The 2012 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM' 12)
Seoul, Korea, August 26-30, 2012

A Simple Method to Estimate Wind Loads on Ships

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ABSTRACT

A simple method for estimating wind load coefficients of ships needs only a couple of information, ship type and ship length. Selective ship types and conditions are tanker full loaded, tanker ballast loaded, bulk carrier full, bulk carrier ballast, LNG carrier full, LNG carrier ballast, containership full, passenger ship, and others. The method estimates seven parameters for the precise method that authors developed in 2005. A parameter, ship breadth, is acceptable and gives better estimates of the other parameters. The simple method employs the precise method's procedure to estimate wind load coefficients using these estimated eight parameters. Validation makes use of data of 76 ships the methods originate from and spare ships' data including large ships.

1. INTRODUCTION

Wind is not only a source of ship resistance but also a cause of marine accidents. Reducing wind resistance, a technological challenge for naval architects, leads to prevention of the global warming by saving fuel oil and cutting down carbon dioxide. Accidents such as dredging anchors and running aground for example could damage ocean environment on a global scale. These are the reasons researchers have proposed estimation methods of wind loads on ships.

Basis of most of all estimation methods reported so far; including Isherwood (1972), Yoneta et al. (1992), and, Yamano and Saito (1997); is the regression analysis of wind tunnel test data. They chose, based on physical consideration, explanatory variables consisting of parameters representing above water structural features of ships. Fujiwara et al. (1998) proposed estimation formulae obtained by analyzing wind tunnel test data fully statistically. Fujiwara et al. (2005) presented another set of formulae where they took physical consideration, instead of the former t-test of statistical analysis, into account in constructing formulae and still used the F-test for coefficients. One of advantages of the latter is it needs smaller number of structural parameters, eight, than the former, nine. However, one cannot easily pick up all eight parameters unless having layout plans of a particular ship. In case of cause investigations of ship accident in wind, they mostly have to work with limited information of the ship. These facts imply the need for a simpler estimation method that does not lose precision much.

Authors developed a simple method that requires only ship type and ship length. Using these two pieces of information, the method estimates the other seven structural parameters for the precise method. Ship breadth can be an additional input, which leads to better estimates of the other parameters. Estimated eight parameters tell wind loads coefficients for a ship through the precise method.

2. SIMPLE ESTIMATION METHOD

2.1. Outline of the Precise Estimation Method

Figure 1 shows a coordinate system $o\text{-}xyz$ that defines apparent wind speed U_A, apparent wind direction ψ_A where 0 degree stands for head wind condition. The origin is at a cross point of midship section, center plane, and the calm water level. X_A, Y_A, N_A, and K_A stand for longitudinal and lateral forces, and yaw and heel moments due to wind, respectively.

The precise estimation method (Fujiwara et al., 2005) uses eight parameters, pictured in Fig. 2, representing above water structural features of ships; L_{OA}, length overall, B, breadth, H_{BR}, bridge top height from the calm water level, A_F, longitudinal projected area, A_L, total lateral projected area, A_{OD}, lateral projected area above upper deck, C, distance from midship to A_L centroid, positive fore, H_C, height of A_L centroid.

Followings are formulae of wind load coefficients consisting of physical components, C_X longitudinal force, C_Y lateral force, C_N yaw moment, C_K heel moment.

$$\begin{cases} C_X(\psi_A) = \frac{X_A}{\frac{1}{2}\rho_A A_F {U_A}^2} \\ = C_{LF} \cos\psi_A + C_{XLI}\left(\sin\psi_A - \frac{1}{2}\sin\psi_A \cos^2\psi_A\right)\sin\psi_A \cos\psi_A \\ +C_{ALF}\sin\psi_A \cos^3\psi_A \\ C_Y(\psi_A) = \frac{Y_A}{\frac{1}{2}\rho_A A_L {U_A}^2} \\ = C_{CF}\sin^2\psi_A + C_{YLI}\left(\cos\psi_A - \frac{1}{2}\sin^2\psi_A \cos\psi_A\right)\sin\psi_A \cos\psi_A \\ C_N(\psi_A) = \frac{N_A}{\frac{1}{2}\rho_A A_L L_{OA} {U_A}^2} = C_Y(\psi_A) L_N(\psi_A) \\ C_K(\psi_A) = \frac{K_A}{\frac{1}{2}\rho_A A_L (A_L/L_{OA}) {U_A}^2} = C_Y(\psi_A) L_K \end{cases} \quad (1)$$

