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Quick Strip Theory Calculations in Ship Design

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Abstract

This paper describes a strip theory based calculation method for ship design purposes, which delivers information on ship motions and added resistance within a very short computation time. The practical sense of using strip theories for this tool is discussed. Comparative validations of calculated data with results of the more accurate parent computer program are given.

1 Introduction

Generally, ship design is focussed on still water performance. In many cases the designer also needs information on seakeeping variables such as local motions or accelerations, added resistance, shipping water and bow slamming. Model experiments to obtain this information during the ship design process are expensive, time consuming and not practical.
Since two decades it is possible to incorporate seakeeping considerations from the beginning of the design by numerical methods. These numerical methods include linear theories like strip theories up to complete three-dimensional theories. Non- linear theories will become available for design purposes too.
Nowadays various ship motion programs, generally based upon linear strip theories, are occasionally used during the ship design process. The practical sense of using strip theories in an early design stage of a ship will be discussed. In an iterative design process these programs are often complicated in use and too slow. The designer needs more quick computational tools which are convenient in use, well protected against human input errors and calculated data which are easy to interpret.
For this purpose, a strip theory based computational method has been developed, which delivers the designer this relevant information within a very short computing time. Use has been made of a newly constructed database, which contains all required information on two-dimensional potential hydrodynamic coefficients in the sway, heave and roll mode for a very wide range of mono-hull cross-sections. For the determination of these two-dimensional coefficients of ship-like cross-sections,

these sections are conformally mapped to the unit circle by the so-called two-parameter Lewis transformation.
The advantage of conformal mapping is that the velocity potential of the fluid around an arbitrarily shape of a cross-section in a complex plane can be derived from the more convenient circular cross-section in another complex plane. In this manner hydrodynamic problems can be solved directly with the coefficients of the mapping function.
The advantage of making use of the two-parameter Lewis conformal mapping is that the non-dimensionalised frequency-depending potential coefficients are a function of two parameters only. These parameters are represented by half the breadth to draught ratio H_0 and the area coefficient s_s of the cross-section. So, a database can be filled with the potential coefficients for a sufficient large number of these parameters.
Now the hydrodynamic potential coefficients of cross sections of any mono-hull ship can be found by an interpolation in this database. According to the strip theory, the total hydrodynamic coefficients for the ship can be found easily by integrating the sectional values over the ship length.
For several ship types, calculated responses for six degrees of freedom by this relatively simple tool are compared with those obtained by accurate strip theory calculations when using N-parameter conformal mapping techniques or pulsating sources on the submerged cross section contour of the actual hull form.

2 Application of Ship Motions in Ship Design.

Faltinsen and Svensen (1990) have discussed the incorporation of seakeeping theories in Computer Aided Ship Design. An overview of seakeeping theories for ships is presented and it is concluded that, nevertheless some limitations, the strip theory is still the most successful and practical theory for the calculation of the wave induced motions of the ship in an early design stage of a ship.
The strip theory is a slender body theory, so one should expect less accurate predictions for ships with low length to breadth ratios. However, experiments showed that the strip theory appears to be remarkably effective for predicting the motions of ships with length to breadth ratios down to about three.
The strip theory is based upon the potential flow theory. This holds that viscous effects are neglected, which can deliver serious problems when predicting roll motions at resonance frequencies. In practice, viscous roll damping effects can be accounted for by empirical formulas.
Because of the way that the forced motion problems are solved generally in the strip theory, substantial disagreements can be found between the calculated results and the experimental data of the wave loads at low frequencies of encounter in following waves. In practice, these “near zero frequency of encounter” problems can be solved by forcing the wave loads to go artificial to zero.
For high-speed vessels and for large ship motions as appear in extreme sea states, the strip theory can deliver less accurate results. The strip theory accounts for the interaction with the forward speed in a very simple way. The effect of the steady wave system around the ship is neglected and the free surface conditions are simplified, so that the unsteady waves generated by the ship are propagating in directions perpendicular to the centre plane of the ship. In reality the wave systems around the ship are far more complex. For high-speed vessels, unsteady divergent wave systems become important. This effect is neglected in the strip theory.
The strip theory is based upon linearity. This means that the ship motions are supposed to be small, relative to the cross

sectional dimensions of the ship. Only hydrodynamic effects of the hull below the still water level are accounted for. So when parts of the ship go out of or into the water or when green water is shipped, inaccuracies can be expected. Also, the strip theory does not distinguish between alternative above water hull forms.

