

Comparison of Different Added Power in Waves Prediction Methods

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Abstract: In order to predict the speed loss in the actual sea states more precisely, delivered power shall be measured more accurately as an input. Therefore, based on a 50,000 DWT tanker, various results obtained from different prediction methods were compared by a series of model tests performed in calm water and in waves. It is shown that speed loss deprived from RTIM (resistance and thrust identity method) method in regular waves test could satisfy the engineering requirements most.

Key words: Added power, model test, speed loss, sea keeping prediction, self propulsion test in waves.

1. Introduction

The speed loss of ships in the actual sea state has been attracting more and more attentions since the EEDI (energy efficient design index) policy enforcement was raised by IMO (international maritime organization) in the MEPC (maritime environment protection committee). This means that those ships with unacceptable speed loss performance would be eliminated from the market gradually.

The speed loss is related to the added resistance and power. There are mainly 4 different methods recommended by ITTC (international towing tank conference) to calculate those performances, such as DPM (direct power method), QNM (torque and revolution method), TRM (thrust and revolution method) and RTIM (resistance and thrust identity method) [1]. To predict the speed loss in actual sea state combining with the non-dimensional response curves of kinds of physical quantities, results from self-propulsion model test in waves are required in the former three methods. While, the latter is based on the assumption that the self-propulsion factors in waves are the same as those in calm water. Then, the added resistance, added power and speed loss of the ship in

actual sea state could be calculated by combining with the results obtained from regular wave model tests and adopting ITTC two parameter spectrum.

In order to compare the difference of speed loss calculated by different methods recommended by ITTC, the exploration and research on model self-propulsion test in waves have to be proceeded. Fundamental introductions have been made by S. Kans. in his research [2] in earlier 1960s. And lots of researches have been done afterwards. Ikegami and Imaizumi had predicted the speed loss by doing self-propulsion model test in waves in 1978. HE [3] made his research on a small boat by adopting direct powering method to analyze the self-propulsion factors in waves. Tanizawa et al. [4] had contrived a suit of simulation devices of crude oil engine to do the research of self-propulsion model test in waves. However, available published research data in self propulsion test in waves are relatively insufficient. One purpose of the work is to explore the ways of self-propulsion model test in waves [5-7], while the other is to analyze the differences of prediction results by using different methods suggested by ITTC to investigate the accuracy of different methods [8, 9].

In this article, a 50,000 DWT tanker was selected to be the research object. Model tests, especially self-propulsion model test in regular waves, had been

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carried out combined with a series of powering tests in calm water. The results in this paper were based on the self propulsion point on model scale on the condition that full scale ship was sailing in the sea without any restrictions.

2. Model Test

Main dimensions of the 50,000 DWT tanker are listed in Table 1. The vertical-shape bulbous bow which is prevailing due to the higher performance in resistance and in waves is adopted.

The hull lines are listed in Fig. 1.

2.1 Test Method and Parameters

Powering test in calm water and added resistance test in head waves are common practice, while the way of self-propulsion model test in waves is not clarified. However, it is the combination of both tests mentioned above. In addition, friction drag correction

F_d in waves also comes from that in calm water and the theoretical hypothesis is that the wave added resistance of the full scale meets the requirements of λ^3 proportional to model.

The test information is listed in Tables 2 and 3.

2.2 Test Data and Processing of the Results

Like the motion of ship, the average wave resistance and propeller thrust, torque and rotation rate in irregular waves could be predicted by means of the response amplitude operator observed in model test.

The added power prediction in irregular waves includes two aspects, one is to predict the power increase of the model according to the RAO obtained from the tests, and the other is to predict the full scale power increase by analyzing the model test data. The RAO of wave added resistance, added thrust, added rotation rate, added power of model is measured during

Table 1 Main dimensions of 50,000 DWT tanker.

	Unit	Full scale	Model scale
Length between perpendiculars	m	180.0	5.871
Breadth moulded	m	32.2	1.050
Draft moulded	m	11.0	0.359
Displacement volume moulded	m ³	51,885.793	1.8
Height of central of gravity (from baseline)	m	10.06	0.328
LCB position aft of FP	m	87.712	2.86
Longitudinal initial radius	---	0.25 Lpp	
Scale ratio	---	30.66	

