Ana Đigaš, Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje
Maro Ćorak, Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje
Joško Parunov, Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje

COMPARISON OF LINEAR SEAKEEPING TOOLS FOR CONTAINERSHIPS

Summary

The size of modern ultra-large containerships is such to fall outside the scope of the validity of rules of ship classification societies. Furthermore, in design and operation of large containerships important hydroelastic effects appear in addition to the rigid body response. Therefore, design loads for those ships are to be assessed based on direct seakeeping analysis. The aim of the present paper is to compare linear seakeeping tools in frequency-domain that may be used in different stages of ship design. The simplest tool is closed-form semi-analytical expressions formulated by Jensen, which are intended for ship conceptual design. Next tool in the comparison is the linear strip theory, which is very old, but still a very popular tool for ship seakeeping assessment. Finally, the most advanced tool employed in this study is the modern 3D panel method. The comparison is performed for 3 containerships of different sizes, and, when available, with experimental results from model tests. Two ship responses on regular waves that are analyzed are vertical wave bending moment at midship and relative velocity at bow. For each ship, two ship speeds and two heading angles (head and bow seas) are considered. Extensive comparison enables useful conclusions to be drawn.

Key words: containership, seakeeping, wave loads

USPOREDBA PROGRAMSKIH ALATA ZA LINEARNU ANALIZU POMORSTVENOSTI KONTEJNERSKIH BRODOVA

Sažetak

Dimenzije modernih ultra-velikih kontejnerskih brodova su takve da izlaze van granica valjanosti pravila klasifikacijskih društava. Također se u projektiranju i službi velikih kontejnerskih brodova pojavljuju značajni hidroelastični efekti osim odziva broda kao krutog tijela. Stoga se projektna opterećenja takvih brodova procjenjuju na temelju analiza pomorstvenosti. Cilj ovog rada je usporediti linearne alate za analizu pomorstvenosti u frekventnoj domeni, primjenjivih u različitim fazama projektiranja kontejnerskih brodova. Najjednostavniji alat su polu-analitički izrazi koje je formulirao Jensen, a koji su namijenjeni fazi idejnog projektiranja. Sljedeći alat korišten u usporednoj analizi je linearna strip teorija, koja je vrlo star, ali još uvijek popularan alat za analizu pomorstvenosti. Konačno, najnapredniji alat korišten u ovoj studiji je moderna 3D panel metoda. Usporedba je izvršena za 3 kontejnerska broda različitih veličina, a kada su dostupni, uključeni su i eksperimentalni rezultati dobiveni modelskim ispitivanjima. Analizirane su dvije vrste odziva na harmonijskom valu – vertikalni valni moment savijanja na glavnom rebru i relativna brzina na pramcu. Za svaki brod, razmatrane su dvije brzine napredovanja i dva kursna kuta (valovi u pramac i valovi između pramca i boka broda). Zahvaljujući brojnim usporedbama, mogu se izvući korisni zaključci.

Ključne riječi: kontejnerski brod, pomorstvenost, valna opterećenja

1. Introduction

The structural design of the large container ships is characterized by open midship sections and consequently rather low structural natural frequencies. Consequently, the global hydroelastic structural responses can become a critical issue in the ship design and should be properly modelled by the simulation tools. The most relevant hydroelastic phenomenon concerning the longitudinal strength of large containership is whipping, the transient vibration of ship hull occurring as a consequence of slamming. Such vibration may considerably increase the extreme vertical wave bending moments amidships and thus needs to be considered in the ship structural design. The main parameter influencing slamming load of containership is relative vertical velocity at bow flare of the vessel. Depending on relative velocity, considerable impact load may occure causing whipping of a hull girder [1].

Assessment of vertical wave bending moments of rigid hull and relative velocities causing transient vibration may be performed by linear seakeeping tools in frequency domain. Seakeeping methods available for these predictions may be devided by their level of complexity as:

1. Semi-analitical closed form expressions [2]
2. Strip theory [3]
3. 3D panel method [4].

The aim of the present paper is to compare these tools for containerships of different sizes. Comparison is performed among three different methods and, when available, with experimental results from model tests. Two ship responses on regular waves that are analyzed are vertical wave bending moment at midship and relative velocity at bow. For each ship, two ship speeds and two heading angles (head and bow seas) are considered. The aim is to have comparison of responses which are the most important for dimensioning of midship section modulus.