Because of the added resistance of a ship due to the waves is proportional to the vertical relative motions squared, its inaccuracy will be gained strongly by inaccuracies in the predicted motions.

Nevertheless these remarks, seakeeping prediction methods based upon the strip theory provide a sufficiently good basis for optimisation studies at an early design stage of the ship.

At a more detailed design stage, it can be considered to carry out additional model experiments to investigate for instance added resistance or extreme event phenomena, such as shipping green water and slamming.

3 Strip Theory Method

The equations of motions for six degrees of freedom of a sailing ship, influenced by external loads, are based upon Newton's second law of dynamics. Because of the symmetry of a ship, two uncoupled sets of three coupled equations of motion can be distinguished.

In a right-handed co-ordinate system, with the origin in the ship's centre of gravity, these equations read as follows:

$$\sum_{j=1}^{6} \left\{ \left(M_{kj} + A_{kj} \right) \ddot{x}_j + B_{kj} \dot{x}_j + C_{kj} x_j \right\} = X_k$$

for k = 1, 2, 3, 4, 5, 6

where:

k = 1, 3, 5: Coupled surge, heave and pitch motions

k = 2, 4, 6: Coupled sway, roll and yaw motions

$\ddot{x}_j$ Acceleration of harmonic oscillation in direction j

$\dot{x}_j$ Velocity of harmonic oscillation in direction j

x_j Displacement of harmonic oscillation in direction j

X_k Harmonic exciting wave force or moment in direction k

M_{kj} Solid mass or inertia coefficient

A_{kj} Hydrodynamic mass or inertia coefficient

B_{kj} Hydrodynamic damping coefficient

C_{kj} Spring coefficient

As a result of this formulation in the frequency domain, any system influencing the behaviour of the vessel should have a linear relation with the displacement, the velocity and the acceleration of the body.

The hydrodynamic mass and damping coefficients and the external wave loads are depending on the amplitude and the frequency of oscillation. The restoring spring coefficients are constant. To calculate the hydrodynamic mass and damping coefficients and the external wave loads in these equations of motions, several approaches of the strip theory can be found in literature. Here, use has been made of a strip theory method, as has been incorporated in the recently developed computer program SEAWAY by Journée (1990a).

SEAWAY is a ship motions computer program, suitable for use on a PC or a main frame and based upon the ordinary and the modified strip theory method, to calculate wave-induced loads, motions and mechanic loads with six degrees of freedom of mono- hull ships and barges in seaway. The incident wave potential has been defined for a restricted water depth. This holds that the program is suitable for shallow water, with keel clearances down to about half the ship's draught. When not accounting for interaction affects between two individual hulls, the program is suitable for twin-hull ships, such as catamarans or semi-submersibles, too.

Potential Coefficients

The coefficients A_{kj} and B_{kj} of the ship are defined here in a right-handed co-ordinate system with the origin in the ship's centre of gravity, the longitudinal axis forward parallel to the water line and the vertical axis upwards.

The coefficients are derived from the two-dimensional hydrodynamic potential coefficients a_{kj} and b_{kj} (for k, j = 1,1 2,2 3,3 4,4 and 2,4 or 4,2) with the co-ordinate system in the local water line.

For the determination of the two-dimensional coefficients for the sway, roll and yaw motions of ship-like cross-sections, the pulsating source method of Frank (1967) can be used. This method is suitable for fully submerged cross-sections too. The disadvantage of the method is a relatively large computing time.

Results will be obtained much quicker by mapping these cross sections conformably with N parameters to the unit circle. The advantage of conformal mapping is that the velocity potential of the fluid around an arbitrarily shape of a cross-section in a complex plane can be derived from the more convenient circular cross-section in another complex plane. In this manner, the hydrodynamic problems can be solved directly with the coefficients of the mapping function.

