Estimation Program for Steady Wave Loads on Ships at Zero Forward Speed Using Database

by

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Abstract

The authors made an estimation program for steady wave loads on ships at zero forward speed based on a database on the basis of calculation results by a three-dimensional panel method for five types of ship which are tanker, container ship, pure car carrier, cargo carrier, and fishing boat. The inputs are ship type, length to breadth ratio, and breadth to draft ratio. The outputs are non-dimensional steady wave loads as functions of wavelength to ship length ratio and wave encounter angle. Distributions of maxima of steady wave loads, and comparison with estimates by the three-dimensional panel method and experimental data are provided.

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1. Introduction

Steady wave forces and moment play an important role in manoeuvring motion of ships at actual seas. They induce not only speed decrease but also drift motion that might lead accidents like collision and running aground. In order to analyze such accidents, we need to estimate the steady wave loads especially steady lateral force and yaw moment due to waves.

Some theories and numerical methods have been proposed so far for estimating steady lateral force and yaw moment due to waves, but they are not fully validated because of some difficulties on experiment. On the other hand, three-dimensional (3D) panel method is relatively reliable to estimate steady wave loads acting on ships at zero forward speed. The estimates would be much informative in accident analyses even though they consider no effect of forward speed on wave loads.

However, calculation of 3D panel method requires detailed data of ship form and such data are hard to obtain in accident analyses. Since time for accident analyses is limited, we often manage to estimate steady wave loads approximately without detailed data of ship form.

The authors made a program to estimate steady wave loads on ships at zero forward speed based on a database of calculated results. The database consists of a series of calculation results by 3D panel method using the ship forms generated by scaling the form of type ships. The type ships are tanker, container ship, pure car carrier (PCC), cargo carrier, and fishing boat. Inputs of the estimation program presented here are ship type, length to breadth ratio (L/B), and breadth to draft ratio (B/d) where L represents ship length between perpendiculars. No detailed data of ship form are required. Outputs are non-dimensional steady wave loads; longitudinal and lateral forces, and yaw moment; as functions of wavelength to ship length ratio λ/L, and wave encounter angle χ, obtained by interpolation of the database. Distributions of maxima of steady longitudinal and lateral forces due to waves, and comparison with estimates by the 3D panel method and experimental data are provided.

2. Type ships and modified ship forms

Type ships consist of tanker, container ship, PCC, cargo carrier, and fishing boat. Principal particulars of the type ships are shown in Table 1. Body plans are in Figs. 1 through 5.

Ship form data for the 3D panel method calculation are generated by scaling the type ship form in longitudinal, lateral, and vertical directions independently. The authors determined the ranges of L/B and B/d by surveying the existing ship data [1-4] and considering applicability of created mesh data. The number of resultant modified ship forms is 25 for tanker, PCC, cargo carrier, and fishing boat, respectively. L/B is 3.0, 4.5, 6.0, 7.5, and 9.0; and B/d is 2.0, 3.5, 5.0, 6.5, and 8.0 for each ship form. The number of modified ship forms of container ship is also 25. L/B is 3.0, 4.5, 6.0, 7.5, and 9.0; and B/d is 3.0, 3.5, 5.0, 6.5, and 8.0. Figure 6 shows combinations of L/B and B/d for the modified ship forms.

Table 1 Principal particulars of type ships

Item	Tanker	Container s.	PCC	Cargo c.	Fishing b.
Length between p.s, *L* (m)	320.00	200.00	180.00	156.00	53.00
Breadth, *B* (m)	58.00	32.00	32.00	26.60	9.40
Draft, *d* (m)	18.50	10.50	8.50	9.00	3.60
Depth (m)	28.80	16.50	14.00	14.10	3.95
GM (m)	9.82	2.53	1.62	2.31	1.04
Dead weight (t)	258000	23700	12500	18000	N/A
L/B	5.52	6.25	5.63	5.86	5.64
B/d	3.14	3.05	3.76	2.96	2.61
Block coefficient	0.834	0.558	0.55	0.704	0.656
l_{cb}* (% aft)	–3.70	2.40	2.38	–0.54	1.15