In the next section of the paper description of ships that are analysed is presented. After that, brief description of tools used in the comparative study is given. Finally, results of comparison and corresponding conclusions are presented.

2. Description of ships

Three ships are used in this comparative study. The first vessel is known as Flokstra containership. Model tests for this ship were performed and published in [5]. Therefore, for Flokstra ship, comparison is performed among closed-form expressions, strip theory and experimental results. The remaining vessels are 4400 TEU and 9200 TEU containerships. For those ships comparison is performed among closed-form expressions, linear stip theory and 3D panel hydrodynamic method. The main particulars of these three ships are presented in Table 1.

Table 1 Main particulars of containerships

Tablica 2. Osnovne značajke kontejnerskih brodova

Particular/Ship	Flokstra	4400 TEU	9200 TEU
Length bpp, Lpp (m)	270	264.62	341.8
Breadth, B (m)	32.2	37.1	42.8
Depth, D (m)	18.66	21.55	27.3
Scantling draugth, T (m)	10.85	11.88	13.17
nominal speed, v (knots)	24.5	20.0	25.4

3. **Closed – form expressions**

Closed-form expressions are derived by Jensen [2], according to the linear strip theory, assuming constant sectional added mass equal to the displaced water and also by decoupling heave and pitch motions. The equations of motion in regular waves with amplitude *a* can be written as:

$$2\frac{kT}{\omega^2}\ddot{w}+\frac{A^2}{kB\alpha^3\omega}\dot{w}+w=aF\cos(\varpi t) \tag{1}$$

$$2\frac{kT}{\omega^2}\ddot{\theta}+\frac{A^2}{kB\alpha^3\omega}\dot{\theta}+\theta=aG\sin(\varpi t) \tag{2}$$

where,

a		Wave amplitude
A		Approximation of the sectional hydrodynamic damping
B	m	Breadth of the box
F		Heave forcing function
G		Pitch forcing function
k	1/m	Wave number
t	s	Time
T	m	Draught of the box
w	m	Heave amplitude
α		Parameter
θ	rad	Pitch amplitude
ω	rad/s	Wave frequency
ϖ	rad/s	Frequency of encounter

Based on expressions (1) and (2), transfer functions of heave and pitch motions as well as transfer functions of relative motions can be derived analytically [2]. All expressions can be found in the paper [2] as well as in graduation thesis [1].

Transfer function of vertical wave bending moment at midship can be calculated as:

$$\frac{\Phi_M}{\rho g B_0 L^2}=\kappa\frac{1-kT}{(k_eL)^2}\left[1-\cos\left(\frac{k_eL}{2}\right)-\frac{k_eL}{4}\sin\left(\frac{k_eL}{2}\right)\right]F_V\left(Fn\right)F_C\left(C_b\right)\times\sqrt[3]{\left|\cos\beta\right|} \tag{3}$$

where,

B_0	m	Maximum waterline breadth of the ship
$F_C\left(C_b\right)$		Correction factor for the block coefficient
$F_V\left(Fn\right)$		Speed correction factor
g	m/s^2	Gravitational acceleration
k	1/m	Wave number
k_e	1/m	Effective wave number

L	m	Lenght of the ship
T	m	Draught of the ship
β	°	Heading angle
κ		Smith correction factor
ρ	kg/m^3	Average seawater density
Φ_M	Nm/m	Frequency response function for the wave-induced vertical bending moment amidships

4. Strip theory

For ship structures, characterized by forward speed, two-dimensional strip theory is still the most popular method for seakeeping computations. The essence of strip theory is is to reduce the three-dimensional hydrodynamic problem to a series of two-dimensional boundary value problems that are easier to solve. The principle is to divide the underwater part of the ship into a number of strips (usually about 20). The two-dimensional flow about an infinite cylinder of the same cross-section as the ship at the strip's position determines hydrodynamic forces. The two-dimensional forces for each strip are combined to obtain the forces for the entire ship. Analytical or numerical methods are used to solve the two-dimensional problem for each strip.