Results will be obtained in a shorter time with the simplest form of conformal mapping, the so-called two-parameter Lewis transformation. The advantage of making use of this simple mapping method is that the non-dimensionalised hydrodynamic potential coefficients are depending on two parameters only: the half breadth to draught ratio H_0 and the area coefficient s_s as of the cross section.

An elaborate survey of ship hull forms, obtained by Lewis conformal mapping functions, is given by Von Kerzeck and Tuck (1969).

The theory on the calculation of the two-dimensional hydrodynamic potential coefficients is given by Ursell (1949) and Tasai (1961). The total hydrodynamic coefficients for the sway, roll and yaw motions can be found easily by integrating the cross sectional values over the ship length. The pitch and yaw coefficients follow from the heave and sway moments respectively around the centre of gravity. For the surge motions a separate approach has to be used. All algorithms are described in detail by Journée (1990b).

Viscous Damping

For surge and roll, additional damping coefficients have to be introduced. Because these additional contributions to the damping are from a viscous origin mainly, it is not possible to calculate the total damping in a pure theoretical way.

A relatively small additional viscous surge damping has been derived from the derivative to the forward ship speed of the empirical resistance-speed curve of Troost (1955):

$$R_{sw} = C_R \cdot \boldsymbol{r} \cdot \nabla^{2/3} \cdot V^2$$

or:

$$\begin{aligned} b_{11v} &= \frac{dR_{sw}}{dV} \\ &= 2 \cdot C_R \cdot \boldsymbol{r} \cdot \nabla^{2/3} \cdot V \end{aligned}$$

where:

$$10^3 \cdot C_R = 3.6 + \frac{15.2}{{}^{10}\log\{L_{pp}\} + 0.6}$$

with L_{pp} in meters.

The viscous contribution into the total roll damping is large. Experiments show also a strong non-linear behaviour of some parts of the additional roll damping.

For the estimation of the additional roll damping parts, use has been made of work published by Ikeda, Himeno and Tanaka (1978). Their empirical method is called here the “Ikeda Method” and it estimates the following components of the additional roll-damping coefficient of a ship:

$b_{44s}^{(1)}$ Linear forward speed correction of potential damping

$b_{44l}{}^{(1)}$ Linear lift damping

$b_{44f}{}^{(2)}$ Non-linear friction damping

$b_{44e}{}^{(2)}$ Non-linear eddy damping

$b_{44k}{}^{(2)}$ Non-linear bilge keel damping

Then the linear and non-linear additional roll damping coefficients are given by:

$$b_{44v}{}^{(1)} = b_{44s}{}^{(1)} + b_{44l}{}^{(1)}$$
$$b_{44v}{}^{(2)} = b_{44f}{}^{(2)} + b_{44e}{}^{(2)} + b_{44k}{}^{(2)}$$

So, the roll damping term in the left-hand side of the equation of motions for roll should be given by:

$$b_{44v}{}^{(eq)} \cdot \dot{x}_4 = b_{44v}{}^{(1)} \cdot \dot{x}_4 + b_{44v}{}^{(2)} \cdot |\dot{x}_4| \cdot \dot{x}_4$$

The non-linear term can't be used in frequency domain equations. However, an equivalent linear additional roll-damping coefficient can be found by the requirement that the equivalent linear damping has to dissipate an equal amount of energy as the non-linear damping.

Then the equivalent linear additional roll-damping coefficient $b_{44v}{}^{(eq)}$ becomes:

$$b_{44v}{}^{(eq)} = b_{44v}{}^{(1)} + \frac{8}{3p} \cdot x_{4a} \cdot w \cdot b_{44v}{}^{(2)}$$

So, this equivalent linear additional roll damping is depending on the amplitude x_{4a} and the frequency w of the roll motion.

Ikeda, Himeno and Tanaka (1978) claim fairly good agreements between their prediction method and experimental results. They conclude that the method can be used safely for ordinary ship forms. But for unusual ship forms, very full ship forms and ships with a large breadth to draught ratio the method is not always sufficiently accurate.

Wave Loads

In strip theory calculations, the wave loads on a ship are found by integrating the two-dimensional loads on the cross sections of a restrained ship over the ship length. These loads consist of a Froude-Krilov part and a diffraction part.

