PREDICTION OF SHIP MOTIONS IN HEAD WAVES USING LINEAR STRIP THEORY

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Abstract: *Prediction of ship motions is an importance step in the ship design phases and considerable researches are related to this subject. It plays a unique role in main seakeeping characteristics such as maximum ship speed in sea waves, voluntary and involuntary speed reduction due to wave forces and added resistance as well as ship safety and ship routing, which affect transportation time, fuel consumption and total cost. This paper describes linear strip theory to predict quickly with sufficient accuracy ship motion characteristics in head wave, including added ship resistance, pitch and heave motion. The effects of environmental condition on calculation results is analyzed by performing some calculation with different wave parameter of JONSWAP spectra. The calculation results for the DTMB are examined by the comparisons with experimental data carried out at Ship Design and Research Centre's towing tank in Poland, and show good agreement, which demonstrates the ability of the present method to assess seakeeping characteristics at the initial ship design phases. The calculation is performed by using the commercial software MAXSURF.*

Keywords: *Ship motion, strip theory, added ship resistance, pitch motion, heave motion*

Classification number: *2.1*

1. Introduction

When planning design of new vessels one always needs to have a rational basis for a techno-economic evaluation of alternative designs. This evaluation should include the vessel's operational performance where the seakeeping capability is one of the most importance factors. Study seakeeping provide information about the behaviour of the ship in seaway. The results from such study are motion characteristics and added ship resistance in waves would be used to assess the plans of design in aspect of economy in service, regularity and adequate operation. In recent year, there are three general ways to evaluate ship motions, including: Measurement in full scale ship; model test and numerical methods. All approaches mentioned above have some restrictions. Although, both of the first and the second method are advance in providing high reliability results, these require highest cost and time. As a result, these methods may not use in the concept design phase. The last one, though, having reliability not as high as the two previous ones, its advantage is saving calculation time as well as the expenditure thus it is applying widely in the initial design stage, in which many plans need to be estimated in order to finger out the most optimal one in very limitted time. Depending on the assumption to simplify the fluid equations, there are two different fields for numerical approach in marine hydrodynimics:

- Potential flow theory: Panel method [1], [2], [3] and strip theory [4].
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eynolds-Averaged Navier-Stock Equation (RANSE) modeling.

In spite of having higher level of accuracy of RANSE than that of Potential flow theory, the computational time required by Potential flow theory is much lower than the requiring calculation time of RANSE [2, 5]. For that reason, it is more suitable to use Potential flow theory in the plan design period because in this period, the calculation time of finding the most optimal plan among a numerous plans is very short. This study presents the theoretical background and application of the linear strip theory for ship seakeeping calculation by using commercial software MAXSURF.

2. Theoretical Background of Strip Theory

2.1. Strip theory method

Strip theory is a frequency-domain method. This mean that the proplem is formulate as a funtion of frequency, so it is simpler and less computationally intensive than time domain approach. With Strip theory, the forces on and motions of a three-dimensional floating body can be determined by using results from two-dimensional potential theory. The values of two-dimensional hydromechanics coefficients will be integrated over the ship length numerically. The ship is considered to be a rigid body. Strip theory considers a ship to be made up of a finite number of transverse two dimensional strips or cross sections, which are rigidly connected to each other (fig.1). It is assumed that the problem of the motions of this floating body in waves is linear. Then, the differential equations will be solved to obtain the motions [5], [6]. The procedure of this method is showed in fig.2.

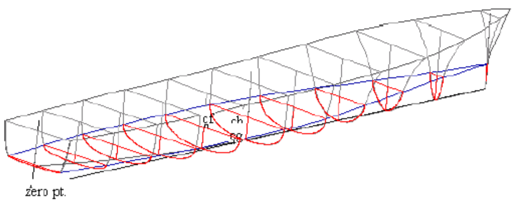

Fig.1. *Strip theory representation by sross sections.*

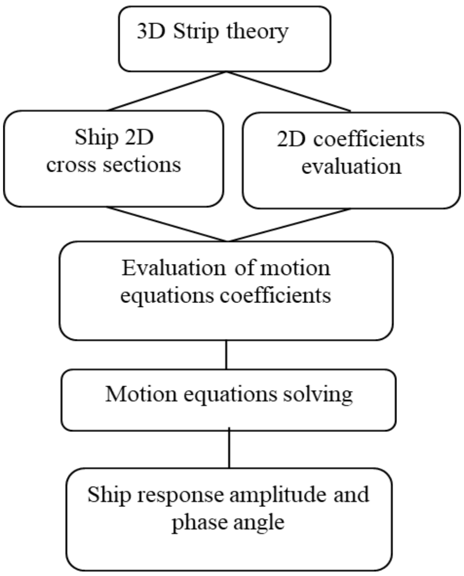

Fig.2. *Strip theory procedure.*

The details of basic background of strip theory is provided in detail in reference [4, 5, 7], thereby in the content of this article the authors will no longer concern about this issue.