Although strip methods are considered the most practical tool to assess global wave-induced loads at this time, they have some limitations. They fail for waves shorter then about one-third of the ship lenght and strip theory does not properly account for the interaction between the steady wave system and the oscilatory effects of ship motions and is questionable when applied to severe sea states [6]. Strip theory program Waveship is employed in the present study [3].

5. 3D panel hydrodynamic method

3D panel methods discretize the average wetted hull surface into a large number of small surface elements (panels). The calm-water floating position defines the wetted surface, neglecting dynamic trim and sinkage as well as the steady wave profile. For each panel, a Green function defines the velocity potential. Usually, these potentials are sources that model the displacement effect of the ship [6].

All the potentials automatically fulfill the Laplace equation, the radiation condition, and the linearized free-surface condition, leading to an integral equation for the potentials (source strenghts). To determine the unknown potentials, the integral equation is replaced by a set of linear equations, such that the no-penetration condition is satisfied at the collocation points of each panel. 3D panel program Hydrostar is employed in the present comparative study [4].

6. **Comparative study**

Comparison of transfer functions for Flokstra containership is presented in Figure 1. Flokstra containership is well known ship for which model tests are performed and published in the literature [5]. Comparison is performed for vertical relative velocity at ship bow and for vertical wave bending moment at midship. For both responses, comparison is done for nominal ship speed and for two different heading angles.

Comparative analysis of transfer functions for relative velocity at bow section of 4400TEU containership is presented in Figure 5-8 for two different speeds and two different heading angles. The comparison for vertical wave bending moment at midship section of 4400TEU containership is presented in Figures 2 and 3.

Results of the comparison of transfer functions for 9200TEU containership are presented in Figures 4 and 5 for relative velocities and vertical wave bending moments respectively.

7. Conclusions

Short summary of three different methods for seakeeping assessment is presented: closed-form expressions, strip theory and 3D panel method. Using tools that employ these methods, comparison of ship responses in regular sea is performed for three different containerships.

Firstly, transfer functions of relative velocity at the bow and vertical wave bending moment at midship are compared with experimental results for Flokstra containership. From these results it can be concluded that linear strip theory employed within Waveship overestimates model tests up to 20% while closed-form expressions underestimates model test for about 10%. Peak values of relative velocity, obtained from closed-form expressions seem to be shifted and occur at the longer waves. Peak values of transfer functions of vertical wave bending moment occur at approximately the same wave length, but both, strip theory and closed-form expressions underestimate results of model tests.

Comparison of transfer functions of relative velocity for 4400 TEU containership shows that highest responses are obtained by 3D panel method. The same phenomenon already found for Flokstra containership, i.e shifting of peak values for closed-form expressions toward longer waves, can be seen for this ship as well. In the case of wave induced bending moment quite good agreement is found between 3D panel method and closed-form expressions, while linear strip theory exceeds peak values of transfer functions for about 10%. Similar conclusions as for 4400TEU containership can be drawn for 9200 TEU containership, although in this case agreement between transfer functions of wave bending moments, obtained by 3D panel method and closed-form expressions is somewhat less favourable. Two general conclusions may be drawnd from the analysis: both strip theory and closed-form expression underestimate relative velocity at bow obtained by 3D panel method while strip theory oversetimates vertical wave bending moments at midship compared with two other methods.

Taking into account the simplicity of the method, closed-form expressions give surprisingly good estimate of vertical ship responses.

ACKNOWLEDGEMENT

The investigation is funded by EU FP7 Project “Tools for Ultra Large Container Ships” (TULCS), what is gratefully acknowledged.

REFERENCES

[1] ĐIGAŠ, A., “Whipping Induced Stresses of Containerships”, Graduation thesis, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, 2011.

[2] JENSEN, J. J.; MANSOUR A. E.; OLSEN A. S.: “Estimation of Ship Motions Using Closed-Form Expressions”, Elsevier, Ocean Engineering. 31 61-85, 2004.

[3] DET NORSKE VERITAS, WAVESHIP – Wave Loads on Slender Vessels, SESAM User’s Manual, H⌀vik, 1993.

[4] HYDROSTAR, User's manual. Bureau Veritas, Pariz, 2006.