*Ratio of length from midship to the center of buoyancy to *L*

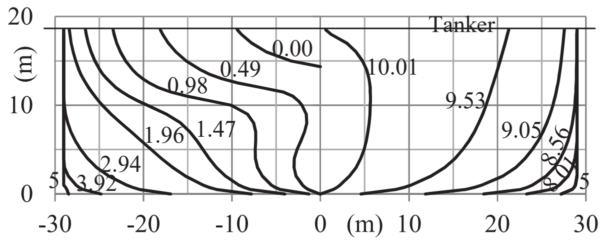

Fig. 1 Body plan of type ship, tanker.

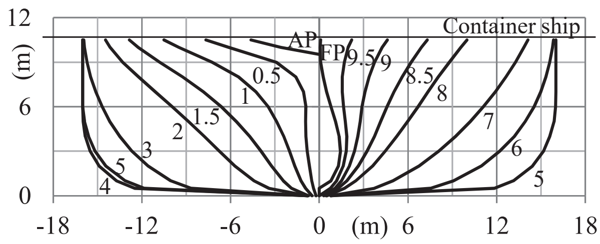

Fig. 2 Body plan of type ship, container ship

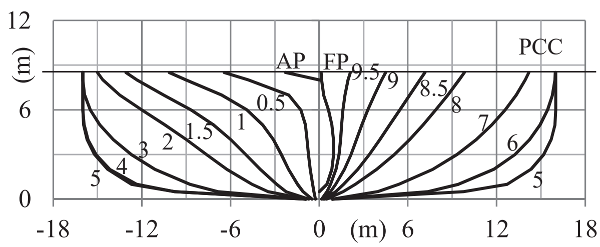

Fig. 3 Body plan of type ship, PCC

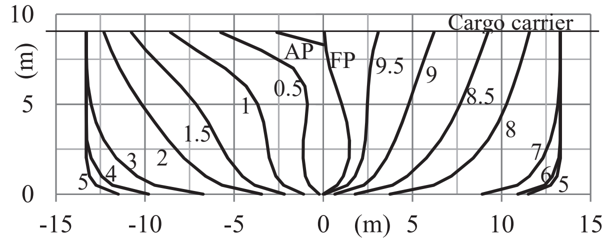

Fig. 4 Body plan of type ship, cargo carrier.

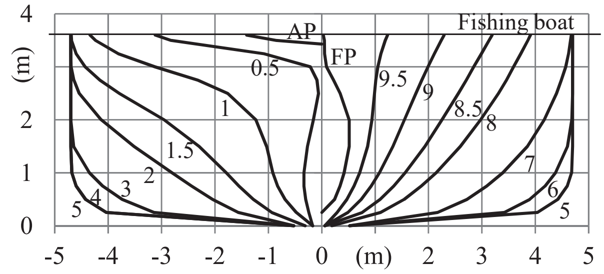

Fig. 5 Body plan of type ship, fishing boat.

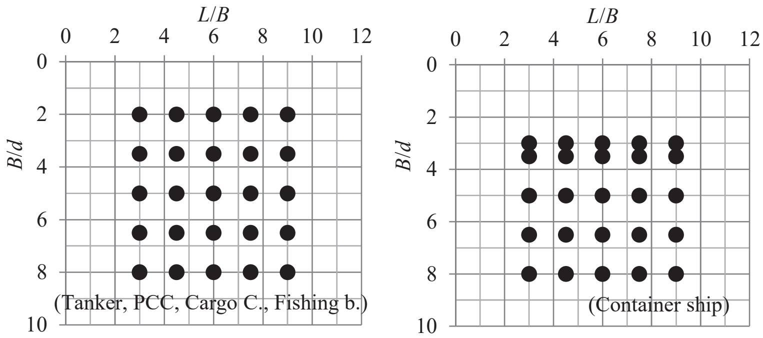

Fig. 6 Combination of L/B and B/d of modified ship forms for calculation (Left; tanker, PCC, cargo carrier, and fishing boat: Right; container ship).