2.2. Assumptions of strip theory

Recently, the strip theory has been widely used for seakeeping analysis, this theory is based on the following assumptions [8]:

- The fluid is inviscid;
- The ship is slender ship (i.e. the length is much greater than beam or draft and beam is much less than the wavelength).
- Ship hull is rigid so that no flexure of the structure occurs.
- The speed is moderate so there is no appreciable planning lift;
- Motions are small (or at least linear with wave amplitude);
- Hull sections are wall-sided.
- Water depth is much greater than wavelength so that deep-water wave approximations may be applied.
- The hull has no effect on the incident waves (so called Froude-Krilov hypothesis).

3. Numerical Simulations

3.1. Reference vessel

The vessel under study in this paper is a US Navy Combatant DTMB, shown in Figure 3, with characteristics of the ship are given in table 1. The main reason for using this hull is that the hull geometry is a public domain [9], and extensive database of seakeeping test exists at different Froude numbers and sea state, that were carried out by Ship Design and Research Centre CTO S.A.

Fig. 3. *Geometry of DTMB.*

Tab. 1. *Main particulars of the DTMB.*

Description ship parameter		value
Length between perpendiculars	$L_{PP}(m)$	142.0
Length at water level	$L_{WL}(m)$	142.0
Breadth	$B(m)$	18.9
Draft	$T(m)$	6.16
Volume	$\nabla(m^3)$	8425
metacentric height	$GM\ (m)$	1.95
Wetted surface	$S\ (m^2)$	2949
Gyration	ixx/B	0.37
	izz/L_{PP}	0.25

3.2. Input data for ship motion calculation

The commercial software MAXSURF was used for the computation. For ship motion calculation, it is necessary to require the following input data:

- 3D ship geometry
- Vessel conditions: Vessel draft and trim; Vertical centre gravity; vessel hydrostatics (these parameters can be defined automatically by Maxsurf base on the hull geometry)
- Ship speed and wave heading (the angle between the vessel track and the wave direction).
- Environmental conditions: wave spectrum (spectrum type, characteristic height, period…).

3.3. Test cases

Computations were performed for the following conditions:

- Vessel condition: draft T = 6.16 m; VCG = 7.55m; Trim = 0.
- Vessel speed: at three speed 18, 24 and 30 knots for calculating added ship resistance; and 8, 13 and 18 knots for calculating pitch, heave and acceleration and motion at bow.
- Environmental condition:

+ The following parameters were considered in the simulations added ship resistance: JONSWAP spectrum, h_s = 2.41 and 4.25m; modal periods Tp = 9.24s and 9.8s in head sea condition.

+ The following parameters were considered in the simulations heave and pitch motion: JONSWAP spectrum, hs = 2.16, 2.07 and 2.26m; average periods is corresponding to T_{01} =8.111s, 8.033s and 8.188 in head sea condition.

3.4. Computational setup

3.4.1. Measure hull

After importing 3D ship geometry and ship hull has been measured, the conformal mapping which are used to approximate the vessel's sections should be computed. The mapped sections are used to compute the section hydrodynamic properties. It is advisable to check that the mapped sections are an adequate representation of the hull before proceeding with the more time consuming response and seakeeping calculations. For DTMB ship, 18 numbers of mapped sections are used. Typical mappings of DTMB ship are shown in fig. 4. The Lewis mappings are calculated from the section's properties: draft, waterline beam and cross-sectional area.

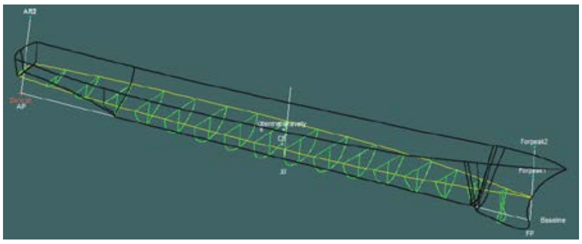

Fig. 4. *The mapped sections of DTMB*

3.4.2. Setting mass distribution

To calculate ship motion requires the pitch and roll inertias of the vessel. These are input as gyradii in percent of overall length and beam respectively. For DTMB vessel the roll gyradius ixx/B = 0.37, pitch gyradius izz/LPP = 0.25. The vertical centre of gravity VCG = 7.55.