[5] FLOKSTRA, C., “Comparison of ship motions theories with experiment for container ship”, International Shipbuilding Progress, Vol. 21, June 1974.

[6] FALTINSEN, O.M., “Sea loads on ships and offshore structures", Cambridge, UK, 1990.

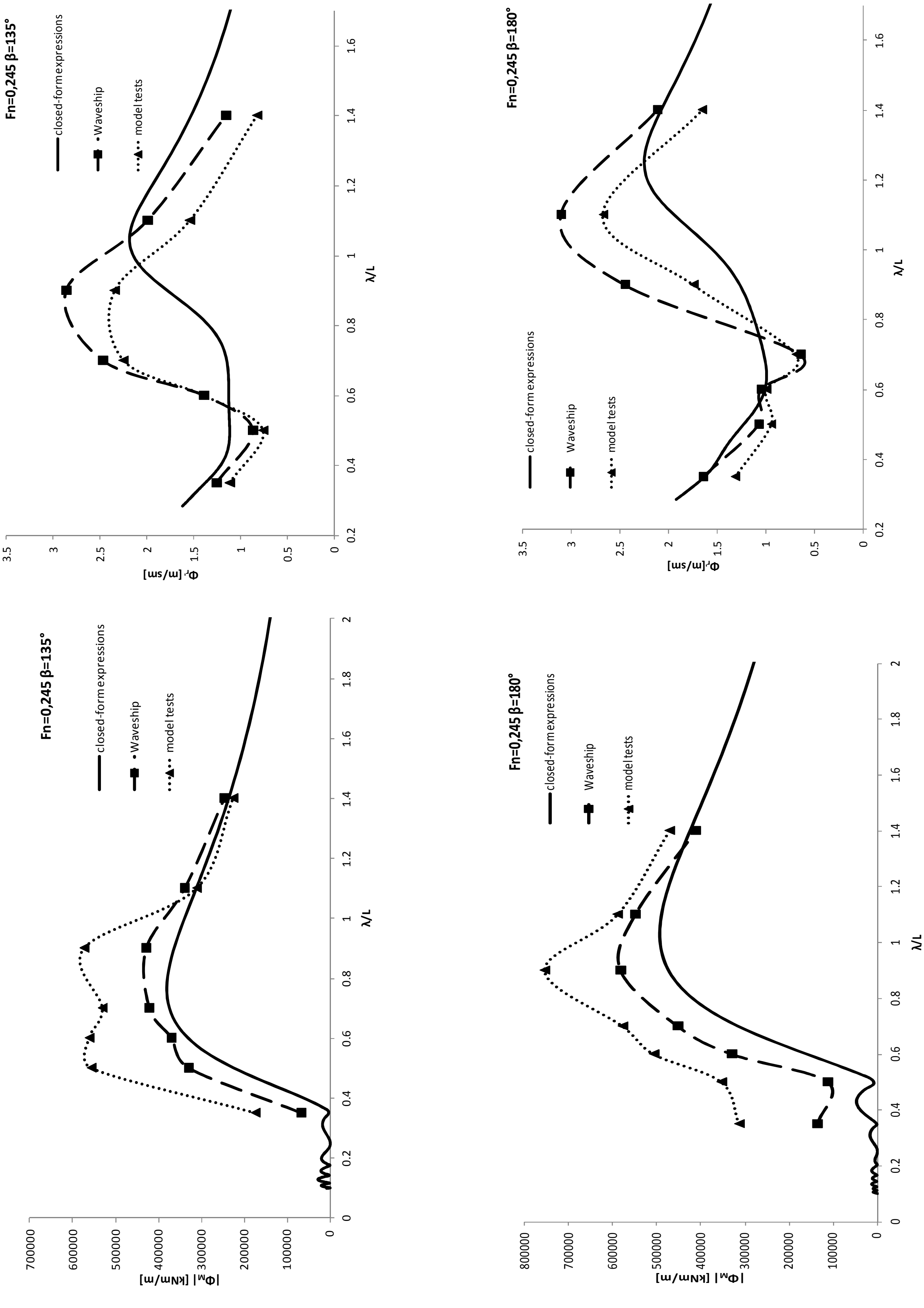

Fig. 1 Transfer functions of relative velocity at FP and vertical wave bending moment at midship for the Flokstra containership