3. Steady wave loads data and interpolation

The 3D panel method used here calculates steady wave loads in regular waves using following equations based on Maruo's method [5)] for the longitudinal force and Newman's method [6)] for the lateral force and yaw moment.

$$\begin{cases} X_W = \dfrac{\rho k^2}{8\pi}\displaystyle\int_0^{2\pi} |H_{(\theta)}|^2 (\cos\theta - \cos\chi) d\theta \\ Y_W = \dfrac{\rho k^2}{8\pi}\displaystyle\int_0^{2\pi} |H_{(\theta)}|^2 (\sin\theta - \sin\chi) d\theta \\ N_W = \dfrac{\rho k}{8\pi} Im \displaystyle\int_0^{2\pi} H_{(\theta)}{}^* H_{(\theta)}{}' d\theta - \dfrac{1}{2k}\rho\omega\zeta_a Re(H_{(\pi+\chi)}{}') \end{cases} \quad (1)$$

X_W, Y_W, and N_W stand for steady longitudinal and lateral forces, and yaw moment around the center of gravity due to waves, respectively. ρ is the density of water. k, ω, and ζ_a are wave number, wave circular frequency, and wave amplitude, respectively. χ is wave encounter angle. Definitions of X_W, Y_W, N_W, and χ are shown in Fig. 7. $H_{(\theta)}$ stands for Kochin function and asterisk * represents complex conjugate. The following equation defines $H_{(\theta)}{}'$.

$$H_{(\pi+\chi)}{}' = \left.\frac{dH_{(\theta)}}{d\theta}\right|_{\pi+\chi} \tag{2}$$

Haraguchi and Nimura [7], and Ueno et al. [8] validated the method by comparing the estimated steady wave loads together with ship motion in waves with experimental data.

The database consists of 12 cases of which λ/L is equal to 0.3, 0.5, 0.7, 0.9, 1.1, 1.3, 1.5, 1.7, 1.9, 2.1, 2.5, and 3.0. Wave encounter angle χ is from 0° to 350° with 10° interval, total 36 cases, for each λ/L though ship form symmetry about the centerline is assumed. Values in the database are non-dimensional ones defined by the following equations in which dash ’ attached to the symbols represents non-dimensional value.

$$\begin{cases} X_W{}' = \dfrac{X_W}{0.5\rho g {\zeta_a}^2 B} \\ Y_W{}' = \dfrac{Y_W}{0.5\rho g {\zeta_a}^2 L} \\ N_W{}' = \dfrac{N_W}{0.5\rho g {\zeta_a}^2 L^2} \end{cases} \tag{3}$$

Figures 8 through 12 show distribution in L/B - B/d planes of absolute maxima of X_W’ and Y_W’ larger than 1.0 among those for all combination of λ/L and χ. The figures are rough contours of X_W’ and Y_W’ providing users with an idea how steady wave loads calculated by the 3D panel method vary depending on combination of L/B and B/d. Contours of N_W’ are omitted since such a rough contour cannot represent general characteristics of N_W’ due to its complicated variation depending on λ/L and χ.

The present program estimates steady wave loads depending on input ship type, L/B, and B/d using the calculation database. If an input L/B is out of the range of type ship, either the closest minimum or maximum value replaces the input. The same pre-procedure is applied to an input B/d. After checking the input L/B and B/d, two-dimensional linear interpolation for data of every combination of λ/L and χ makes a set of outputs, estimated steady wave loads as functions of λ/L and χ. Steady wave loads in the database outside the L/B or B/d ranges of type ships are assumed to be equal to the value on the border line of the range.

