Development of a Practical Calculation Method for Added Resistance in Short Waves

Project Team for Ship Performance Index (10 mode at Sea)

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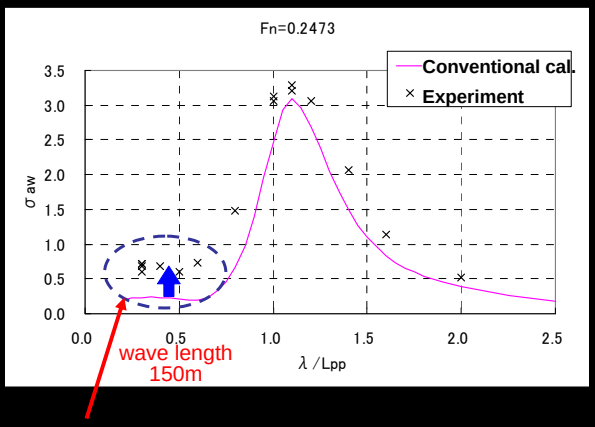
Added resistance in regular heading waves



Container ship
length: 300m

Fine ship: theoretical estimation in short waves is poor

Accurate estimation is required especially for a large ship

Introduction

Added resistance in short waves (conventional method)

$$R_{AW} = \frac{1}{2}\rho g \zeta_a^{\,2} B B_f \alpha_d (1+\alpha_U)$$

Added resistance due to wave reflection (semi-empirical formula)

$$\alpha_d = \frac{\pi^2 I_1^{\,2}(kd)}{\pi^2 I_1^{\,2}(kd) + K_1^{\,2}(kd)}$$

Effect of draft and frequency

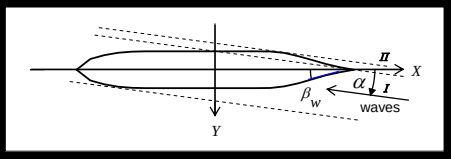
$$\alpha_U = 5\sqrt{F_n}$$

Effect of advance speed

The empirical formula is derived from experiments of full ships by Fujii and Takahashi

$$B_f = \frac{1}{B}\left\{\int_I \sin^2(\alpha+\beta_w)\sin\beta_w dl + \int_{II} \sin^2(\alpha-\beta_w)\sin\beta_w dl\right\}$$

Bluntness coefficient



Relation between hull shape on water plane and wave direction

Calculation method

The calculation method for added resistance in short waves is corrected based on the following experiments:

(1) Effect of draft and frequency

Experiments of added resistance in regular waves are carried out for a wall-sided model with motion fixed.

(2) Effect of advance speed

Experiments of added resistance in regular heading waves; a container ship and PCC.

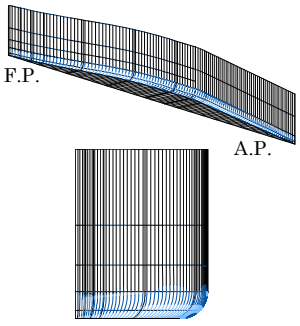
(3) Application to directional waves

Experiments of added resistance in directional regular waves; a container ship and PCC.

Calculation method

(1) investigation on draft and frequency

A wall-sided model which is fixed surge, heave and pitch motion is used for the experiments of added resistance in regular heading waves.



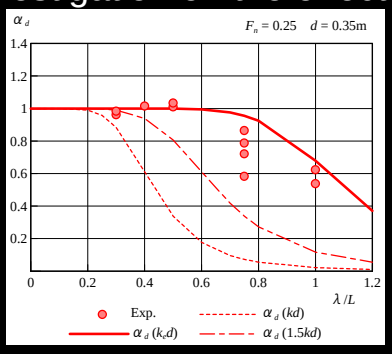
A wall-sided ship

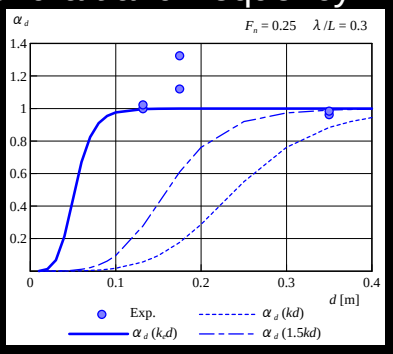
λ/L=0.3, F_n=0.25

Calculation method

Experiment of added resistance in short waves using wall-sided ship with motion fixed

