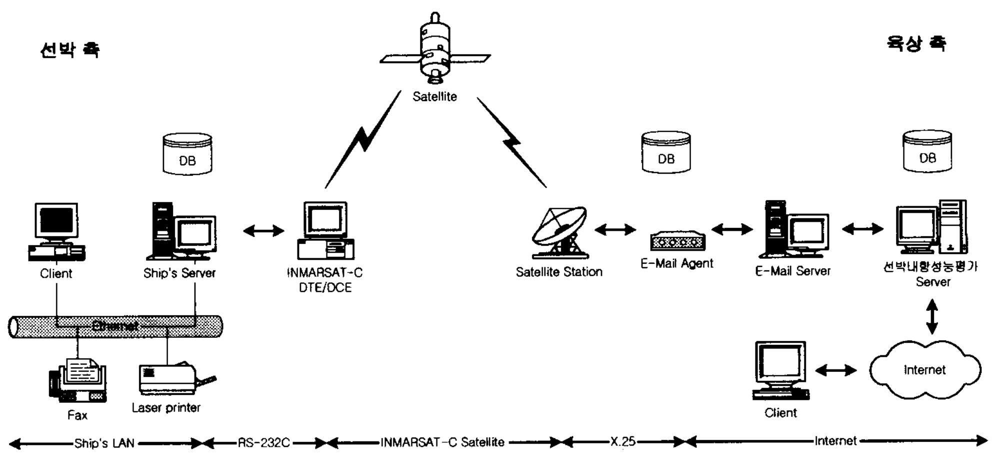

Fig. 1 Schematic Diagram of the System for Internet Service

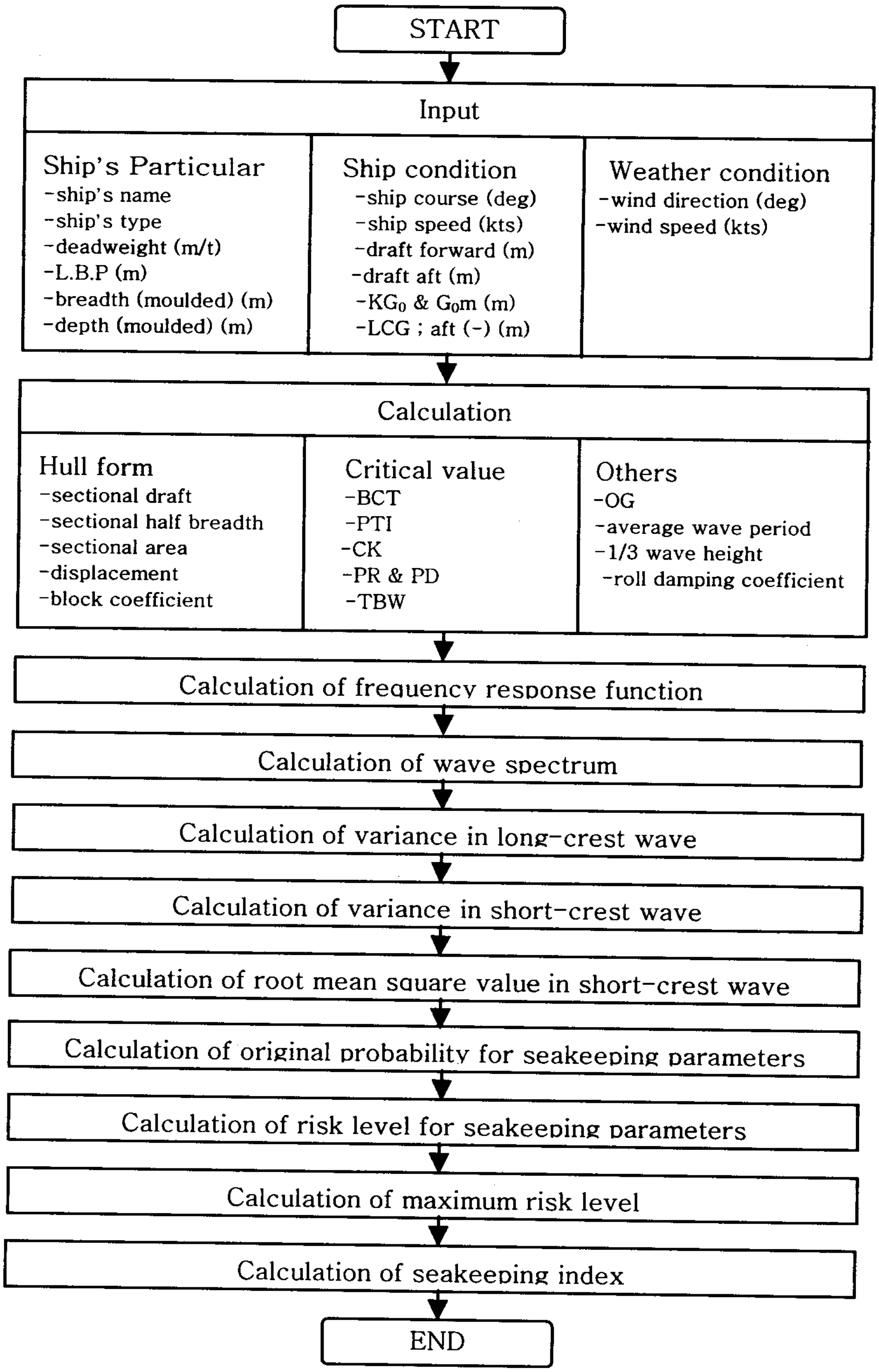

Fig. 2 Flow Chart of Navigational Safety Evaluation Program

operator of the ship are the degree of risk against the navigation safety of the ship and the index of navigational safety.

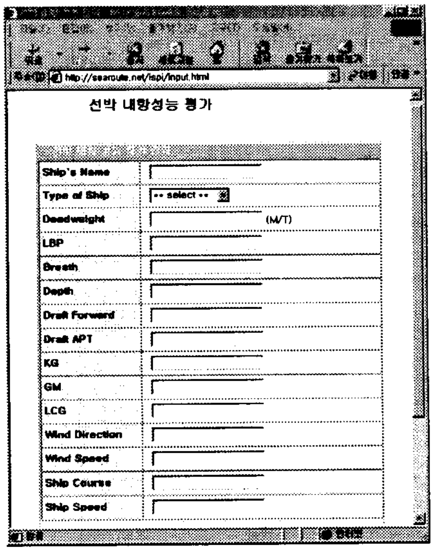

Fig. 3 Data Input Format on Web

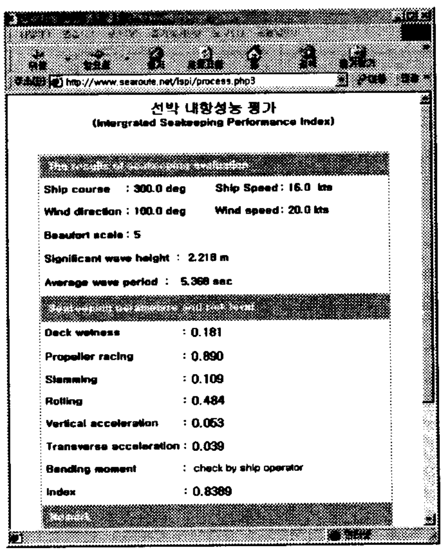

Fig. 4 Data Output Format on Web

2.2 The communication between ship and the system

When the data given by the ship's operator is sent to the server of navigation safety information system, the server performs evaluation and the result is fed back to the ship. For the purpose of file transfer between ships and shore, INMARSAT-C facilities play roles as DTE/DCE(data terminal equipment/data circuit terminating equipment). Both earth station of the satellite and INMARSAT-C satellite connect those between.

3. The evaluation of real-time navigation safety

3.1 Evaluated factors of navigation safety

In order to evaluate the degree of navigational safety of a ship with special consideration to the people on board, ship's body and cargo of the ship, that is navigating rough and irregular sea condition, the following factors are considered for the evaluation.[1]

(1) deck wetness
(2) propeller racing
(3) slamming
(4) rolling
(5) vertical acceleration
(6) transverse acceleration
(7) bending moment

The systemic combination of those evaluated factors has the form of serial combination. If the probability of occurrence of just one factor exceeds the critical occurrence probability, then the overall seakeeping performance fails and the ship may be endangered.[2]

3.2 Variance of navigation safety evaluated factors

When a ship is navigating on sea which has single wave distance and irregularity and is keeping constant course(χ) and speed(V), spectrum $S_{x_i}(\omega_e, \chi)$ is as follows if we put $X_i(t)$(the random process of evaluation factors calculated from the response function of ship's motion) as $H_{x_i}(\omega_e, V, \chi-\theta)$

$$S_{x_i}(\omega_e, \chi) = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} |H_{x_i}(\omega_e, V, \chi-\theta)|^2 S_\zeta(\omega_e, \theta) d\theta \tag{1}$$