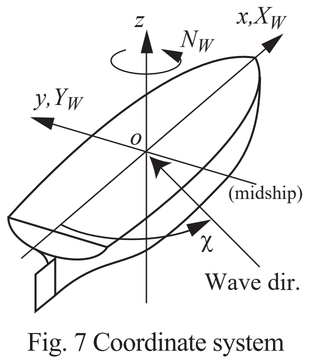

Fig. 7 Coordinate system

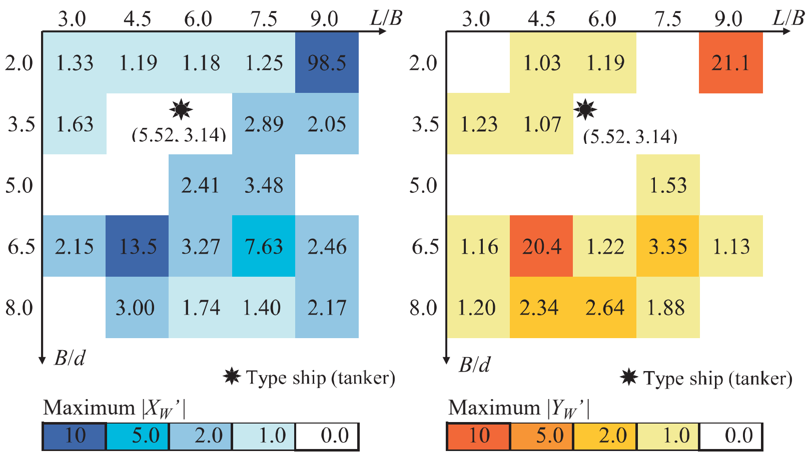

Fig. 8 Distribution of maximum $|X_W'|$ and $|Y_W'|$ larger than 1.0 (tanker)

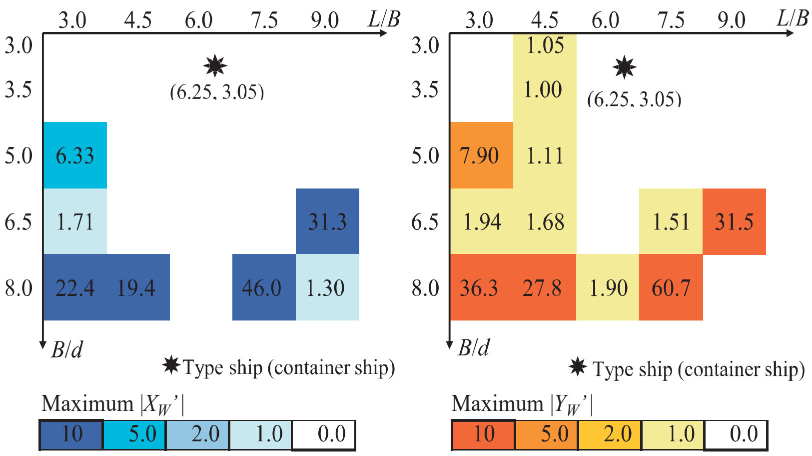

Fig. 9 Distribution of maximum $|X_W'|$ and $|Y_W'|$ larger than 1.0 (container ship).

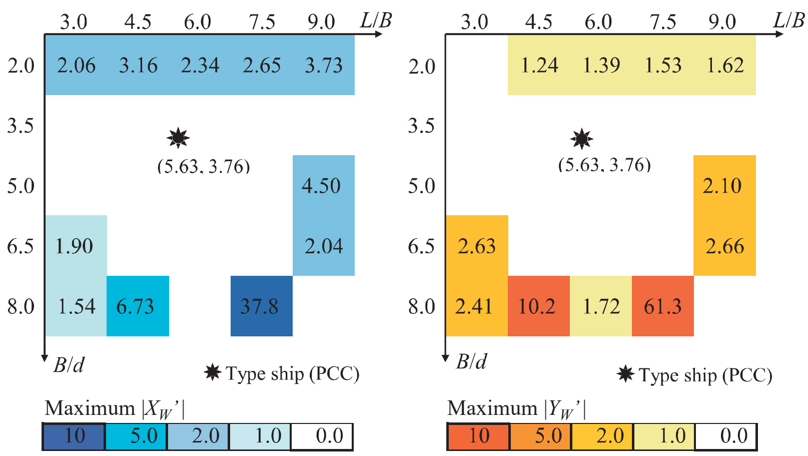

Fig. 10 Distribution of maximum $|X_W'|$ and $|Y_W'|$ larger than 1.0 (PCC).