(1) investigation on the effect of draft and frequency





Theoretical formula by Ursell

$$\alpha_d = \frac{\pi^2 I_1^2(kd)}{\pi^2 I_1^2(kd) + K_1^2(kd)}$$

corrected by Takahashi

$$\alpha_d = \frac{\pi^2 I_1^2(1.5kd)}{\pi^2 I_1^2(1.5kd) + K_1^2(1.5kd)}$$

correction

$$\alpha_d = \frac{\pi^2 I_1^2(k_e d)}{\pi^2 I_1^2(k_e d) + K_1^2(k_e d)}$$

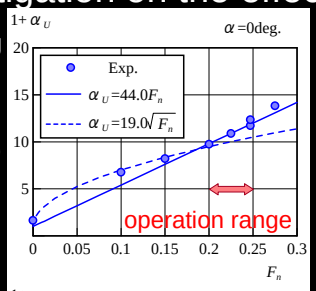
Calculation method

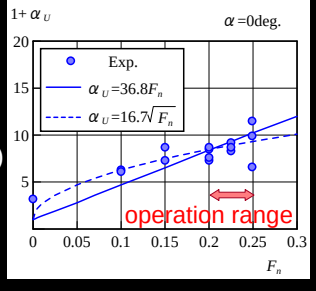
Experiment of added resistance in short waves with different ship speed

(2) investigation on the effect of advance speed

in heading waves

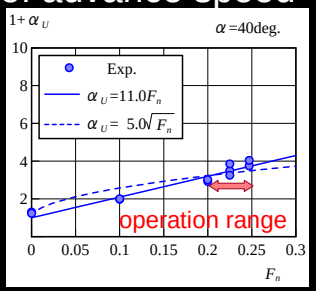
Container ship (Length 300m)



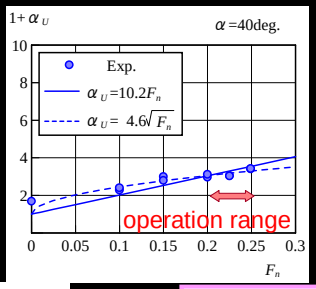


PCC (Length 190m)

in oblique waves



λ /L = 0.3



λ /L = 0.3

correction

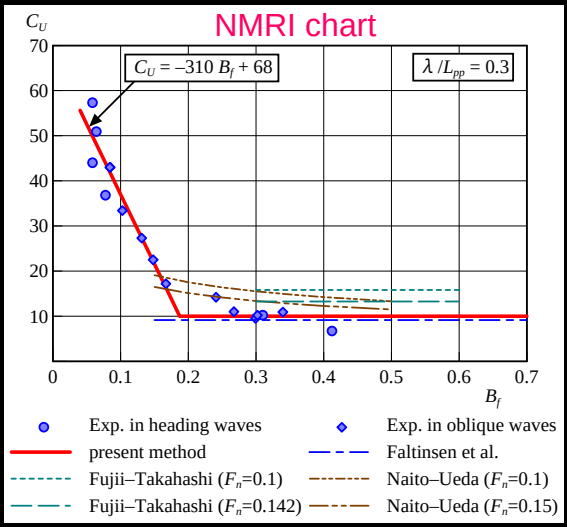
$$\alpha_U = 5\sqrt{F_n} \rightarrow \alpha_U = C_U F_n$$

Calculation method

A chart is made of the experiments in directional waves

(3) application to directional waves

apply the coefficient of advance speed to directional waves



This chart is derived from experiments of conventional ships

Relation between coefficient of advance speed and bluntness coefficient

Simulations

Ships

Container ship

item	dimension	
length (L_{pp})	300	m
breadth	40	m
draft	14	m
M.E. output (NOR)	50,607	kW

PCC (pure car carrier)