Variance $\sigma_{x_i}^2$ is as the following.

$$\sigma_{x_i}^2(\chi, V, S) = \int_0^\infty S_{x_i}(\omega_e, \chi) d\omega_e \tag{2}$$

The variables that let the variance in formula (2) change are the meeting angle of the ship and the wave, the ship's speed(V), and the condition of the sea(S). And also $X_i(t)$ is calculated as [3]:

$$X_i(t) = \int_0^\infty \cos(\omega_e t + \psi_i)\sqrt{2S_{x_i}(\omega_e, \chi) d\omega_e} \tag{3}$$

Where, $\psi_i = \varepsilon_i(\omega) + \gamma_i$

γ_i= phase angle distributed uniformly between 0 and 2π

3.3 The critical occurrence probability of the evaluated factors

The change of the modulation width against an instant time of the $X_i(t)$ has the form of Gauss distribution and the extreme value has the form of Rayleigh distribution.[4] Once the variance $\sigma_{X_i}^2$ is acquired, then Q_{X_i} (which means the probability that the extreme value of $X_i(t)$ exceeds a constant value X_1) is as follows:

$$Q_{X_i} = \int_{X_1}^\infty \left(\frac{X_i}{\sigma_{X_i}}\right)\exp\left(-\frac{X_i^2}{2\sigma_{X_i}^2}\right) dX$$

$$= \exp\left(-\frac{X_1^2}{2\sigma_{X_i}^2}\right) \tag{4}$$

And then σ_{X_i} can be expressed as:

$$\sigma_{X_i} = \sqrt{\frac{-X_1^2}{2\ln Q_{X_i}}} \tag{5}$$

When we consider critical probability $Q_{X_{ic}}$ (i.e. the probability of exceeding X_{ic}), then variance $\sigma_{X_{ic}}$ that is a value of danger can be found:

$$\sigma_{X_{ic}} = \sqrt{\frac{-X_{ic}^2}{2\ln Q_{X_{ic}}}} \tag{6}$$

3.4 Evaluation value of the evaluated factors

The extreme value of the evaluated factors shows the form of Rayleigh distribution and the occurrence probability is expressed as $Q(\overline{X_i})$. In this case E_{X_i} is defined as the evaluation value of X_i factors and is expressed as an inverse number with no dimension.[2]

$$E_{X_i} = \frac{1}{\sqrt{-2\ln\{Q(\overline{X_i})\}}} = \left[\frac{\sigma_{X_i}}{\overline{X_i}}\right] \qquad (7)$$

When the evaluation value E_{X_i} becomes zero, then the confidence level of the random factor (X_i) is 1.0 and when the evaluation value E_{X_i} becomes infinite then the confidence level of the random factor (X_i) is zero.

3.5 The risk of the evaluated factors

We define $E_{X_{ic}}$ as the critical evaluation value done on critical occurrence probability of random factor of X_i, and put μ_{X_i} as the following:

$$\mu_{X_i} = \frac{E_{X_i}}{E_{X_{ic}}} = \frac{\{\overline{X_i}/\sigma_{X_{ic}}\}}{\{\overline{X_i}/\sigma_{X_i}\}} = \frac{\sigma_{X_i}}{\sigma_{X_{ic}}} \qquad (8)$$

On the other hand, when $\mu_{X_i} \geq 1.0$, then X_i(the factor of seakeeping performance) becomes dangerous, and when $\mu_{X_i} < 1.0$, it shows that the ship is safe.

3.6 Development of evaluation index of navigational safety[5]

After investigating which critical occurrence probability of a factor is affecting the most to the overall critical occurrence probability, if the factor has the same degree of danger ('propeller racing' is found to be the largest, i.e. $Q_{Pc} = 0.1$) transformed evaluation value ($\widetilde{E_i}$) is found from the evaluation value (E_i) of each factor.