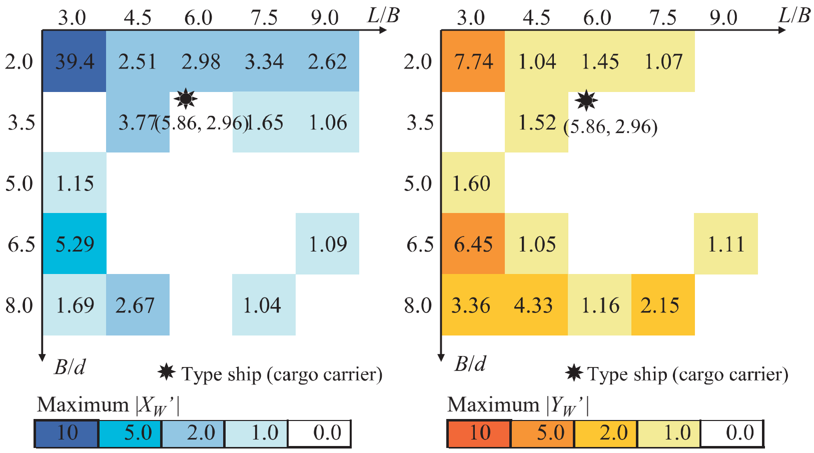

Fig. 11 Distribution of maximum $|X_W'|$ and $|Y_W'|$ larger than 1.0 (cargo carrier).

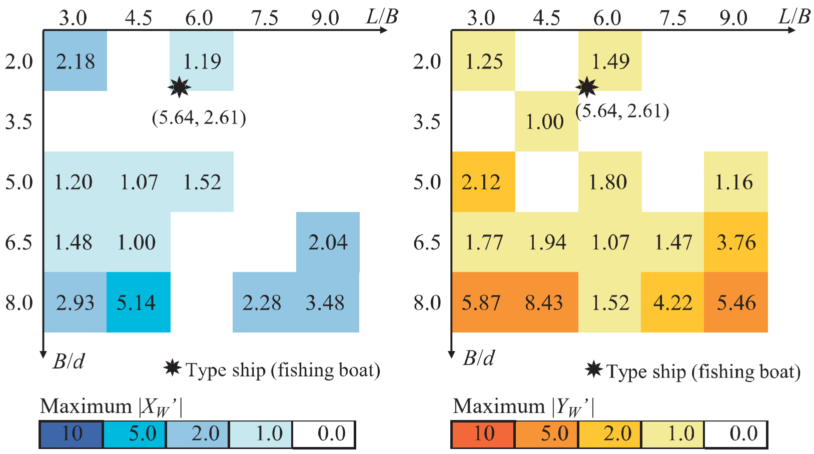

Fig. 12 Distribution of maximum $|X_W'|$ and $|Y_W'|$ larger than 1.0 (fishing boat).

4. Application example

The authors applied the estimation program to a tanker as an example[8] of which principal particulars and body plan are shown in Table 2 and Fig. 13, respectively. The L/B is coincidentally equal to that of the type ship tanker.

Figure 14 shows dependency of X_W', Y_W', and N_W' on λ/L comparing the estimates by the present program with those by the 3D panel method program and the experimental data [8]. The 3D panel method uses detailed offset data representing ship form, while the present program uses only L/B and B/d. Figure 15 shows dependency of X_W', Y_W', and N_W' on χ. The authors consider that the discrepancy between the present program and experimental data would be attributed to not only the difference of ship forms but also that of ship motion affected by the position of the center of gravity.

Although there are some discrepancies, they are not crucial as a whole for practical use comparing with those of the 3D panel method.

Table 2 Principal particulars of a sample tanker

Item	Tanker
Length between p.s, L (m)	320.00
Breadth, B (m)	58.00
Draft, d (m)	19.30
GM (m)	6.46

L/B	5.52
B/d	3.01
Block coefficient	0.8033
l_{cb}^{*} (% aft)	−2.53

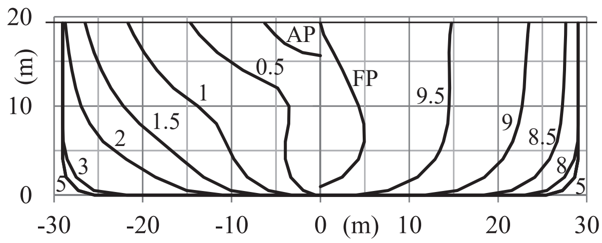

Fig. 13 Body plan of sample ship, tanker.