Slika. 2 Prijenosne funkcije relativne brzine na PP i vertikalnog valnog momenta savijanja na sredini broda za Flokstra kontejnerski brod

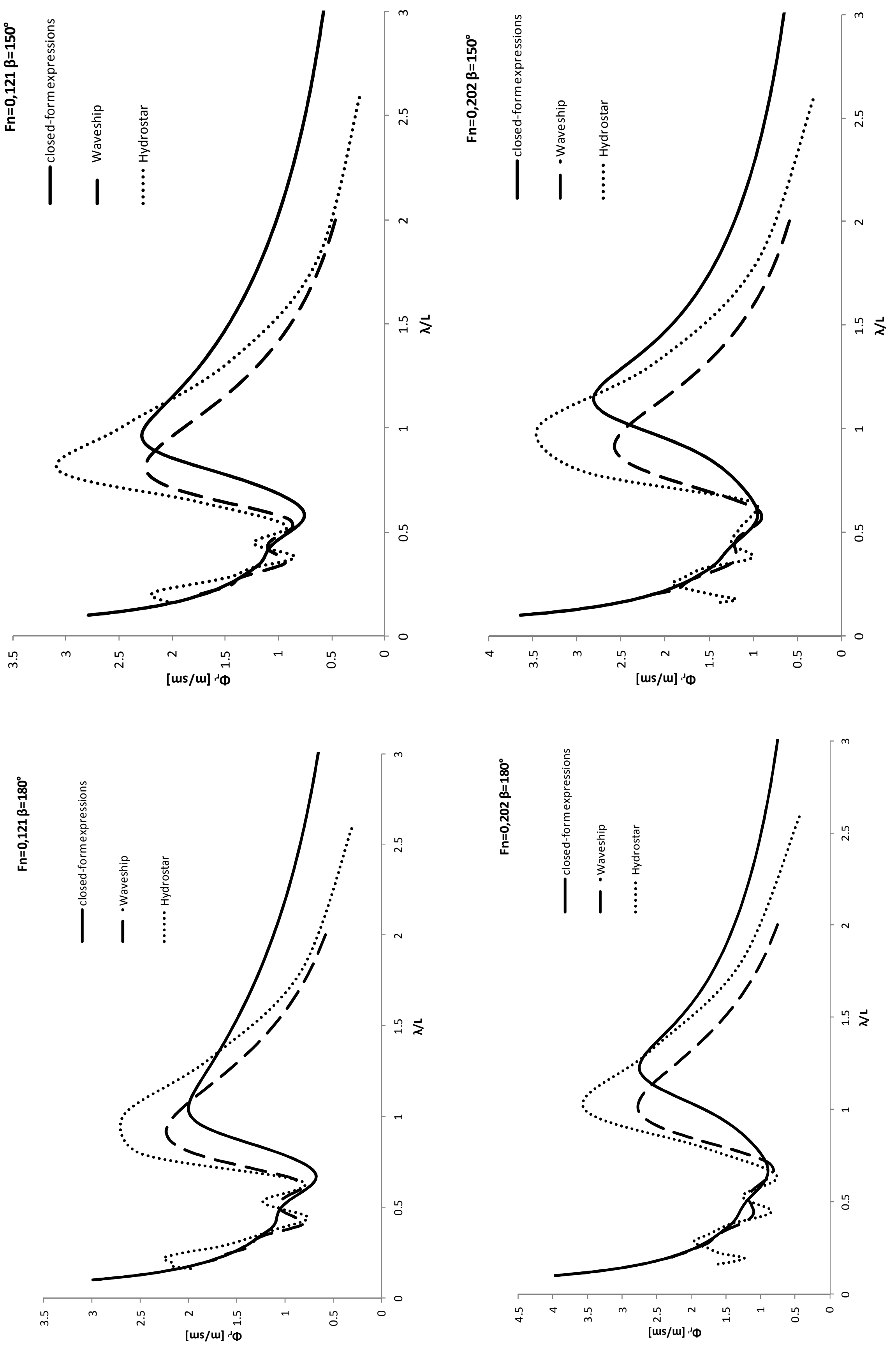

Fig. 2 Transfer functions of relative velocity at FP for the 4400 TEU containership

