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AUTOMATIC ELIMINATION OF SHIP DESIGN PARAMETERS BASED ON DATA ANALYSIS FOR SEAKEEPING PERFORMANCE

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Summary

In this paper, we are proposing a computer-based system which makes the automatic elimination of ship design parameters based on data analysis for seakeeping performance. Usually engineers do not have enough time to analyse the data. In this case it can be better to use less parameters in the data analysis. But if the investment has the high commercial worth then the engineers must consider and analyse all variables and their effects in the concept design to minimise the risks of further stages of the design. We are mainly focused on ship motions to identify their most influential parameters. By the use of statistics, the backward elimination method is constructed in a software based on the SQL Server Database. The system contains two modules named as "Identification" and "Elimination". Identification module is used to find out the weakest parameters by the method and then the elimination module avoids these parameters from the final model. In fact the most engineering areas concern with the problem of different parameters and physical issues to construct meta-models to calculate the closest prediction to real values.

Key words: *Conceptual Design; Ship Motions; Data Analysis; Elimination.*

1. Introduction

In general, the most engineering areas concern with the problem of different parameters and physical issues to construct meta-models to calculate the closest prediction to real values. It is generally accepted that the conceptual design procedures require simplicity in use while assuring sufficient accuracy in prediction[1, 2]. In this paper, there are mainly focused on the ship motions to identify their most influential parameters. For this problem, there are many researches who had interest and work such as the response amplitude operators (RAO) for vertical motions of fishing vessels by [1, 2], bending moment by [3], RMS of motions by [4, 5, 6, 7], ranking of seakeeping performances by [8, 9, 10, 11, 12], and the response amplitude operators (RAO) of destroyer hulls by [12]. These related papers are given in Table 1 with the proposed parameters defining the motion features of their interest.

Table 1 Summary of the references of principal seakeeping models

References	Parameters	Explanations
(Moor, 1967) [3]	L/B , L/T , C_{WP}, k_{yy}/L , $V/L^{1/2}$	Bending Moment Database Ships
(Moor and Murdey, 1968) [4]	$L/\nabla^{1/3}$, L/B , L/T , C_{WP}, C_B, LCB , k_{yy}/L , $V/L^{1/2}$	RMS Database Ships
(Loukakis and Chryssostomidis, 1975) [5]	L/B , B/T , C_B, Fn	RMS Series 60 Ships
(Nabergoj et al., 2003) [6]	$L/\nabla^{1/3}$, T/B , C_{VP} LCF , LCB , C_{VPF}, BML	RMS Mediterranean Fishing Vessels
(Kukner, Aydin, 1997) [7]	L/B , L/T , L/B , C_{WP}, C_B, k_{yy}/L , Fn	RMS Fishing Vessels
(Bales, 1980) [12]	T/L , c/L , C_{WPA},C_{WPF}, C_{VPA}, C_{VPF}	Ranking Destroyers
(Wijngaarden, 1984) [8]	L/B , L/T , C_P^4, C_{WP}, LCF , LCB	Ranking Research Vessels
(Nabergoj et al., 1989) [9]	T/L , c/L , C_{WPA},C_{WPF}, C_{VPA}, C_{VPF}	Ranking Large Trawlers
(Trincas et al., 2001) [10]	L, T/B , L^2/BT , $A_{WP}/\nabla^{2/3}$, C_{VPA}, C_{VPF}, BML/L^3B , $(LCB-LCF)\nabla$, $LCB\nabla^{1/3}$	Ranking Mediterranean Fishing Vessels
(Alkan, 2003) [11]	L/B , L/T , B/T , C_B, C_P, C_M, C_{VP}, C_{WP}, $L/\nabla^{1/3}$, LCB , LCF	
(Sayli et al., 2007) [1] (Sayli et al., 2010) [2]	L/B , B/T , $L/\nabla^{1/3}$, Fn	RAO Estimation of Mediterranean Fishing Vessels
	L/B , B/T , $L/\nabla^{1/3}$, C_{WP}, C_{VP}, Fn	
	L/B , B/T , $L/\nabla^{1/3}$, C_{WP}, C_{VP}, LCF/L , LCB/L , Fn	
	L/B , B/T , $L/\nabla^{1/3}$, C_{WPA}, C_{WPF}, C_{VPA}, C_{VPF} , Fn	

The seakeeping behaviour of a ship is determined by the gross overall hull shape which has been called ship main dimensions. This means that a rough description of the ship is sufficient, and that relatively minor modifications can be made later (to improve powering or manoeuvring characteristics) without changing the seakeeping behaviour [13].