① In case of 'propeller racing'

$$\widetilde{E_P} = \frac{E_P}{\alpha_{PP}} = E_P \cdot \frac{E_{Pc}}{E_{Pc}} = E_P \qquad (9)$$

Where, E_P: evaluation value of propeller racing

$$\left(\frac{\sigma_P}{X_P^*} = \frac{1}{\sqrt{-2\ln(Q_P)}}\right)$$

$\widetilde{E_P}$: transformed evaluation value of propeller racing

E_{Pc}: critica evaluation value of propeller racing

$$\left(\frac{\sigma_{Pc}}{X_P^*} = \frac{1}{\sqrt{-2\ln(0.1)}}\right)$$

② Other than 'propeller racing'

$$\widetilde{E_i} = \frac{E_i}{\alpha_{Pi}} = \frac{E_{Pc}}{E_{ic}} \cdot E_i = \mu_i \cdot E_{Pc}$$

$$\widetilde{E_j} = \frac{E_j}{\alpha_{Pj}} = \frac{E_{Pc}}{E_{jc}} \cdot E_j = \mu_j \cdot E_{Pc} \qquad (10)$$

where, α_{Pi} : ratio of critical evaluation value between propeller racing and i factor

μ_i : dangerousness of i factor

On the other hand, when the degree of danger is the same, then transformed values remain the same, and the occurrence probability(Q_i) shall have the same value.

$$\mu_i = \mu_j \Rightarrow \widetilde{E}_i = \widetilde{E}_j,\ \widetilde{Q}_i = \widetilde{Q}_j \tag{11}$$

If we assume that each element of the factors be independent for the purpose of finding the overall occurrence probability, then the following evaluation index is identified.

$$\widetilde{E}_T = \frac{1}{\sqrt{-2\ln(1-\widetilde{P}_T)}} \tag{12}$$

Where, $\widetilde{P}_T = \prod_{i=1}^{n} \widetilde{P}_i$

$$\begin{aligned}\widetilde{P}_i &= 1-\exp\left\{-\frac{1}{2}\left(\frac{1}{\widetilde{E}_i}\right)^2\right\}\\ &= 1-\exp\left\{-\frac{1}{2}\left(\frac{\alpha_{Pi}}{E_i}\right)^2\right\}\\ &= 1-\exp\left\{-\frac{1}{2}\left(\frac{\alpha_{Pi}\cdot X_i^*}{\sigma_i}\right)^2\right\}\\ &= 1-Q(X_i^*)^{\alpha_{Pi}^2}\end{aligned} \tag{13}$$

$$E_{Tc} = \frac{1}{\sqrt{-2\ln(1-P_{Tc})}} \tag{14}$$

Where,

$$\begin{aligned}P_{Tc} &= \prod_{i=1}^{n} P_{ic}\\ P_{ic} &= 1-\exp\left\{-\frac{1}{2}\left(\frac{X_i^*}{\sigma_{ic}}\right)^2\right\} = 1-Q_{ic}\end{aligned} \tag{15}$$

P_{Tc} : confidence function of seakeeping performance

$Q(X_i)$: occurrence probability of each factor

Q_{ic} : critical occurrence probability of each factor (Rayleigh distribution)

In order to find out the overall degree of danger of the system, the ratio of formula (14) to formula (12) can be expressed as $\widetilde{\mu}_T$.

$$\widetilde{\mu}_T = \frac{\widetilde{E}_T}{E_{TC}} = \sqrt{\frac{\ln(1-P_{TC})}{\ln(1-\widetilde{P}_T)}} \tag{16}$$

If $\widetilde{\mu}_T$ is greater than 1.0, the total system is judged to be in danger. When just one factor of $\widetilde{\mu}_T$ becomes more than 1.0, $\widetilde{\mu}_T$ tends to be greater than 1.0.

4. Discussion on navigation safety evaluated from the model

Fig. 5~7 shows the calculation result that when 2,641 TEU container ship navigates with the speed of 12 knots, 16 knots, 20 knots respectively against wind of 40 knots, with the interval of 15° starting from the head-on wave.

If the ship navigates with the speed of 12 knots, the index of seakeeping performance exceeds 1 when the meeting angle of wave and the ship's steering course remains inside the scope of 0° (head-on) to 60°. And it is evaluated that the ship is in danger, particularly due to deck-wetness and vertical acceleration.

When the ship navigates with higher speed of 16 knots, the index of seakeeping performance exceeds 1 when the meeting angle of wave and the ship's steering course remains inside the scope of 0° (head-on) to 70°. And it is evaluated that the ship is in danger more widely, particularly due to deck-wetness and vertical acceleration.