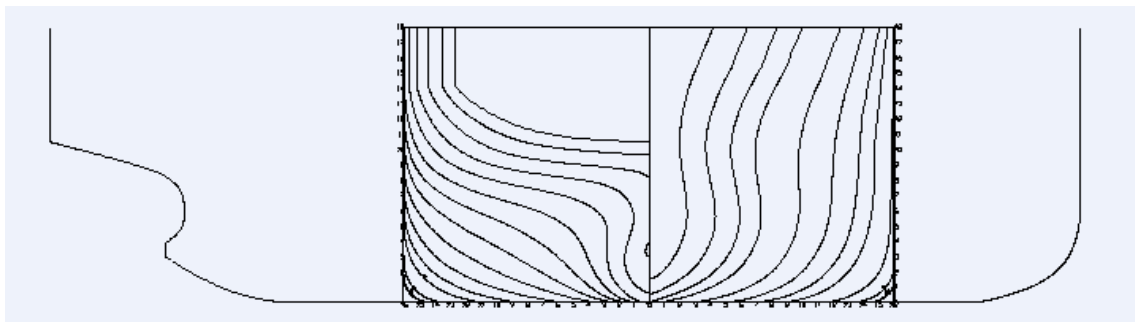


Fig. 1 Hull lines of 50,000 DWT tanker.

Table 2 Model speed and measurements.

Model speed (m/s)	1.096	1.189	1.282	1.375
Full scale speed (kn)	11.8	12.8	13.8	14.8
Measurements	Propeller rotation rate, torque, thrust, added resistance			

Table 3 Regular wave parameters.

λ/L	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Period T	0.858	1.050	1.213	1.356	1.485	1.604	1.715	1.819
Frequency f	1.166	0.952	0.825	0.738	0.673	0.623	0.583	0.550
Wave height H	4~8 cm							
λ/L	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0
T	1.918	2.011	2.101	2.187	2.269	2.426	2.573	2.712
f	0.521	0.497	0.476	0.457	0.441	0.412	0.389	0.369
H	4~8 cm							

model test in calm water and regular waves. All the physical quantities have to be treated in non-dimensional format.

The non-dimensional methods are listed as follows:

$$K_{\Delta R} = \Delta R_w / (4\rho g \zeta_a^2 B^2 / L_{wl}) \quad (1)$$

$$K_{TW}(\omega) = \frac{\Delta T_w(\omega)}{\rho g (B^2 / L) \zeta_a^2}, \Delta T_w(\omega) = T_w(\omega) - T_s \quad (2)$$

$$K_{QW}(\omega) = \frac{\Delta Q_w(\omega)}{\rho g (B^2 D / L) \zeta_a^2}, \Delta Q_w(\omega) = Q_w(\omega) - Q_s \quad (3)$$

$$K_{NW}(\omega) = \frac{\Delta N_w(\omega) D^3 V}{g (B^2 / L) \zeta_a^2}, \Delta N_w(\omega) = N_w(\omega) - N_s \quad (4)$$

$$\Delta P = 2\pi(N(\omega_e)Q(\omega_e) - NQ) \quad (5)$$

$$K_{\Delta P} = \frac{\Delta P}{\zeta_a^2} \lambda^{1.5} \quad (6)$$

where: ΔR_w —wave added resistance; ΔP —added power; ζ_a —wave amplitude; $\Delta T_w(\omega)$ —added thrust; $\Delta Q_w(\omega)$ —added torque; $\Delta N_w(\omega)$ —added rotation rate; w —wave frequency; ω_e —encounter frequency.

It is shown from Figs. 2-6 that, frequency response curve of added resistance, added power, added rotation rate, added thrust and added torque all have the same trend. Along with increasing of λ/L , all physical quantities increase first and then decrease again, the peak appears at λ/L ranging from 1.0 to 1.2. In addition, the peak value will increase as the

ship speed increases. Due to the limitation of test facilities, test ended in λ/L up to 1.8, while, the tendency shows that the tail of the curves will reach towards zero.

2.3 Prediction Method

The added wave resistance, thrust and torque in different sea states could be predicted by combining the ITTC density spectrum and non-dimensional frequency curves.

The ITTC density spectrum is:

$$S(\omega) = 173 H_{1/3}^2 T_1^{-4} \omega^{-5} \exp(-691/T_1^4 \omega^4) \quad (7)$$

where: $H_{1/3}$ —significant wave height; T_1 —characteristic period; ω —circular frequency.

The methods recommended by ITTC to predict the added power of the ship in real states from self-propulsion model test in regular waves could be found in ITTC procedures for seakeeping test.

3. Data Analysis

Different results could be obtained from different methods, the delivered power of the propeller could be directly obtained by using QNM method, but in RTIM and TNM, the power only can be obtained by using the propeller open water test data. In addition, the propeller open water efficiency in the sea state is not the same as that in calm water because the propeller cannot run in sufficient immersed depth. The prediction results are as follows.