In this paper, we are proposing a computer-based system which makes the automatic elimination of ship design parameters based on data analysis for seakeeping performance. By the use of statistics, the backward elimination method is constructed in a software based on the SQL Server Database. The system contains two modules named as "Identification" and "Elimination". Identification module is used to find out the weakest parameters by the method and then the elimination module avoids these parameters from the final model.

The detailed definition of the database is given in Section 2. Our system of automatic elimination of ship design parameters is proposed in Section 3. The elimination model of the system for each motion is presented in Section 4. The discussion about the models for heave, pitch and vertical acceleration is done in Section 5. Conclusions are given in Section 6.

2. Database Definition

In this paper, we continue to use the same database of Mediterranean fishing vessels and their motion transfer functions data in terms of heave, pitch and absolute vertical acceleration at stern which were given in [1, 2]. Moreover, there are thirteen Mediterranean fishing vessels which are single-screw hulls having both round bilge and hard chines with different bow and stern shapes from extreme V-bows to U-bows, and from the shallow wide transom to the deeper narrow sterns. These vessels are used with three different loading conditions, same as our previous studies. These can be found from Table 2 and Figure 1.

The parameters in Table 2 are the principal hull form parameters influencing the ship motions and accelerations. There are other parameters like freeboard, flare and above water form features, but they are not within the scope of this paper. The weight distribution along the vessel is considered as a fixed longitudinal radius of inertia that is kept equal for all the vessels as (k_{yy}/L = 0.26).

In the present analysis, the attention is limited to the influence of geometric, weight and speed characteristics. The parameters under our investigation are $L/\nabla^{1/3}$, L/B, B/T, C_{WP}, C_{VP}, C_{WPA}, C_{WPF}, C_{VPA}, C_{VPF}, LCB, LCF and Fn (non-dimensional Froude number) where waterplane area and vertical prismatic coefficients included with their forward (F) and aft (A) hull portions.

The loading conditions of the vessels reflect possible operating conditions for fishing vessels at different speeds. The first one is to departure from the home port to the fishing ground with 100% consumables, the second is to leave from the fishing ground with full holds and 40% consumables, and the last but not least important one is to arrival to the home port with full holds and 10% consumables. The fishing vessel, for instance Vessel 1, is coded as V_011, V_012 and V_013, for their respective three loading conditions. Considering the hydrostatic curves from the hull forms and final estimate of KG, the initial stability of each vessel is checked for the three loading cases. Free surface effects were included. Intact stability criteria were based on IMO statutory minimum standards.

During our computer based analysis, the geometric description of a number of fishing vessels, with a seakeeping database and the response amplitude operators in regular waves of each vessel are combined in order to have a complete database. The seakeeping database is built with the computed ship responses that include the transfer function values of heave, pitch and vertical acceleration at aft perpendicular located in the stern working area (Figure 2). The considered response amplitude operators constitute the design information that is required to predict ship responses in confused seas using the superposition technique. The calculations have been performed at seven ship speeds as non-dimensional Froude numbers like Fn = 0.00, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30. The intention is to cover the whole range of vessel's speed profile including transfer from port to fishing ground and as well as fishing activities. The range of the wave length to ship length (λ/L_{PP}) is a set of 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50 and 3.00 that enabled to analyse 9 cases covering all physical instances.

Table 2 Vessel database

Vessel	L (m)	L/B (-)	B/T (-)	$L/\nabla^{1/3}$ (-)	C_{WP} (-)	C_{VP} (-)	C_{WPA} (-)	C_{WPF} (-)	C_{VPA} (-)	C_{VPF} (-)	LCF/L (-)	LCB/L (-)
V_011	21.38	3.171	2.582	3.955	0.857	0.490	0.965	0.621	0.513	0.583	0.392	0.463
V_012	21.38	3.171	2.458	3.827	0.874	0.505	0.979	0.635	0.535	0.589	0.393	0.456
V_013	21.38	3.171	2.846	4.234	0.807	0.468	0.909	0.591	0.479	0.570	0.400	0.479
V_021	25.74	3.677	2.646	4.200	0.841	0.574	0.846	0.663	0.608	0.670	0.406	0.488
V_022	25.74	3.677	2.541	4.103	0.864	0.576	0.871	0.673	0.613	0.701	0.399	0.482
V_023	25.74	3.677	2.769	4.312	0.796	0.587	0.804	0.654	0.611	0.696	0.426	0.494
V_031	25.00	3.472	3.158	4.216	0.832	0.610	0.834	0.698	0.635	0.689	0.436	0.494
V_032	25.00	3.472	2.988	4.091	0.853	0.617	0.868	0.703	0.638	0.701	0.427	0.488
V_033	25.00	3.472	3.398	4.386	0.770	0.630	0.744	0.690	0.675	0.674	0.468	0.499