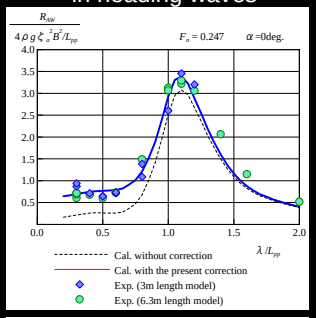
item	dimension	
length (L_{pp})	190	m
breadth	32.26	m
draft	9	m
M.E. output (NOR)	13,534	kW

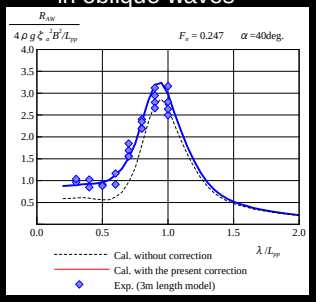
Simulations

Added resistance in regular waves

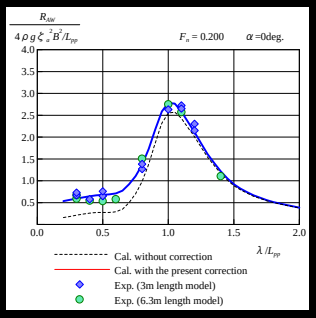
in heading waves | in oblique waves

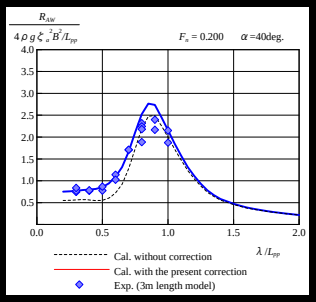
F_n =0.247





F_n =0.200





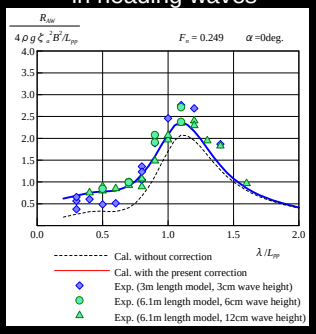
container ship (length 300m)

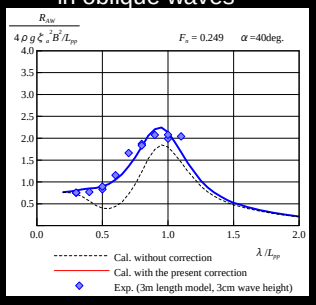
Simulations

Added resistance in regular waves

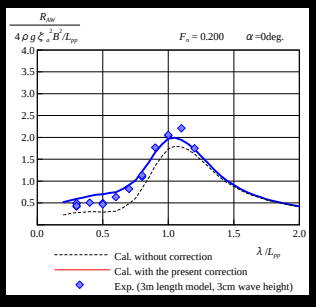
in heading waves | in oblique waves

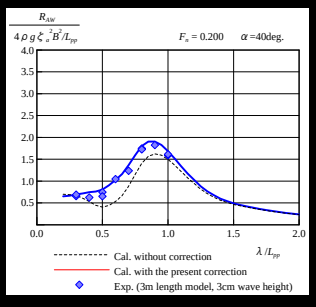
F_n =0.249





F_n =0.200





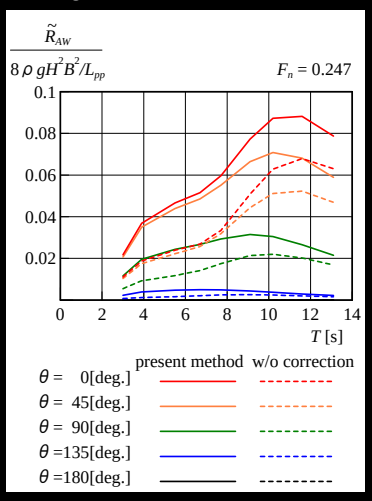
PCC (length 190m)

Simulations

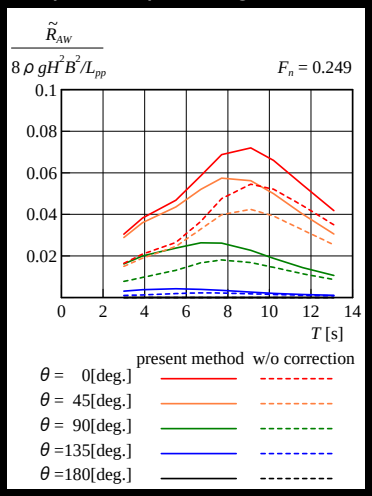
Added resistance in short crested irregular waves