The Froude-Krilov force or moment in waves can be expanded in series. The dominating term in the relevant part of the series delivers equivalent directional components of the orbital acceleration and velocity. These components are used by Journée (1991) to calculate the diffraction part of the wave loads.

Motion Characteristics

Now two sets of six coupled equations of motions with in and out of phase terms become available, which can be solved by a numerical method. From these solutions follow the frequency characteristics of the motions, which are the motion amplitude to wave amplitude ratios and the phase lags of the motions relative to the wave elevation at the ship's centre of gravity.

With these basic motions, the harmonic translations in the three directions in any selected point on the ship can be calculated. The harmonic velocities and accelerations in the three directions are obtained by taking the first and second derivatives of the displacements. However, for the accelerations in the longitudinal and lateral direction in a ship-bounded axes system, a component of the acceleration of gravity has to be added. Harmonic vertical relative displacements with respect to the undisturbed wave surface can be obtained too.

Added Resistance Characteristics

Two theoretical methods have been used here for the estimation of the time-averaged added resistance of a ship due to the waves and the resulting ship motions:

- a radiated wave energy method, as proposed by Gerritsma and Beukelman (1972), used here for head to beam waves and

- an integrated pressure method, as proposed by Boese (1970), used here for beam to following waves.

The frequency characteristics are found by dividing the added resistance by the wave amplitude squared.

Wave Spectra Definitions

For a comparison of the calculated behaviour of different designs or to get an impression of the behaviour of a specific design in a seaway, standard representations of the wave energy distributions are required. Three mathematical definitions with two parameters of normalised spectra of irregular unidirectional waves have been used here:

- a Neumann wave spectrum, a somewhat wide wave spectrum,
- a Bretschneider wave spectrum, also called ISSC, ITTC or Modified Pierson-Moskowitz wave spectrum, an average wave spectrum and
- a mean JONSWAP wave spectrum, a narrow wave spectrum.

These two parameters are the significant wave height and the average wave period.

Statistical Values and Probability Density Functions

The energy spectrum of the motions of a sailing ship in irregular waves is obtained by multiplying the square of the transfer function of the motions with the wave energy spectrum. From this spectral density function the significant amplitude of the motions can be calculated. An average period can be defined by the centroid of the spectrum or the average zero-crossing period, found from the spectral gyradius. In case of not too wide motion spectra, the probability density functions of the maximum and minimum values are given by the Rayleigh distribution. Then the probability of exceeding a threshold value by the amplitude of the motions and the number of occurrences per hour can be calculated.

The energy spectrum of the added resistance is obtained by multiplying twice the transfer function of the added resistance with the wave energy spectrum. From this follows the average added resistance in irregular waves.

Shipping Water

Shipping water is defined by exceeding the geometrical freeboard by the vertical relative motions. But the freeboard will be influenced by static swell-up, the waves produced by the ship sailing in still water. Also an oscillating ship will produce waves it-self, which will change the amplitude of the vertical relative motion. So a dynamical swell-up will be introduced too. These phenomena are not included yet here in the calculation of shipping water.

Bow Slamming

Slamming is a two-node vibration of the ship caused by suddenly pushing the ship by the waves. Ochi (1964) has translated these vibration phenomena into requirements for the vertical relative motions of the ship. He defined bow slamming by an emergence of the bow of the ship and exceeding a certain threshold value by the vertical relative velocity between the wave surface and the bow of the ship. The reference location of the bow along the ship length is defined by Ochi at 10 per cent of the length aft of the forward perpendicular. The static and dynamical swell-up are ignored.

4 Quick Strip Theory Calculations

As mentioned in the introduction, nowadays it is possible to use ship motions programs based upon the linear strip theory in ship design. In an iterative design process, these programs are often complicated in use and too slow. The designer needs much quicker computational tools which are convenient in use, well protected against human input