3.4.3. Setting dapping factor

The specified non-dimensional damping is assumed to be evenly distributed along the length of the vessel. This is added to the inviscid damping calculated from the oscillating section properties and is applied when the coupled equations of heave and pitch motion are computed. The roll response is calculated based on the vessel's hydrostatic properties. For DTMB vessel the Non-dimensional damping factors are setup at 0.075 for Roll (total) and zero for Heave/Pitch (additional).

3.4.4. Choice analysis method

No Transom terms, Salvesen method and Head seas approximation were applied for analysis method for calculating seakeeping of DTMB vessel.

3.5. Result and discussion

Computational results for added ship resistance, heave and pitch motion in head wave at different ship speed and sea state are shown in table 2, 3, 4 and fig.5, 6 and 7.

Table 2. *Added ship resistance in head wave at different ship speed and sea state.*

STT	Ship speed, [knots]	Wave parameter		R_{AW}, [kN]		Relative error, [%]
		h_s, [m]	T_p, [m]	Simulation	Exp. [10]	
1	18.0	4.25	9.236	252.00	285.40	11.70%
2	18.0	2.41	9.775	93.57	105.00	10.89%
3	24.0	2.41	9.775	81.00	83.41	2.89%
4	30.0	2.41	9.775	67.90	63.70	-6.60%

Table 3. *Pitch motion in head wave at different ship speed and sea state.*

STT	Ship speed, [knots]	Wave parameter		$U_{A\_1/3p}$ [m]		Relative error, [%]	T_{01p} [s]		Relative error, [%]
		h_s, [m]	T_{01}, [m]	Simulation	Exp. [10]		Simulation	Exp. [10]	
1	8	2.16	8.111	1.37	1.28	-7.0%	7.701	7.956	3.2%
2	13	2.07	8.033	1.36	1.385	1.8%	6.828	7.078	3.5%
3	18	2.26	8.188	1.51	1.375	-9.8%	6.312	6.509	3.0%

Table 4. *Heave motion in head wave at different ship speed and sea state.*

STT	Ship speed, [knots]	Wave parameter		$U_{A\_1/3h}$ [m]		Relative error, [%]	T_{01h} [s]		Relative error, [%]
		h_s, [m]	T_{01}, [m]	Simulation	Exp. [10]		Simulation	Exp. [10]	
1	8	2.16	8.111	0.436	0.402	-8.5%	8.002	8.369	4.4%
2	13	2.07	8.033	0.518	0.508	-2.0%	7.061	7.310	3.4%
3	18	2.26	8.188	0.721	0.671	-7.5%	6.495	6.664	2.5%

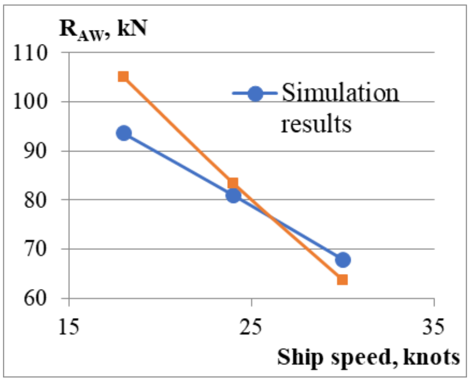

Fig.6. *Relationship between added ship resistance and ship speed in head wave at h_s=2.41 and Tp=9.775*

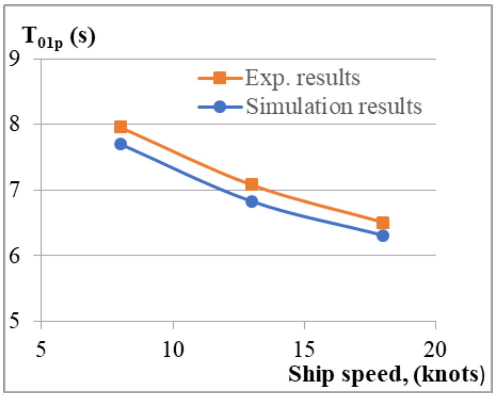

Fig.7. *Relationship between average period of pitch motion and ship speed in head wave.*