Table 2 (continued)

Vessel	L (m)	L/B (-)	B/T (-)	$L/\nabla^{1/3}$ (-)	C_{WP} (-)	C_{VP} (-)	C_{WPA} (-)	C_{WPF} (-)	C_{VPA} (-)	C_{VPF} (-)	LCF/L (-)	LCB/L (-)
V_041	26.35	3.513	2.914	4.144	0.813	0.621	0.852	0.666	0.626	0.715	0.427	0.489
V_042	26.35	3.513	2.833	4.083	0.823	0.625	0.868	0.668	0.628	0.720	0.423	0.486
V_043	26.35	3.513	3.158	4.327	0.771	0.624	0.789	0.659	0.635	0.698	0.447	0.497
V_051	25.00	3.125	2.835	3.692	0.875	0.628	0.882	0.668	0.710	0.757	0.397	0.472
V_052	25.00	3.125	2.752	3.634	0.890	0.629	0.890	0.674	0.719	0.763	0.393	0.468
V_053	25.00	3.125	3.000	3.802	0.819	0.651	0.800	0.658	0.753	0.760	0.423	0.477
V_061	20.50	2.941	2.766	3.852	0.804	0.521	0.845	0.559	0.511	0.614	0.435	0.492
V_062	20.50	2.941	2.585	3.691	0.834	0.533	0.879	0.574	0.530	0.622	0.429	0.484
V_063	20.50	2.941	3.066	4.117	0.742	0.512	0.769	0.536	0.495	0.597	0.451	0.503
V_071	25.00	3.125	2.835	3.631	0.898	0.644	0.891	0.690	0.719	0.746	0.398	0.467
V_072	25.00	3.125	2.753	3.576	0.903	0.651	0.894	0.696	0.732	0.747	0.398	0.463
V_073	25.00	3.125	3.001	3.739	0.860	0.652	0.852	0.679	0.723	0.743	0.413	0.473
V_081	27.25	3.733	2.547	4.118	0.782	0.650	0.799	0.669	0.661	0.747	0.440	0.501
V_082	27.25	3.733	2.394	3.989	0.818	0.642	0.836	0.679	0.657	0.750	0.426	0.495
V_083	27.25	3.733	2.700	4.243	0.753	0.654	0.746	0.661	0.674	0.740	0.452	0.507
V_091	21.00	2.770	2.627	3.514	0.861	0.540	0.844	0.672	0.515	0.652	0.424	0.481
V_092	21.00	2.770	2.406	3.332	0.887	0.563	0.881	0.697	0.556	0.663	0.424	0.472
V_093	21.00	2.770	2.756	3.619	0.831	0.537	0.816	0.660	0.572	0.643	0.433	0.486
V_101	30.80	2.962	3.870	4.061	0.766	0.662	0.873	0.544	0.718	0.695	0.388	0.424
V_102	30.80	2.962	3.402	3.811	0.783	0.688	0.884	0.567	0.759	0.688	0.392	0.418
V_103	30.80	2.962	4.132	4.199	0.756	0.648	0.862	0.533	0.700	0.689	0.386	0.428
V_111	20.00	3.061	2.633	3.967	0.799	0.495	0.734	0.666	0.495	0.509	0.428	0.486
V_112	20.00	3.061	2.455	3.787	0.824	0.514	0.754	0.691	0.527	0.520	0.430	0.478
V_113	20.00	3.061	2.901	4.239	0.738	0.484	0.667	0.636	0.474	0.487	0.447	0.497
V_121	27.30	4.015	2.729	4.275	0.884	0.636	0.831	0.784	0.663	0.651	0.447	0.485
V_122	27.30	4.015	2.484	4.072	0.915	0.648	0.866	0.806	0.679	0.663	0.444	0.480
V_123	27.30	4.015	2.941	4.447	0.841	0.642	0.785	0.765	0.665	0.642	0.461	0.490
V_131	28.00	3.060	3.386	3.825	0.854	0.663	0.903	0.699	0.658	0.770	0.428	0.488
V_132	28.00	3.060	2.995	3.599	0.885	0.680	0.939	0.707	0.685	0.788	0.416	0.477
V_133	28.00	3.060	3.704	4.003	0.823	0.657	0.859	0.694	0.650	0.755	0.442	0.496
max	30.80	4.015	4.132	4.447	0.915	0.688	0.979	0.806	0.759	0.788	0.468	0.507
min	20.00	2.770	2.394	3.332	0.738	0.468	0.667	0.533	0.474	0.487	0.386	0.418

The hull form parameters in Table 2 are given as follows. L: length overall; B: moulded beam; ∇: displacement volume; C_{WP}: Waterplane area coefficient; C_{VP}: longitudinal prismatic coefficient; C_{VPA}: longitudinal prismatic coefficient of aft body; C_{VPF}: longitudinal prismatic coefficient of forward body; C_{WPA}: waterplane area coefficient of aft body; C_{WPF}: waterplane area coefficient of forward body; LCF: longitudinal position of center of flolation; LCF: longitudinal position of center of buoyancy.