According to the P_d and V_s relations from Figs 2-8 and Tables 4-7, the coefficient of speed loss at the EEDI sea state ($H_{1/3} = 3$ m, $T_1 = 6.7$ s) could be predicted.

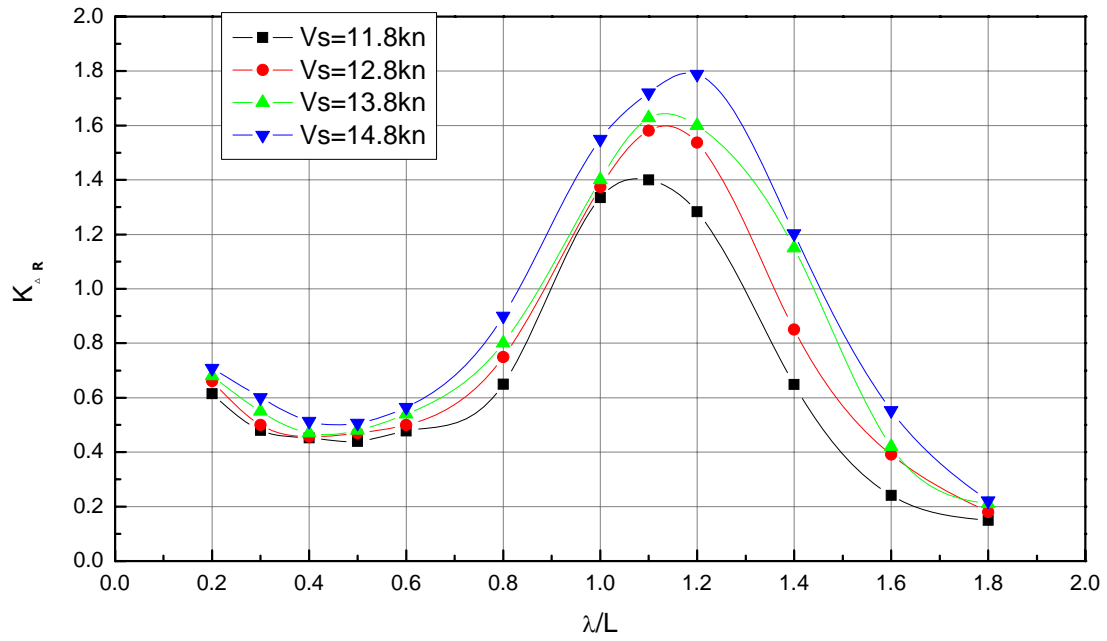


Fig. 2 Frequency response curve of added resistance.