Slika 2. Prijenosne funkcije relativne brzine na PP za 4400 TEU kontejnerski brod

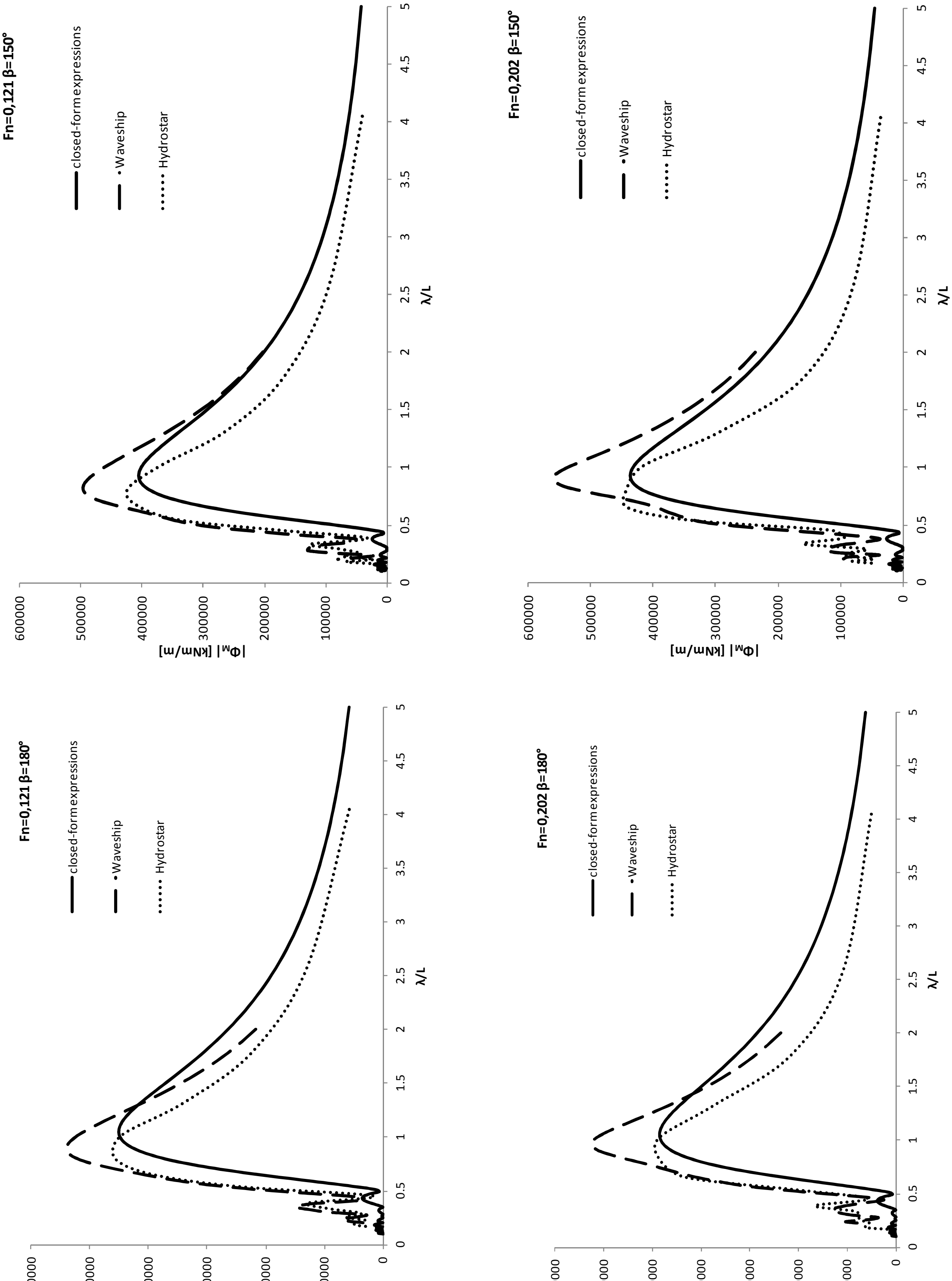

Fig. 3 Transfer functions of vertical wave bending moment at midship for the 4400 TEU containership