When the ship navigates with speed of 20 knots, the index of seakeeping performance exceeds 1 when the meeting angle of wave and the ship's steering course remains inside the scope of 0° (head-on) to 75°. And it is evaluated that the ship is in danger much more widely, due to deck-wetness and vertical acceleration as well as slamming.

Fig. 8~10 shows the calculation result that when 4,000 TEU container ship navigates with the speed of 12 knots, 16 knots, 20 knots respectively against wind of 40 knots, with the interval of 15° starting from the head-on wave.

When the ship navigates with the speed of 12 knots, the index of seakeeping performance exceeds 1 when the meeting angle of wave and the ship's steering course remains inside the scope of 0° (head-on) to 60°. And it is evaluated that the ship is in danger, particularly due to deck wetness only.

When the ship navigates with higher speed of 16 knots, the index of seakeeping performance exceeds 1 when the meeting angle of wave and the ship's steering course remains inside the scope of 0° (head-on) to 70°. And it is evaluated that the ship is in danger more widely, particularly due to deck-wetness and vertical acceleration.

When the ship navigates with speed of 20 knots, the index of seakeeping performance exceeds 1 when the meeting angle of wave and the ship's steering course remains inside the scope of 0° (head-on) to 75°. And it is evaluated that the ship is in danger much more widely, due to deck-wetness and vertical acceleration as well as slamming.

The overall evaluation on a container ship reveals that the index of seakeeping performance is the highest in case of head-on wave, and it reduces gradually as the wave direction changes to beam direction. As a result, the index has the lowest figure in case of beam wave. And it also shows that the speedier the ship the higher the index is.

This experiment finally advises that speed reducing and changing course is one of desirable way of action when the ship meets rough seas.

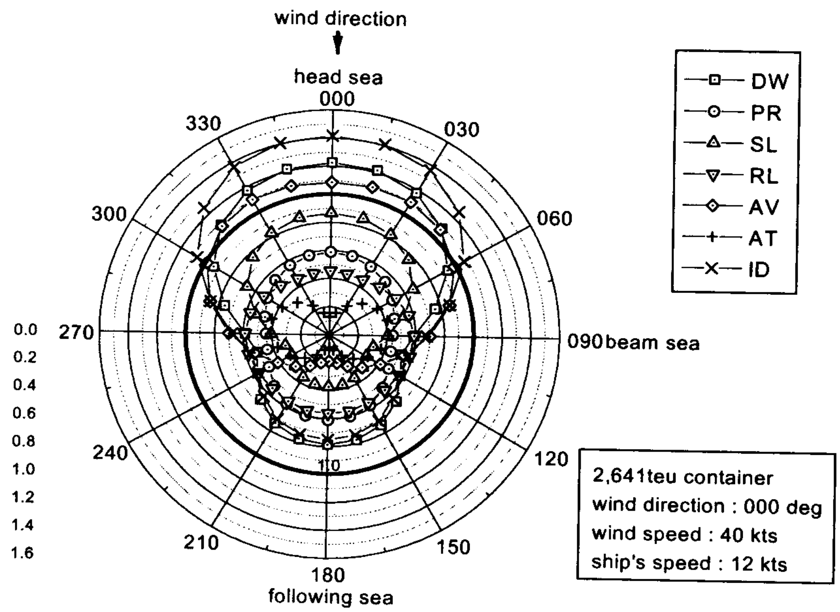

Fig. 5 Seakeeping Evaluation of 2,641TEU Container(Speed=12knots)