In Eq. (1), ρ_A stands for the density of air. C_{LF}, C_{XLI}, C_{ALF}, C_{CF}, C_{YLI}, L_N, and L_K are coefficients of which values multiple regression formulae calculate. The formulae have non-dimensional explanatory variables consisting of a couple of the eight parameters. An example of C_{CF} is written as follows.

$$C_{CF} = \alpha_0 + \alpha_1 \frac{A_F}{B H_{BR}} + \alpha_2 \frac{H_{BR}}{L_{OA}} \quad (2)$$

In Eq. (2), the F-test in statistical iterative procedure chose $A_F/(BH_{BR})$ and H_{BR}/L_{OA} from candidates and numerical values such as α_0, α_1, and α_2.

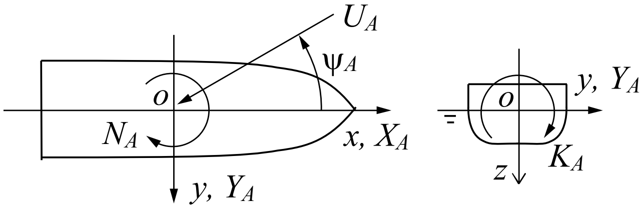


Fig. 1 Coordinate system.

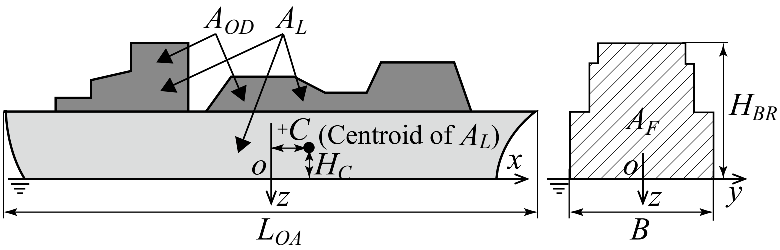


Fig. 2 Definitions of parameters representing above water structural features of ships.

Table 1 Ship types and dimensions of wind tunnel test data

Ship type	Data number	Length overall, L_{OA}, range (m)	Breadth, B, range (m)
Tanker, full	7	72-351	11-58
Tanker, ballast	9	50-351	8-58
Bulk carrier, full	8	141-226	19-31
Bulk carrier, ballast	7	119-226	18-31
LNG carrier, full	4	86-288	15-49
LNG carrier, ballast	4	86-288	15-49
Container ship, full	8	119-232	19-32
Passenger ship	13	85-195	14-32
Others ships	16	25-134	6-18
(Total)	76	25-351	6-58

2.2. Original Ship Data

Data representing above water structural features and wind tunnel test data the simple method is based on are 76, same as those of the precise method (Fujiwara et al. 2005). A method proposed by Blendermann (1995) corrected the effect of boundary layer of different wind tunnels. Table 1 sorts them into nine types, tanker full condition, tanker ballast loaded condition, bulk carrier full, bulk carrier ballast, LNG carrier full, LNG carrier ballast, containership full, passenger ship, and others. The passenger ship type includes pure car carriers and the other ships include research ships, fishing vessels, tug boats, and training ships. L_{OA} and B range wide as shown in Table1.

2.3. Regression Analysis

Length only or length and breadth can be explanatory variable(s) to estimate the other structural parameters. The least-square method determines coefficients, a, b, and c in following regression expressions.