Slika 3. Prijenosne funkcije vertikalnog valnog momenta savijanja na sredini za 4400 TEU kontejnerski brod

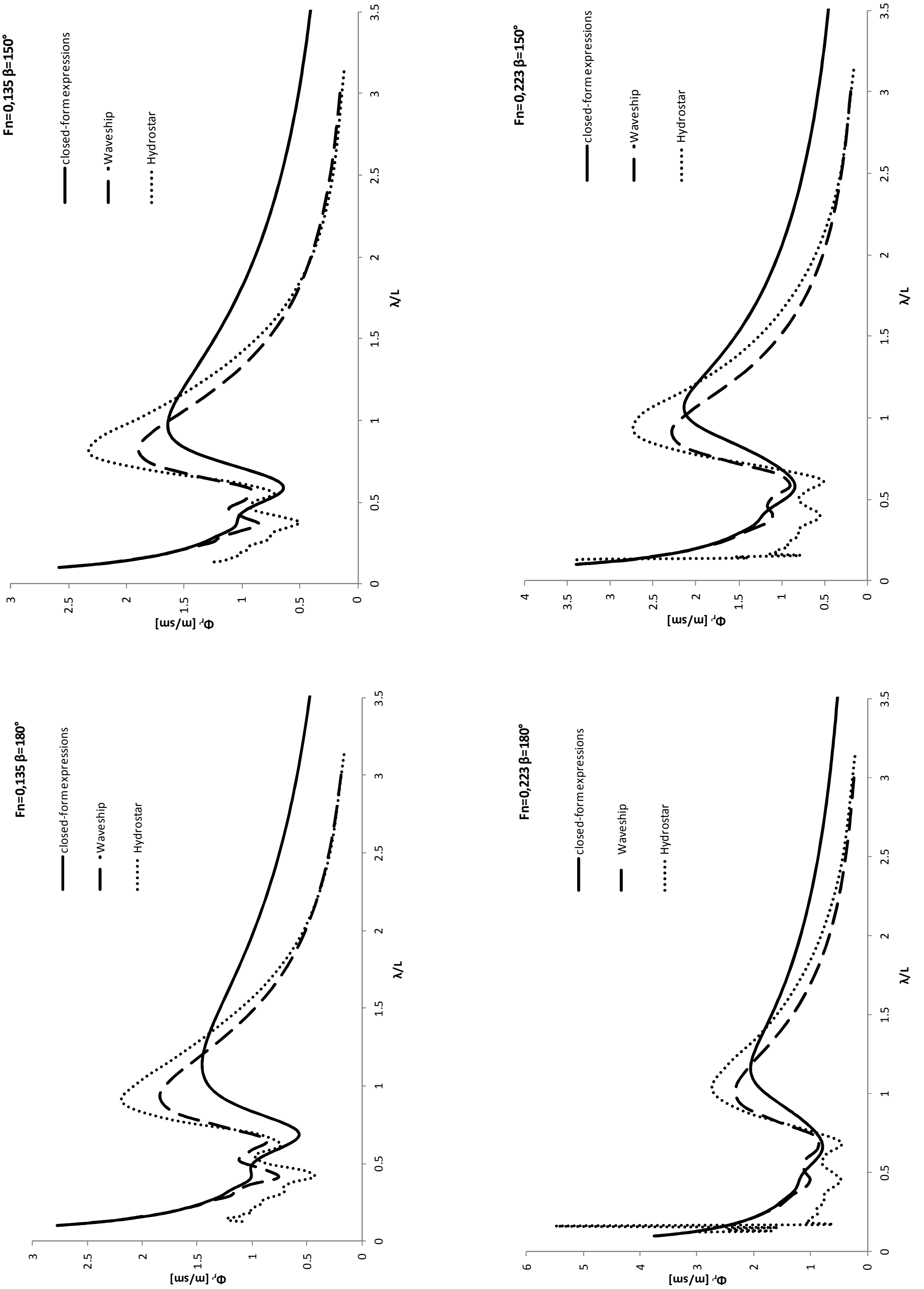

Fig. 4 Transfer functions of relative velocity at FP for the 9200 TEU containership