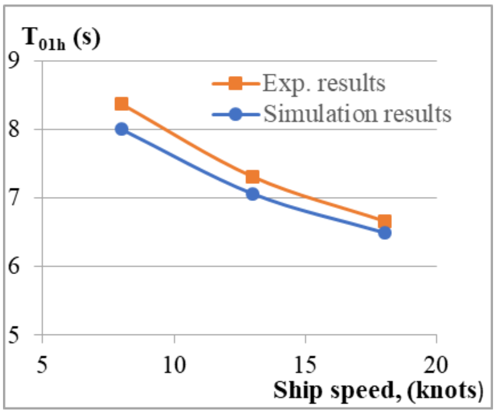

Fig.8. *Relationship between average period of heave motion and ship speed in head wave.*

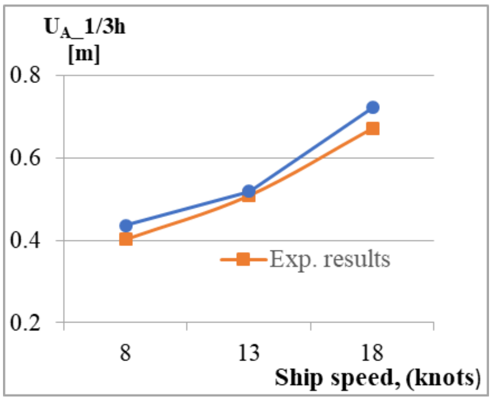

Fig.9. *Relationship between significant amplitude of heave motion and ship speed in head wave.*

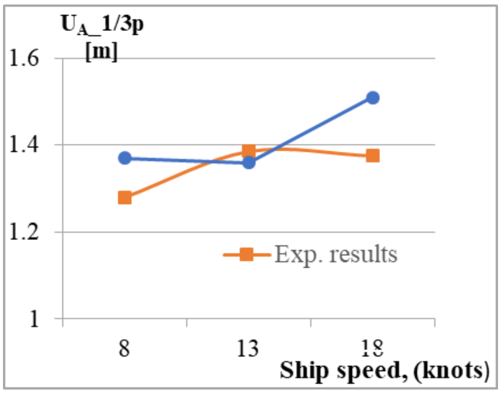

Fig.10. *Relationship between significant amplitude of heave motion and ship speed in head wave.*

By making comparison between the obtained results and those from experiment in towing tank (was translated into full-scale), the bellowed comments are provided:

- The tendency of changes of added ship resistance, pitch and heave motion at different speed are similar to experiment results. This is very important in application of Strip theory in study ship motion in initial ship design phases. Besides, the calculation only shows that the tendency in increase of added ship resistance varies strongly with ship speed;

- The difference in added ship resistance between calculation results and those of experiment is ranged from 7 to 12% depending on ship speed and sea state. This discrepancy can be acceptable in the initial design phase;

- The difference in pitch and heave motion between calculation result and that of experiment is lower than 9% for significant amplitude and lower than 5% for average period.

3.6. Conclusion

In this paper, the authors have considered and solved the following issues:

- Analysis and chose the suitable method to estimate ship motion in the initial design stage;

- Provide the basic background and the assumptions of strip theory in calculating ship motion.

- Present the results of calculating ship motion for DTMB vessel by using Strip theory in *commercial software MAXSURF. Calculation result* agrees well with the experiment data. This is very important in application of Strip theory in study ship motion in initial ship design phases❑

Nomenclature

B [m]:	*Ship breadth*
ixx:	*Moment of inertia for roll*
izz:	*Moment of inertia for pitch*
GM [m]:	*Metacentric height*
h_s *[m]:*	*Significant wave height*
L_{PP} *[m]:*	*Length between perpendiculars*
L_{WL} *[m]:*	*Length at water level*
R_{AW} *[KN]:*	*Added ship resistance due to wave*
S [m²]:	*Wetted surface*
T [m]:	*Ship draft*
Tp [s]:	*Wave model period*
T_{01p} *[s]:*	*Average period of pitch motion*
T_{01h} *[s]:*	*Average period of heave motion*
$U_{A\_1/3h}$ *[m]:*	*Significant amplitude of heave motion*
$U_{A\_1/3p}$ *[m]:*	*Significant amplitude of pitch motion*
∇ *[m³]:*	*Volume*

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