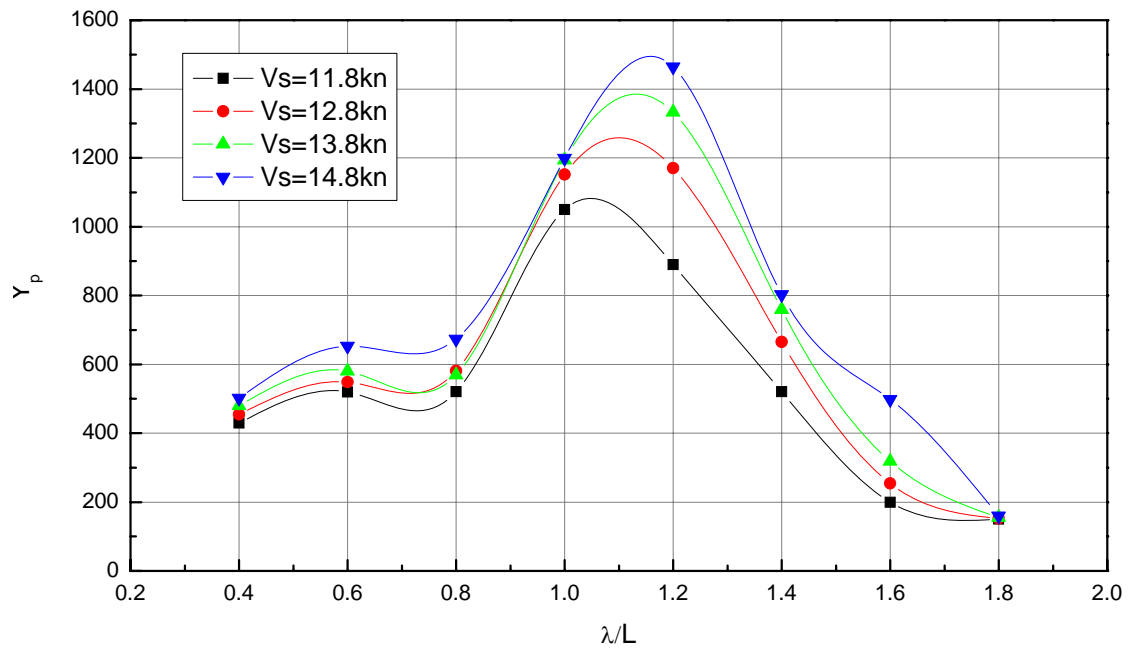


Fig. 3 Frequency response curve of added power.

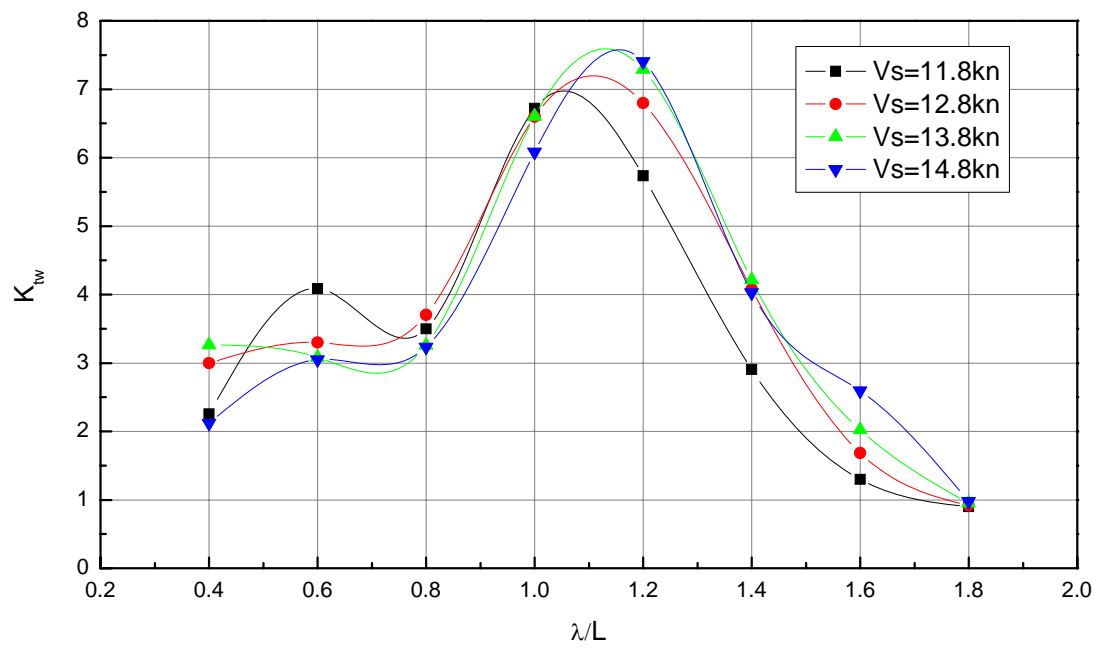


Fig. 4 Frequency response curve of added thrust.