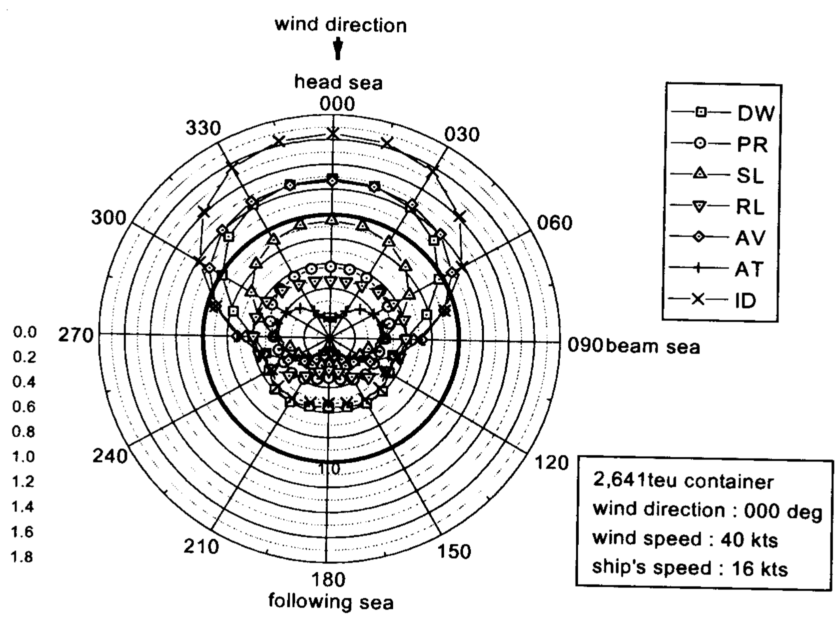

Fig. 6 Seakeeping Evaluation of 2,641TEU Container(Speed=16knots)

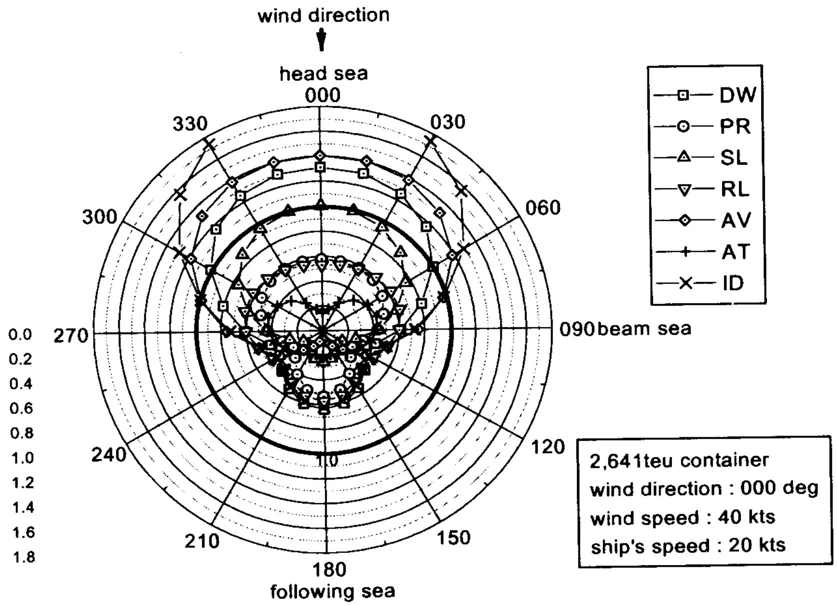

Fig. 7 Seakeeping Evaluation of 2,641TEU Container(Speed=20knots)

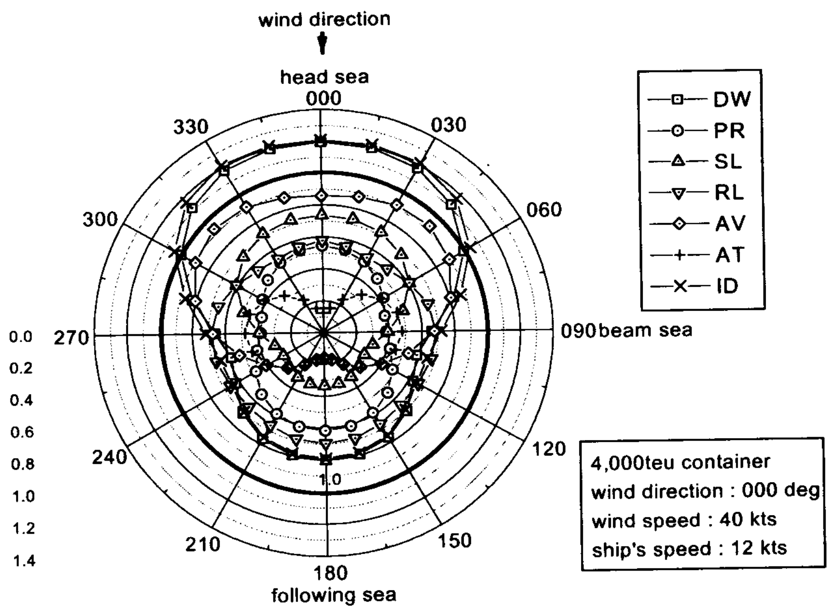

Fig. 8 Seakeeping Evaluation of 4,000TEU Container(Speed=12knots)