5. Conclusions

The authors made an estimation program for steady wave loads on ships at zero forward speed based on a database. The database is for five types of ships such as tanker, container ship, PCC, cargo carrier, and fishing boat; and it consists of the calculation results of 3D panel method for ship forms generated by scaling the type ships. The inputs to the estimation program requiring no detailed ship form data are ship type, L/B, and B/d. The outputs obtained by the database interpolation are non-dimensional steady wave loads as functions of λ/L and χ.

Distributions of maxima of steady longitudinal and lateral forces due to waves in the database give information on applicability of the estimation program. Comparison with the estimates by the 3D panel method and experimental data shows good agreement as a whole and confirms reliability of the present program in spite of a small amount of the input information.

Since the present program can estimate steady wave loads without using detailed ship form data, the authors consider that it would provide some information on steady wave loads in various situations including ship accident analyses.

Acknowledgment

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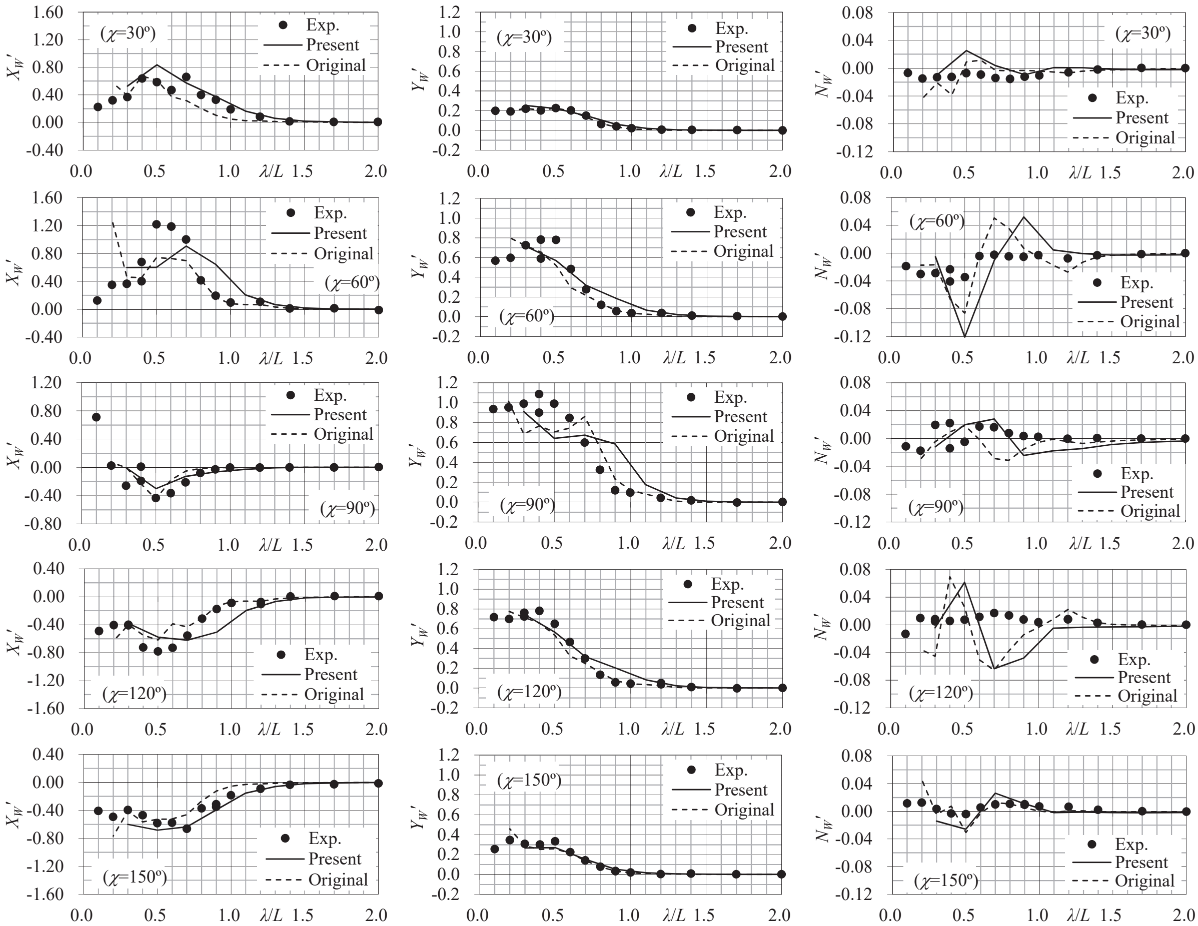