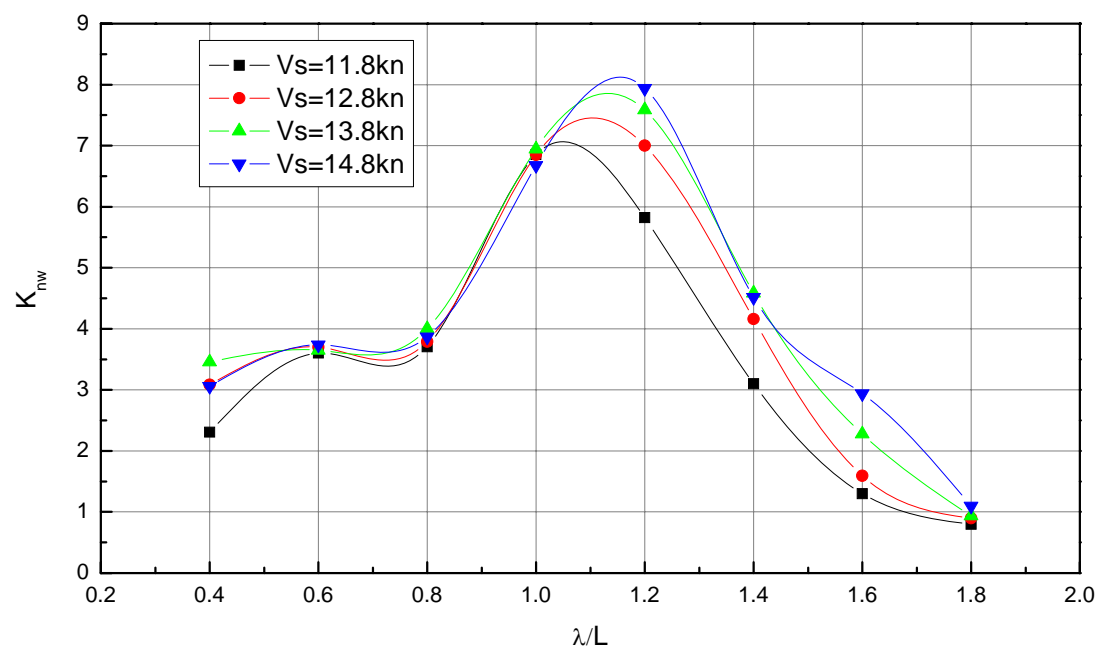


Fig. 5 Frequency response curve of added rotation rate.

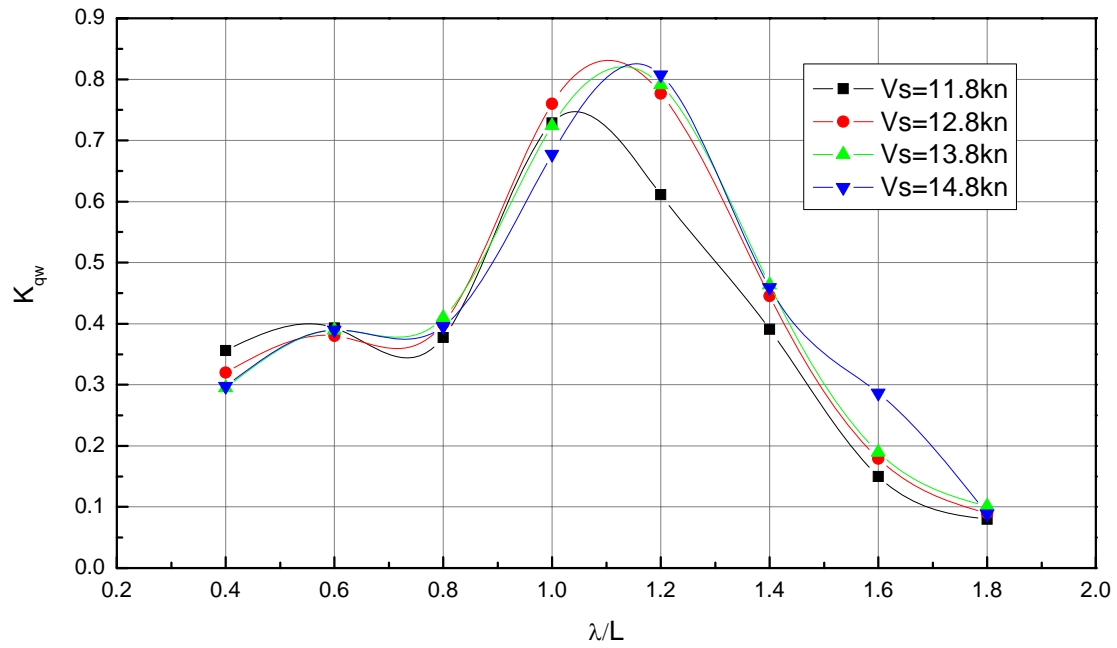


Fig. 6 Frequency response curve of added torque.

Table 4 Delivered power of propeller by DPM.

Calm water (KW)			Vs = 11.8 kn	Vs = 12.8 kn	Vs = 13.8 kn	Vs = 14.8 kn
			3,325.3	4,418.2	5,506.4	6,998.4
H1/3 = 2.0 m	T1 = 5.5 s		3,511.11	4,609.99	5,744.87	7,251.15
H1/3 = 3.0 m	T1 = 6.7 s		4,233.33	5,374.82	6,619.93	8,208.76
H1/3 = 4.0 m	T1 = 7.3 s		5,466.16	6,669.57	8,109.54	9,845.20

Table 5 Delivered power of propeller by QNM.