errors and calculated data which are easy to interpret.
For this purpose, a strip theory based computational method has been developed, which delivers the designer the relevant information within A very short computation time.
The major part of expected human input errors is related to the input of the offsets of the hull form of the ship. The major part of the total calculation time will be consumed by the calculation of the potential coefficients and the solution of the equations of motion. So these parts have to be simplified for the use in a design process.
The risk on offset input errors can be minimised by using the two-parameter Lewis conformal mapping method, which requires an input of the cross-sectional water line breadths, draughts and areas only. Since the non-dimensional potential coefficients are depending then on two coefficients only, use can be made of a database, which contains all required information on two- dimensional potential coefficients in the sway, heave and roll mode for a very wide range of mono-hull cross sections. The ranges of the half breadth to draught ratio H_0 and the area coefficient s_s for the different typical Lewis forms are shown in Figure 1.
For practical reasons, only a reduced region of H_0 and s_s values will be considered now. To obtain ship-like Lewis forms, the area coefficient s_s is bounded by a lower limit to omit re-entrant Lewis forms and by an upper limit to omit non-symmetric Lewis forms:

- for $H_0 < 1.0$:

$$\frac{3p}{32}\left(2 - H_0\right) < s_s < \frac{p}{32}\left(10 + H_0 + \frac{1}{H_0}\right)$$

- for $H_0 > 1.0$:

$$\frac{3p}{32}\left(2 - \frac{1}{H_0}\right) < s_s < \frac{p}{32}\left(10 + H_0 + \frac{1}{H_0}\right)$$

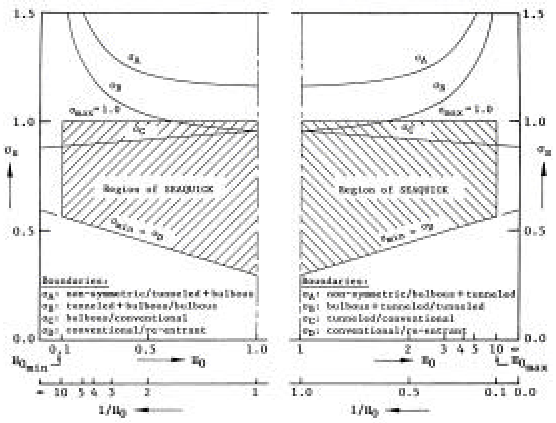

Figure 1 Ranges of H_0 and s_s Values of Lewis Forms

Except for bulbous bow sections, sectional area coefficients s_s larger than 1.0 are seldom. So, generally the upper limit of s_s can be fixed to $s_{max} = 1.0$.
For practical reasons, the half breadth to draught ratio H_0 of the cross sections has been limited to:

$$0.10 \le H_0 \le 10.00$$

Then, a number of intervals are chosen for the half breadth to draught ratios H_0:

- for $0.10 \le H_0 \le 1.00$:
  9 equal intervals of 0.10 for H_0.
- for $1.00 \le H_0 \le 10.00$:
  9 equal intervals of 0.10 for $1/H_0$.

At each H_0-value, 20 equal s_s-intervals have been chosen between the lower and upper limits. These results into 399 H_0-s_s grid points in the region shaded in Figure 1. For each grid point, all potential coefficients will be calculated for a series of 26 non-dimensional frequencies:

w^* = 0.0, 0.1, 0.2 .... 2.0,
2.2, 2.5, 2.9, 3.4 and 4.0.

with:

$$w^* = \sqrt{\frac{B_s/2 + D_s}{2 \cdot g}}$$

where:
B_s = sectional breadth
D_s = sectional draught

Based upon computer program SEAWAY, a pre-processing program, named SEAWAY-Q, has been written. At each grid point and frequency, the coefficients a_{kj} and b_{kj} are calculated for k,j = 2,2 3,3 4,4 and 2,4 or 4,2. The 82,992 calculated two-dimensional hydrodynamic potential coefficients are written to a 400 kBytes unformatted file, named SEAWAY-Q.COF.

A new 300 kBytes ship motions program, also based upon program SEAWAY and named SEAQUICK, has been written. This program is valid for conventional mono-hull ships, sailing in deep water. Cross-sectional water line breadths, draughts and areas are input. The program reads the SEAWAY-Q.COF file and a second degree Lagrange interpolation routine is used to determine the potential coefficients of the cross-sections of the ship.

To obtain the solutions of the equations of motion is computing time-consuming too. In SEAQUICK, the frequency characteristics are calculated for a relatively small number of wave frequencies: w = 0.1, 0.2, 0.3 .... 1.8 rad/sec.