$\underline{B}$ The following formula estimates B, for all ship types if B is not given.

$$B = bL_{OA} + c \tag{3}$$

$\underline{A_F,\ A_L,\ \text{and}\ A_{OD}}$ Following formulae, Eq. (4), estimate A_F, A_L, and A_{OD}, in which P stands for A_F, A_L or A_{OD}. Error evaluation of the regression analysis and physical speculation choose the best combination of left- and right-hand-side expression for each ship type and for each input case, L_{OA} only or L_{OA} and B. The physical consideration involves, for example, that A_F, A_L, and A_{OD} do not become negative within the possible ranges of L_{OA} and B.

$$\left.\begin{array}{c} P \\ P/L_{OA} \\ P/B \\ P/{L_{OA}}^2 \\ P/(L_{OA}B) \\ P/B^2 \end{array}\right\} = \begin{cases} aB + bL_{OA} + c \\ aB + c \\ bL_{OA} + c \end{cases} \tag{4}$$

$\underline{C,\ H_C,\ \text{and}\ H_{BR}}$ Following formulae, Eq. (5), estimate C, H_C, and H_{BR}, in which P stands for C, H_C or H_{BR}. C can be negative.

$$\left.\begin{array}{c} P \\ P/L_{OA} \\ P/B \end{array}\right\} = \begin{cases} aB + bL_{OA} + c \\ aB + c \\ bL_{OA} + c \end{cases} \tag{5}$$

Examples of regression analysis results, Fig. 3, show how linear expressions approximate above water structural features of ships.

$$
\mathrm{RR}_{A_L} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{A_{L(E)i}-A_{L(T)i}}{A_{L(T)i}}\right)^2} \tag{6}
$$

3.2. Wind Load Coefficients

Figure 5 presents examples of comparison of average wind load coefficients, C_{Xm}, C_{Ym}, C_{Nm}, and C_{Km} obtained using wind tunnel test data with estimates by the simple estimation method using L_{OA} and B. Following equation defines C_{Xm}, for example.

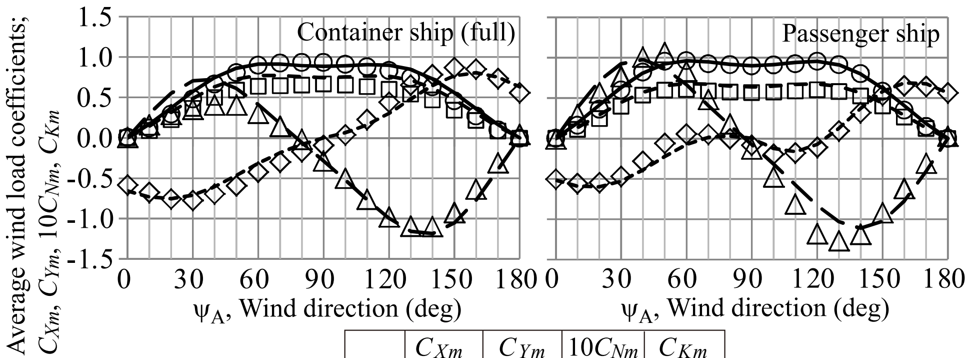
$$C_{Xm}(\psi_A) = \frac{1}{n}\sum_{i=1}^{n} C_X(\psi_A)_j \tag{7}$$

In Eq. (7), n stands for number of ships. Note that C_{Nm} is multiplied by 10 in Fig. 5 for convenience. Although this expression makes discrepancy of $10C_{Nm}$ look large, the estimates explain each ship type's properties depending on wind direction.

Root mean square of residual, Res, of wind load coefficients of all ships and all wind directions measures how precise the estimates are. Equation (8) defines Res on C_X.

$$\mathrm{Res}_{C_X} = \sqrt{\frac{1}{n}\frac{1}{m}\sum_{i=1}^{n}\sum_{j=1}^{m}\left(C_{X(\mathrm{T})ij} - C_{X(\mathrm{E})ij}\right)^2} \tag{8}$$

In Eq. (8), m and n are numbers of wind directions and ships respectively. Suffix (T) and (E) stand for wind tunnel test data and estimates by the simple estimation method respectively. Figure 6 compares Res of estimates by the simple method with those by the precise method. The more information about structural features is available, the higher precision estimates have. Differences, however, is not significant and authors believe the simple estimation method works successfully.