Calm water (KW)			Vs = 11.8 kn	Vs = 12.8 kn	Vs = 13.8 kn	Vs = 14.8 kn
			3,325.3	4,418.2	5,506.4	6,998.4
H1/3 = 2.0 m	T1 = 5.5 s		3,506.82	4,605.97	5,740.05	7,246.61
H1/3 = 3.0 m	T1 = 6.7 s		4,208.03	5,350.84	6,595.9	8,184.73
H1/3 = 4.0 m	T1 = 7.3 s		5,490.76	6,686.52	8,132.18	9,863.3

Table 6 Delivered power of propeller by TNM.

Calm water (KW)			Vs = 11.8 kn	Vs = 12.8 kn	Vs = 13.8 kn	Vs = 14.8 kn
			3,325.3	4,418.2	5,506.4	6,998.4
H1/3 = 2.0 m	T1 = 5.5 s		3,689.75	4,701.22	5,803.37	7,299.89
H1/3 = 3.0 m	T1 = 6.7 s		4,360.05	5,575.38	6,900.17	8,420.64
H1/3 = 4.0 m	T1 = 7.3 s		5,203.6	6,489.42	8,059.96	9,716.02

Table 7 Delivered power of propeller by RTIM.

Calm water (KW)			Vs = 11.8 kn	Vs = 12.8 kn	Vs = 13.8 kn	Vs = 14.8 kn
			3,325.3	4,418.2	5,506.4	6,998.4
H1/3 = 2.0 m	T1 = 5.5 s		3,577.189	4,631.651	5,719.807	7,251.403
H1/3 = 3.0 m	T1 = 6.7 s		4,241.629	5,440.79	6,447.921	8,095.831
H1/3 = 4.0 m	T1 = 7.3 s		5,650.855	6,820.501	7,997.662	9,848.086

By comparing the results, it could be found that the results of DPM, QNM and RTIM are very close to each other, the fw result (weather factor defined in the energy efficiency design index) of TNM is about 2.1% lower than the others. As the delivered power of propeller could be calculated by measuring the

rotation rate and torque, there is no need to consider the effect of immersed depth of propeller. Therefore, the results of QNM are a more reliable method than the others, but RTIM method is of great convenience, as self propulsion test in waves is a kind of time consuming work.

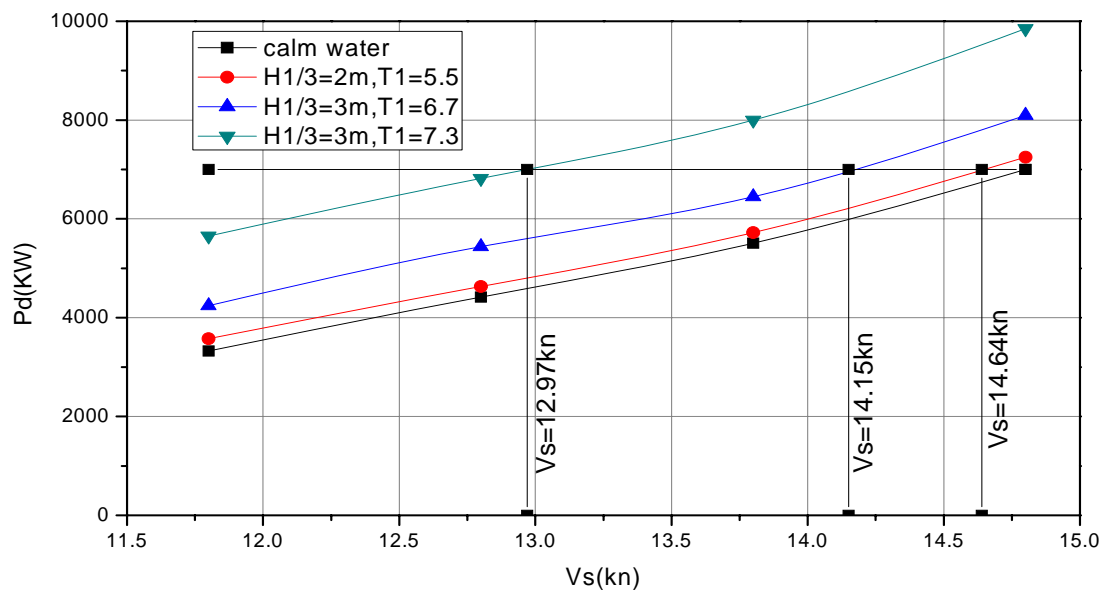


Fig. 7 Pd-Vs of RTIM result.