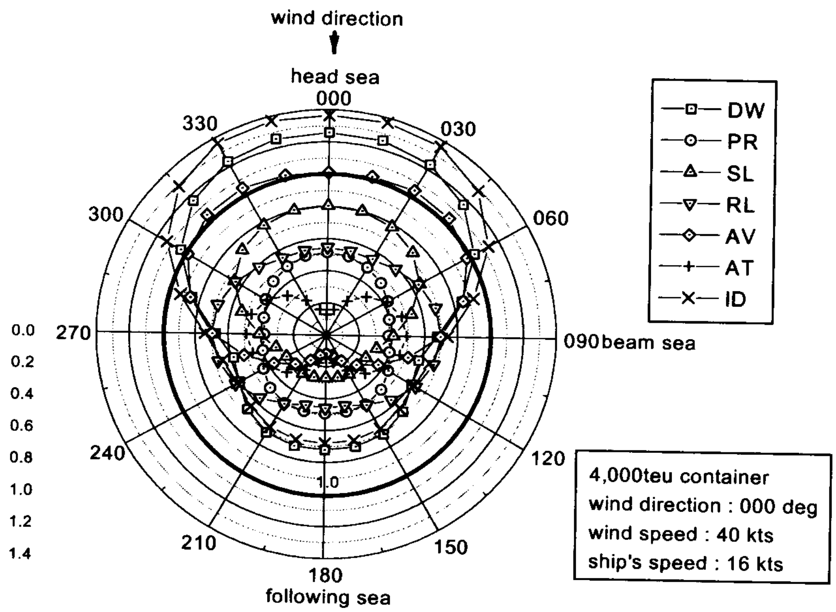

Fig. 9 Seakeeping Evaluation of 4,000TEU Container(Speed=16knots)

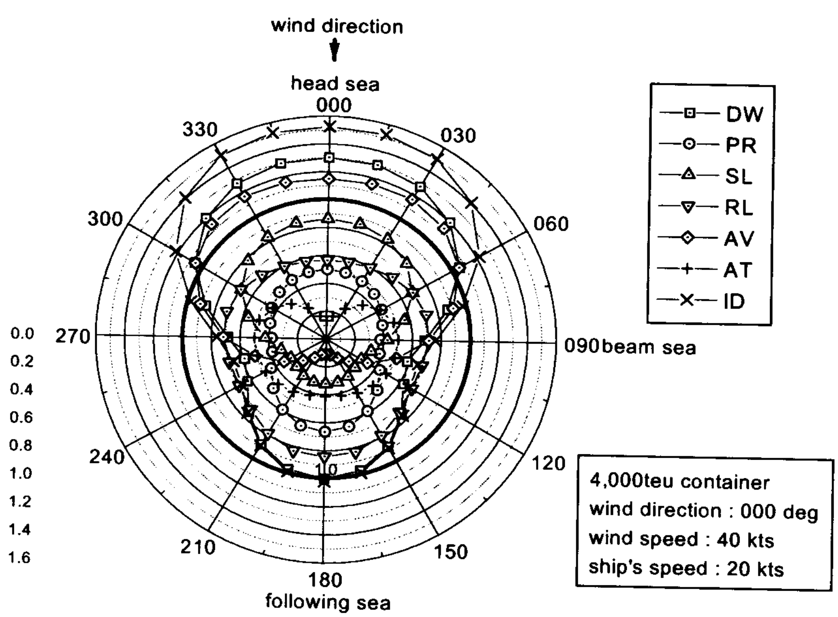

Fig. 10 Seakeeping Evaluation of 4,000TEU Container(Speed=20knots)

5. Conclusion

This study has developed a system that can evaluate navigational safety of a ship in real time on the basis of the following information:

- the current weather information of the area in which the ship is navigating,
- the future information of the area in which the ship shall navigate,
- the ship's principal dimension, and
- the condition of the body of the ship

through internet network.

The followings are suggested and may be implemented.

1) A ship operator can get information about the evaluated information on navigational safety in real time by being connected to the system through internet.
2) In addition to the operator's own experience, safer navigation can be achieved by using the information generated from this system.
3) Ship management division in shore may make use of this system for the management of the ships concerned, fleet management and ship operation contract.
4) Optimal route forecasting may come true by using this system on top of ocean route service.

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