	C_{Xm}	C_{Ym}	$10C_{Nm}$	C_{Km}
Exp.	◇	○	△	□
Est.	-----	———	— —	- - -

Fig. 5 Examples of average wind load coefficients; C_{Xm}, C_{Ym}, C_{Nm}, and C_{Km}, comparing estimated using L_{OA} and B with wind tunnel test data.

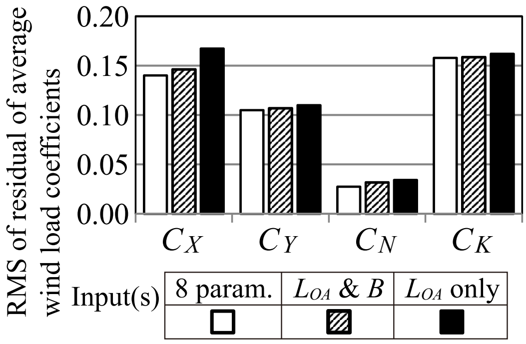


Fig. 6 Root mean square of residual of wind load coefficients, C_X, C_Y, C_N, and C_K, of all ship types and wind directions, comparing estimates by the simple method with the precise method.

3.3. Application to Other Sample Ships

Applying the simple estimation method to ships other than those listed in Table 1 shows how the method works for broader range of ships. Number of ships the method applied is 7 and Table 2 lists their types and sizes. Ranges of L_{OA} and B are wider, including a large tanker and a mega containership, than those of Table 1.

Figure 7 compares six structural parameters estimated using both L_{OA} and B with true values. The estimate of A_{OD} of the mega containership is larger than the true value and estimates of C have scattering tendency. Other parameter's estimates, however, show fairly good agreement with true value even for those of over range ships.

Examples of estimates of wind load coefficients for a large tanker and a mega containership, shown in Fig. 8, imply the simple method has possibility to broaden its application range, though their wind tunnel test data are not available.

Table 2 Applied ship types and dimensions

Ship type	Data number	Length overall, L_{OA}, range (m)	Breadth, B, range (m)
Tanker, full	3	239-380	42-68
Containership, full	4	200-398	32-56
(Total)	7	200-398	32-68