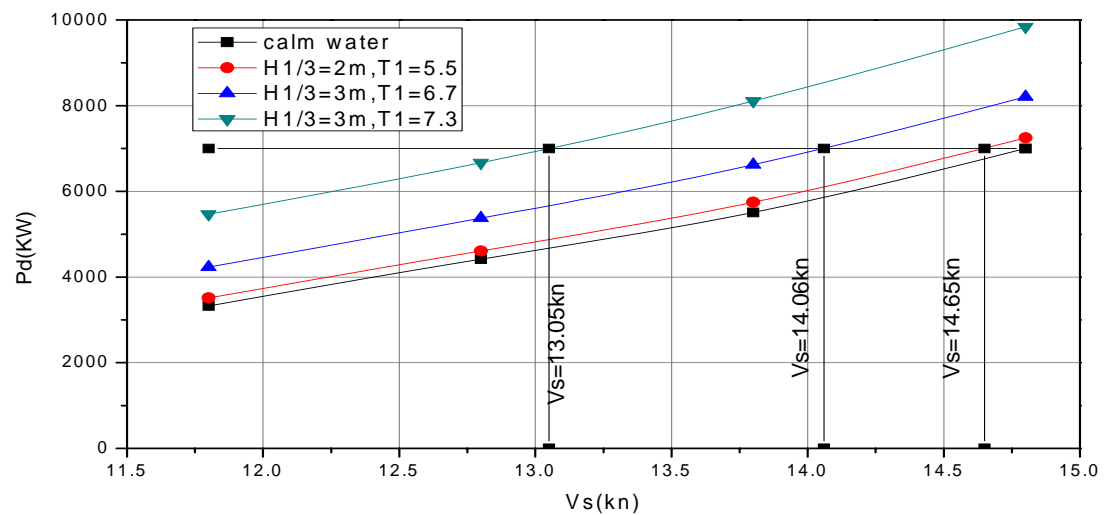


Fig. 8 Pd-Vs of DPM result.

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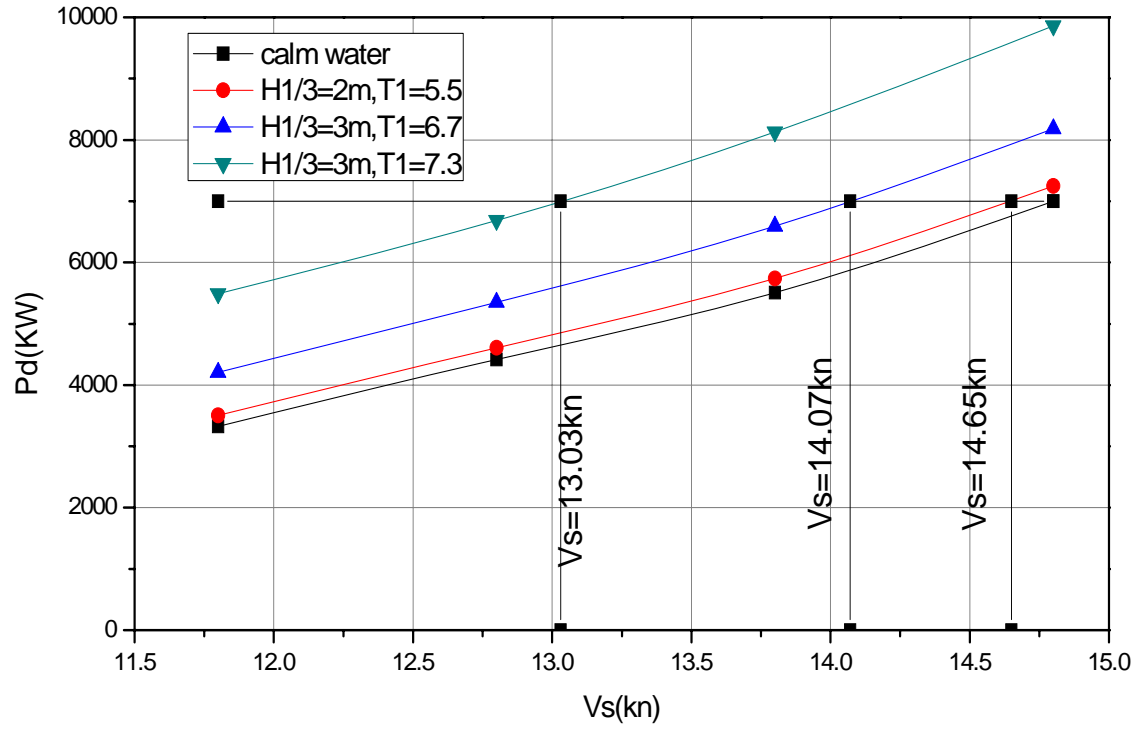


Fig. 9 Pd-Vs of QNM result.