Then, at each frequency interval two additional frequency characteristics are determined by an interpolation with a Theilheimer polynomial. For a correct calculation of the wave loads, information on the underwater hull form of the ship is required. Because the actual hull form is not known, the Lewis hull form has been used for this.

The remaining calculation routines, such as the determination of the potential surge coefficients and the viscous effects, the calculation of the wave loads, the solution the equations of motions and the spectral calculations, are similar to those used in the parent program SEAWAY.

This approach results into a very quick computer program that uses less than 10% of the computing time of the parent strip theory program. Nevertheless bulbous bows is not accounted for quite well, the accuracy is very high when comparing the results with those of the parent program. This will be shown further on.

To obtain a possible further increase of the calculation speed and the accuracy, the coefficients in the grid points can be replaced by Theilhelmer polynomial coefficients.

5 Comparative Validations

With program SEAQUICK, ship motion calculations have been carried out here for several ship types:

- a container ship,
- a crude oil tanker,
- a trawler and
- a number of transformed container ships.

The calculated data have been compared with those of the parent program SEAWAY, of which the calculations have been carried out with high demands on the accuracy of the calculated data. This holds conformal mapping of the cross sections with 10 mapping coefficients, so a_1, a_3, ..., until a_{19}, and the use of the Frank method for bulbous cross sections.

The comparisons are presented here for the ordinary strip theory method. So-called “end-terms” are included. In these comparisons the ships are assumed to sail in bow-quartering seas, with waves coming from 135 degrees off stern. For the container ships and the crude oil tanker, the calculations have been carried out in Open Ocean areas and for the trawler in North Sea areas. The wave spectra in the Open Ocean areas are defined by a Bretschneider wave spectrum. The wave spectra in the North Sea areas are defined by a mean JONSWAP wave spectrum with $g = 3.3$.

Contestable relations between the significant wave height $H_{1/3}$ and the centroid period T_1 of the waves are given in Table 1.

BF	Open Ocean Areas		North Sea Areas	
	$H_{1/3}$ (m)	T_1 (s)	$H_{1/3}$ (m)	T_1 (s)
1	1.10	5.8	0.50	3.5
2	1.20	5.9	0.65	3.8
3	1.40	6.0	0.80	4.2
4	1.70	6.1	1.10	4.6
5	2.15	6.5	1.65	5.1
6	2.90	7.2	2.50	5.7
7	3.75	7.8	3.60	6.7
8	4.90	8.4	4.85	7.9
9	6.10	9.0	6.10	8.8
10	7.45	9.6	7.45	9.5
11	8.70	10.1	8.70	10.1

Table 1 Assumed Relations of Wave Energy Spectra

For each ship, the accelerations in the three directions have been calculated in selected points on the ship defined by:

- 75% of L_{pp} forward of the aft perpendicular
- 75% of half the breadth from the centre line to port side
- 50% of the amidships draught above the load water line.

For each ship, bow slamming is defined at 10% of L_{pp} aft of the forward perpendicular. The added resistance due to the ship motions in waves has been calculated with the radiated energy method.

Container Ship

As an average seagoing vessel, the S-175 Container Ship Design with a length of 175.00 meters has been chosen for this validation study. Elaborate comparative results on experiments and calculations of that ship have been published by the Seakeeping Committee of the ITTC and many others. The calculations have been carried out here for a sustained ship speed of 16.1 knots ($Fn = 0.20$). The viscous roll damping has been determined by the Ikeda method.

Crude Oil Tanker

As a very large ship, a 200,000 tons deadweight tanker with a length of 310 meter has been chosen. The calculations have been carried out for a sustained ship speed of 15 knots. The non-dimensional total roll-damping coefficient has been fixed to $k = 0.075$.

Trawler

As a very small ship, a 30.60 m length trawler has been chosen. The calculations have been carried out for a sustained ship speed of 8 knots. The non-dimensional total roll-damping coefficient has been fixed to $k = 0.050$.

Validations with Three Ship Types

In Figure 2, a comparison of the calculated acceleration, added resistance and bow slamming phenomena has been given.