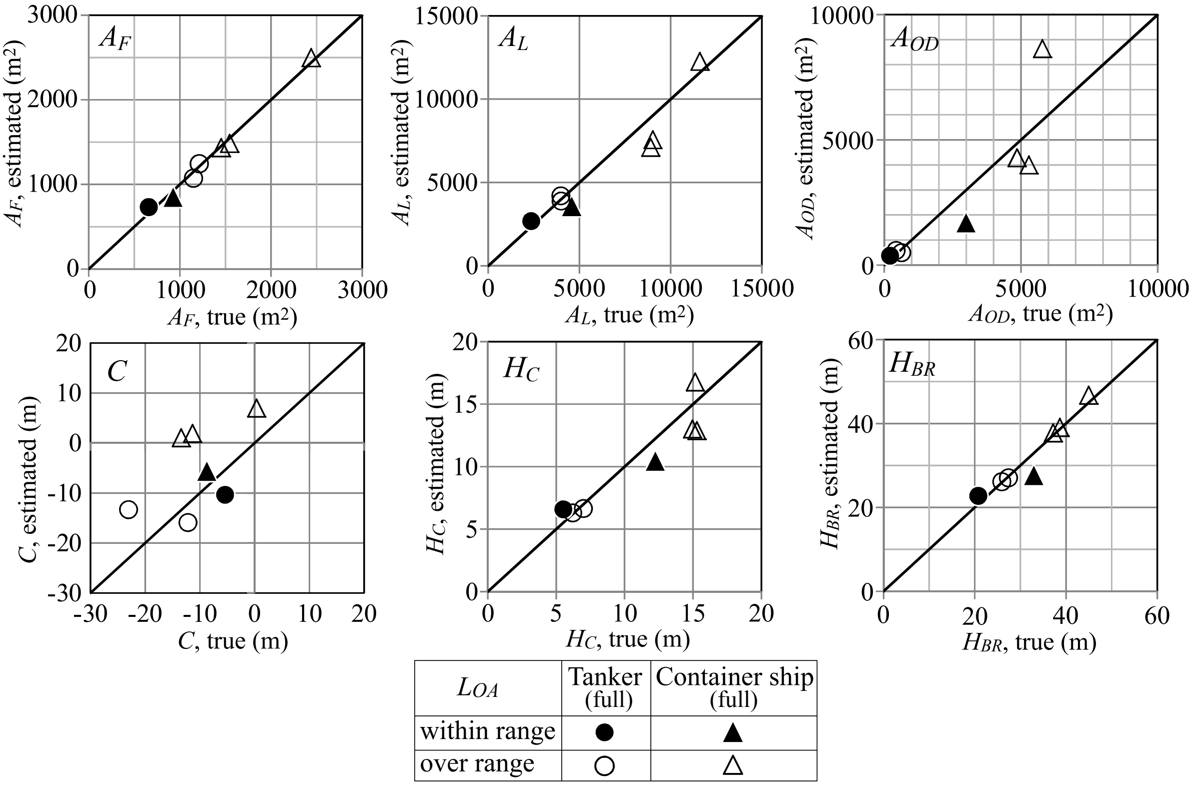


Fig. 7 Comparison of structural parameters estimated using L_{OA} and B with true values.

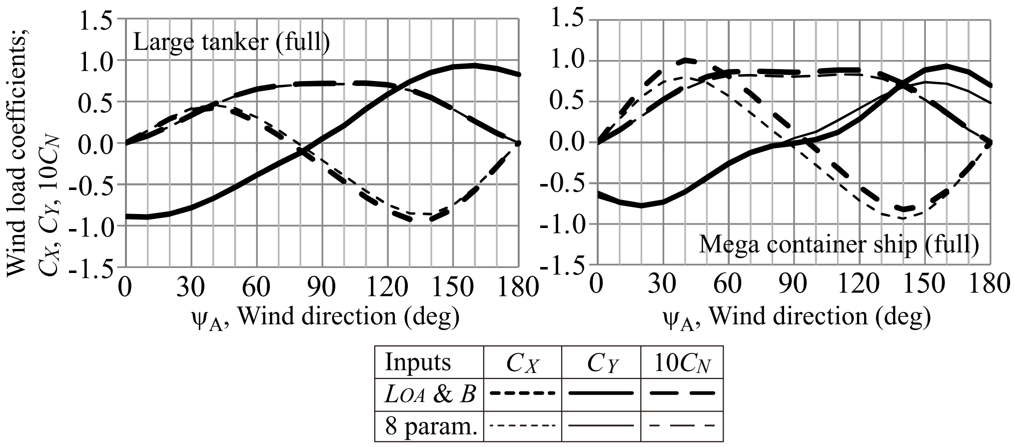


Fig. 8 Examples of wind load coefficients estimated for a large tanker and a mega containership.

CONCLUSION

Authors proposed a simple method to estimate wind load coefficients of ships. The method, in its first phase, estimates well using ship type and length overall, and additional ship breadth if possible, six or seven parameters representing above water structural features of ships. Selective ship types and conditions are nine; tanker full loaded, tanker ballast loaded, bulk carrier full, bulk carrier ballast, LNG carrier full, LNG carrier ballast, containership full, passenger ship, and others. The passenger type includes pure car carriers and the others type includes research ships, fishing vessels, tug boats, and training ships. Application example proved that this process works even if ship length is over the range of original ship data the simple method is based on.

The method gives, in the second phase, estimates of wind load coefficients using eight structural parameters, known and estimated in the first phase, and the procedure of precise method developed by authors. Comparison of wind load coefficients estimated by the simple method with wind tunnel test data and those by the precise method showed the simple method has allowable precision and usefulness.

This method should be worthwhile in case they need estimates of wind forces and moments acting on a ship especially in situations that limited information and/or time is available.

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