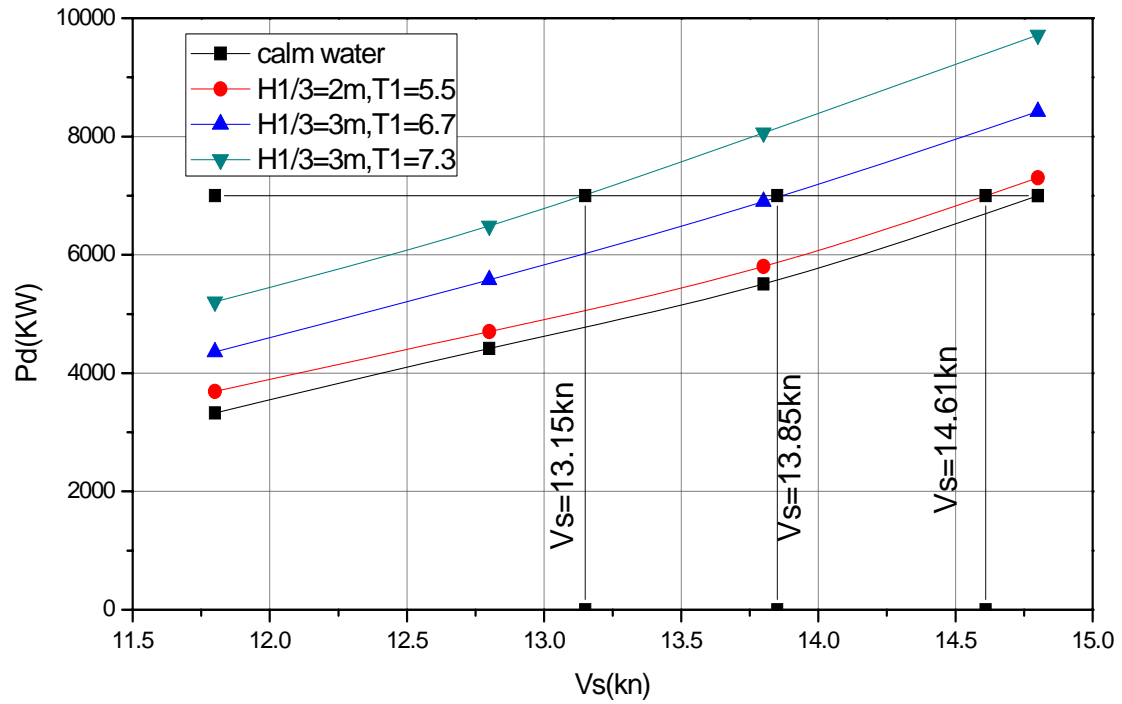


Fig. 10 Pd-Vs of TNM result.

Table 8 fw prediction results ($V_s = 14.8$ kn, $H_{1/3} = 3$ m, $T_1 = 6.7$ s).

	DPM	QNM	TNM	RTIM
ΔV	0.74	0.73	0.95	0.65
fw	0.95	0.951	0.936	0.956

4. Conclusions

According to the research of self-propulsion model test in waves, the preliminary test method needs to be further studied. On the other hand, the follow-up work and efforts should be made to pick up more precise and reliable data from huge raw test data.

By analyzing the different added power in waves prediction methods, it could be concluded as follows. All the four methods are based on the hypothesis that the added resistance in waves is proportional to the wave amplitude. The RTIM method needs the input from calm water and regular waves model test results, and wind resistance could be considered additionally. While the QNM, TNM and DPM methods need the input from self-propulsion model test data in regular waves and calm water, and wind resistance could not be considered directly. Although the test items of the QNM and DPM methods are less than others, the amount of test work load is still 3 to 4 times than that of the model test in regular waves. It is assumed in the RTIM and TNM method that the open water performance of propeller and self-propulsion factor in calm water are the same as in waves.

RTIM method can be used to predict the added power directly with the results from tests in head waves, while the others should adopt data obtained from self propulsion model tests on the same condition that the full scale ship is free of constraints in the actual sea state. What is more, speed loss deprived from RTIM method in regular waves test could satisfy the engineering requirements most.

Only when the data of model self-propulsion point have been used in the paper to compare the differences of four kinds of added power calculation

methods recommended by ITTC, more data from the full scale sea trial should, rather than model test, be collected to analyze the model full scale correction.

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