Slika 4. Prijenosne funkcije relativne brzine na PP za 9200 TEU kontejnerski brod

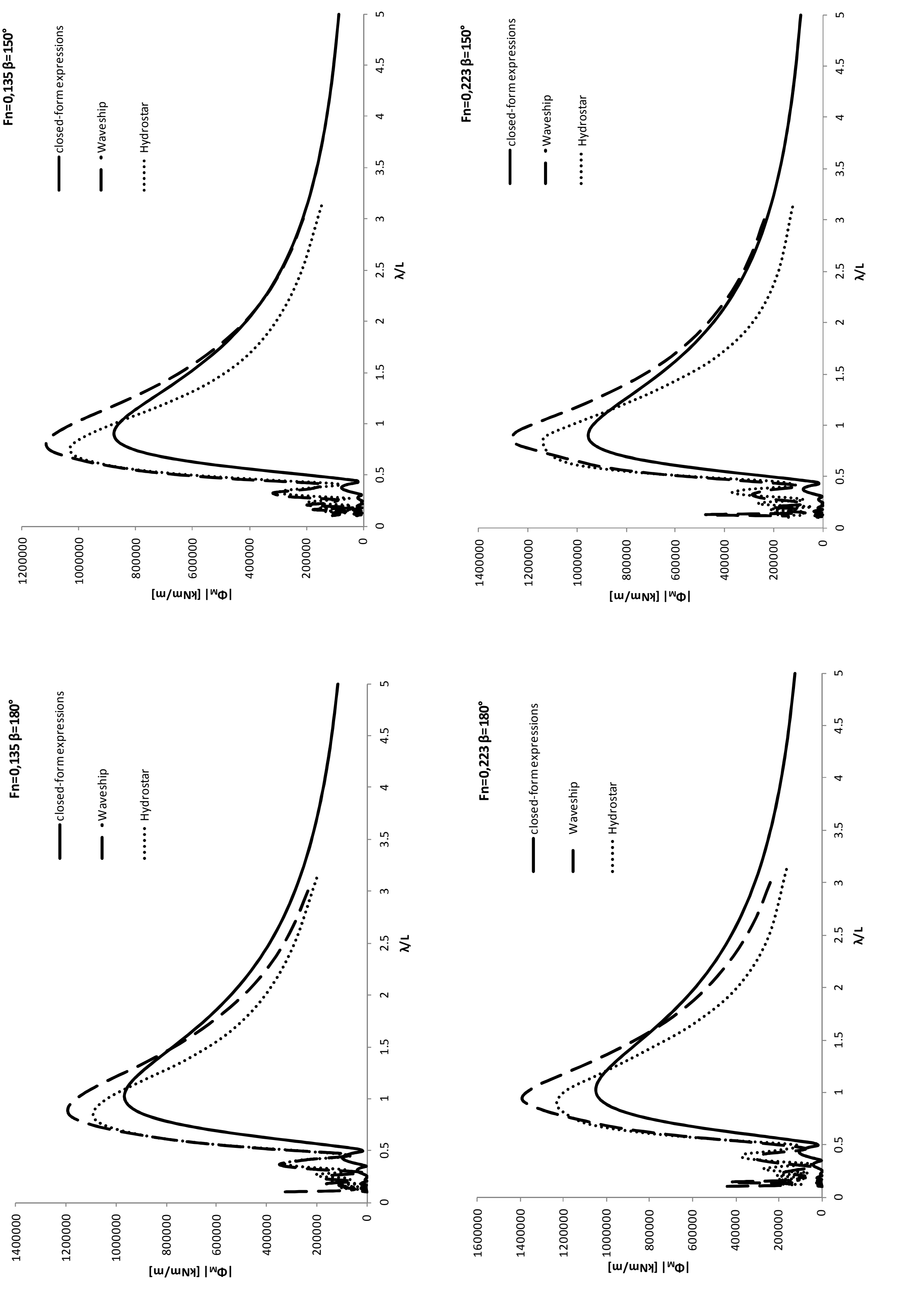

Fig. 5 Transfer functions of vertical wave bending moment at midship for the 9200 TEU containership

Slika 5. Prijenosne funkcije vertikalnog valnog momenta savijanja na sredini za 9200 TEU kontejnerski brod