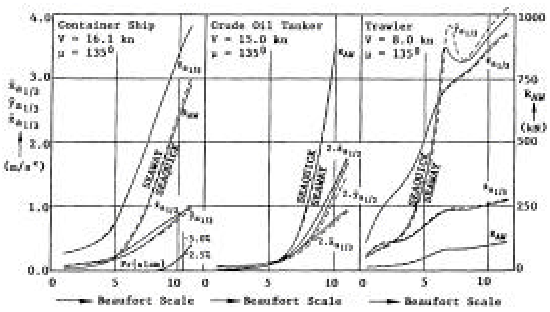

Figure 2 Comparison of Calculated Data of a Container Ship, a Crude Oil Tanker and a Trawler

In all sea states a good agreement has been found. Some small deviations in high seas are caused by using a Lewis hull form instead of the actual hull form, when calculating the sectional Froude-Kriloy loads and equivalent orbital accelerations. Because the ships were fully loaded, only for the containership bow slamming appeared in the calculated data.

Validations with Transformed Container Ships

For the S-175 Container Ship, some of the hull form parameters have been varied extremely to investigate the accuracy of calculated trends of motions of alternative ship designs, sailing with $Fn = 0.20$ in a sea state defined by Beaufort 8. The longitudinal position of the centre of buoyancy LCB and the block-coefficient C_b have been varied by a transformation method for ship hull forms, as developed by Versluis (1977). The size of the ship has been varied by linear scaling of the three-dimensional hull form with multiplication factors α.

$$LCB_0 - 0.015L_{pp} \leq LCB \leq LCB_0 + 0.015L_{pp}$$

$$C_{b0} - 0.04 \leq C_b \leq C_{b0} + 0.04$$

$$0.50 \leq \alpha \leq 1.50$$

In Figure 3, a comparison of the calculated acceleration and added resistance has been given. According to the calculations, in this sea state no bow slamming appears.

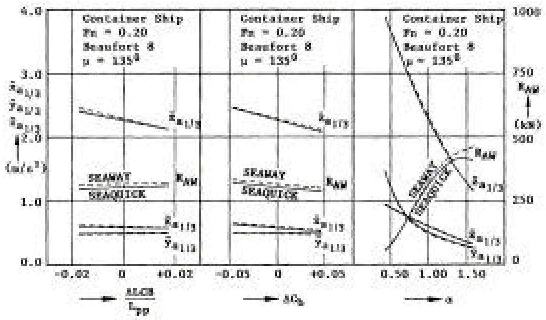

Figure 3 Comparison of Calculated Data of Several Transformed S-175 Container Ship Designs

Again, a very good agreement between the two calculation methods has been found.

Figure 3 shows too that, within practical regions for the location of the centre of buoyancy and for the block-coefficient, no significant reductions of the accelerations in the selected point and the added resistance will be achieved. For this, the ship's size appears to be a more important parameter. However, an optimisation study is not the aim of this paper.

6 Conclusions

Based upon the validations, it is expected that this simple calculation method can be used safely for conventional mono-hull ships, at least in a preliminary design stage of a ship.

However, a few restrictions have to be made here:

- For high-speed vessels, for ships with length to breadth ratios lower than 3.0 and for ships with a significant influence of submerged cross-sections or bulbous bows, more or less inaccurate results can be expected.
- Because of using a linear theory, less accurate results can be expected for large motions in extreme sea conditions.
- The method is based upon Lewis conformal mapping of the cross-sections. This holds that sections with different shapes, but with an equal breadth, draught and area, will receive equal values for the two-dimensional hydrodynamic potential coefficients and wave loads.
- When calculating vertical motions relative to the waves or calculating probabilities on shipping water or bow slamming, the static and dynamical swell-up is not accounted for.
- The method of Ikeda to estimate the viscous roll damping is less suitable for an unusual ship form, very full ships or ships with a large breadth to draught ratio. But, estimated or experimental roll damping coefficients can be input too.
- The calculation method is used here for an infinite water depth. Restricted water depth effects are not included.

When more accurate results are required, use has to be made of strip theory programs like the parent program. However, some of these restrictions are related to the strip theory method it-self. In that case one is dependent on other computing techniques or model experiments.

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