Correction:
(1) draft & frequency
(2) advance speed
(3) directional waves

frequency spectrum: IACS spectrum
angular distribution function: cosine squared spreading



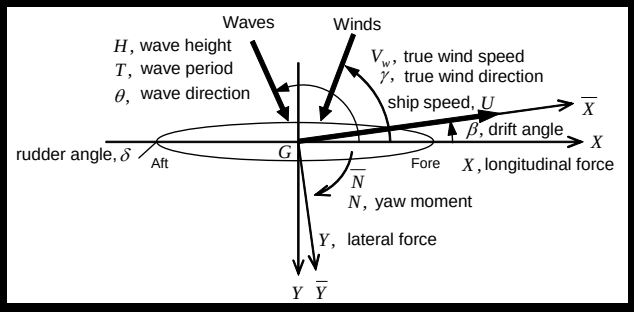
container ship (length 300m)



PCC (length 190m)

Simulations

Ship speed in actual seas (Equilibrium equations)



- ship resistance in still waters
- added resistance in oblique motion
- propeller thrust
- rudder forces
- wind forces
- added resistance in waves

Time mean behavior is considered.

Equilibrium equations

$$\bar{X} = X\cos\beta + Y\sin\beta = 0$$
$$\bar{Y} = X\sin\beta - Y\cos\beta = 0$$
$$\bar{N} = N = 0$$

Simulations

Weather conditions

Weather conditions are determined based on Beaufort scale of wind

Beaufort number	mean wind speed V_w [m/s] (V_w [knot])	significant wave height H [m]	mean wave period T [s]
BF3	4.4 (8.5)	0.6	3.0
BF4	6.9 (13.5)	1.0	3.9
BF5	9.8 (19.0)	2.0	5.5
BF6	12.6 (24.5)	3.0	6.7
BF7	15.7 (30.5)	4.0	7.7

mean wind speed:
central value of Beaufort scale

significant wave height:
probable wave height of Beaufort scale

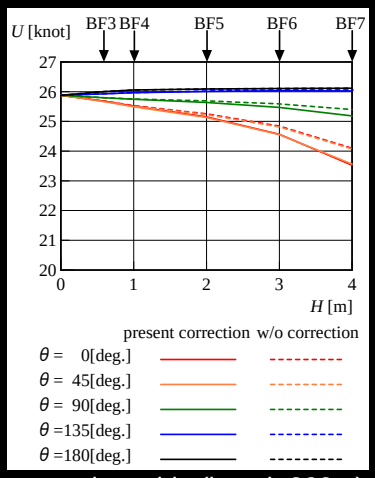
mean wave period:

$$T = 3.86\sqrt{H}$$

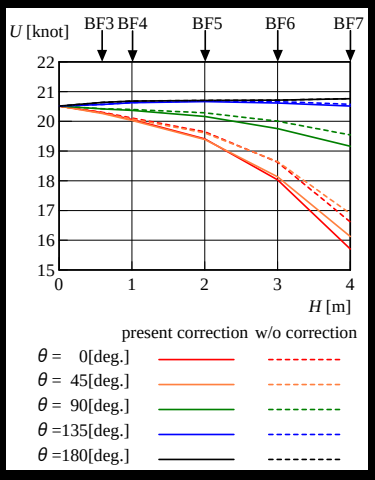
derived from a frequency spectrum for full-developed wind waves

Simulations

Decrease of ship speed



container ship (length 300m)



PCC (length 190m)

Output of main engine: constant at NOR

Conclusions

Practical correction method for added resistance in short waves was developed.

correction is:

(1) draft & frequency $\alpha_d = \frac{\pi^2 I_1^2(k_e d)}{\pi^2 I_1^2(k_e d) + K_1^2(k_e d)}$

(2) advance speed $1 + \alpha_U = 1 + C_U F_n$

(3) application to directional waves
using NMRI chart

Determination of the coefficient of advance speed by tank test is important in the point of accuracy.

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