Fig. 14 Steady wave loads of a sample tanker depending on wavelength to ship length ratio estimated by present program (Present), 3D panel method (Original), and experimental data (Exp.)

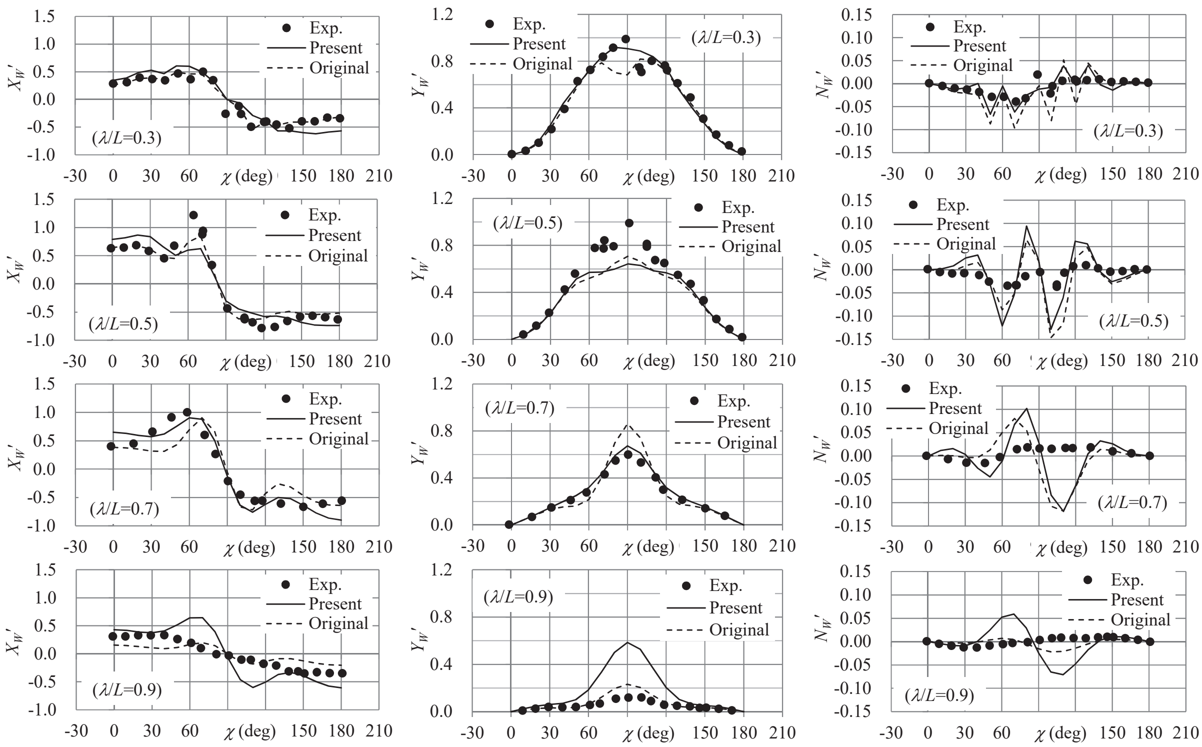

Fig. 15 Steady wave loads of a sample tanker depending on wave encounter angle estimated by present program (Present), 3D panel method (Original), and experimental data (Exp.)