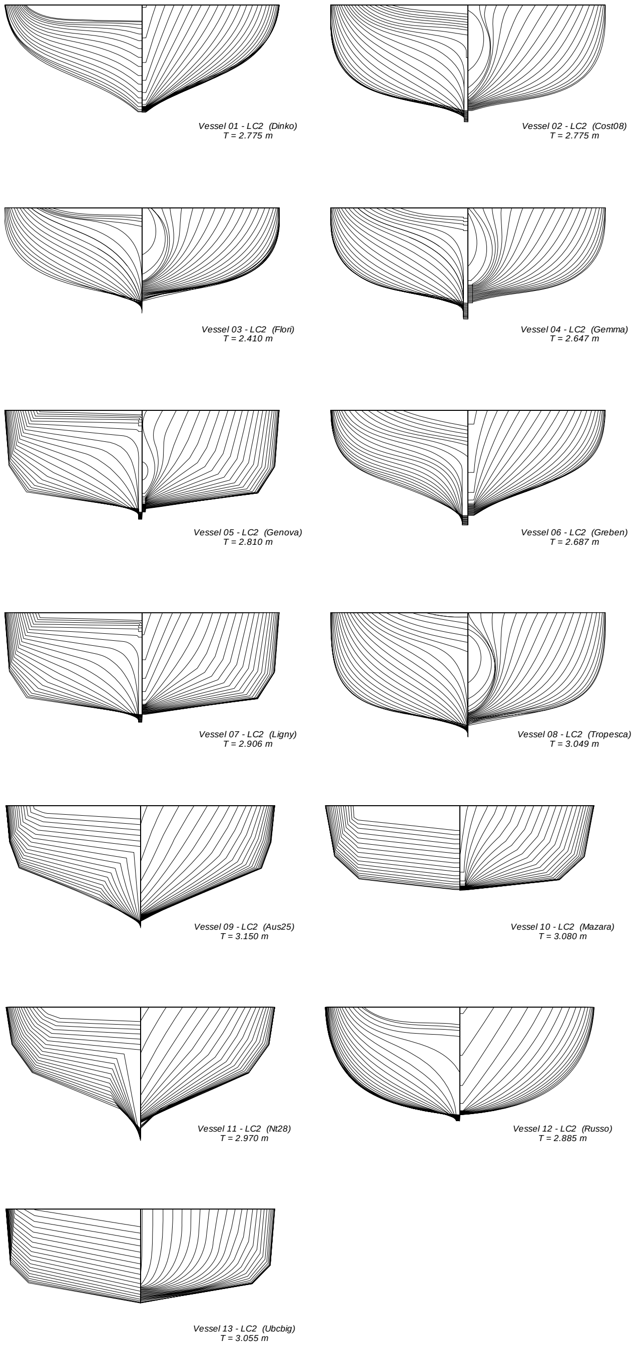


Figure 1 Hull forms of the vessels

(a) (b) (c)

Figure 2 Representation of ship responses onboard of a fishing vessel: a) Heave motion, b) Pitch motion c) Absolute acceleration in the stern working area.

3 Automatic Identification of Ship Design Parameters Based on Data Analysis

The automatic elimination of ship parameters is mainly based on using collinearity from the statistics in order to analyse the data from the ship motions database [14, 15, 16], which is given in Subsection 3.1. There are three approaches of eliminating parameters, which are **"Backward Elimination", "Forward Selection" and "Bidirectional Elimination".**

Backward Elimination starts with all candidate variables, tests the deletion of each variable using a chosen model comparison criterion, deletes the variable (if any) that improves the model the most by being deleted, and repeats this process until no further improvement is possible.

Forward Selection starts with no variables in the model, tests the addition of each variable using a chosen model comparison criterion, adds the variable (if any) that improves the model the most, and repeats this process until none improves can be made to the model.

Bidirectional elimination, a combination of the first two, tests at each step for variables to be included or excluded.

In this study, we use the first approach which will be shown in Subsection 3.2. Also we tested the forward selection for the heave motion and estimated the similar results but had not yet looked deeply. In this paper, we had completed the computational results of the backward elimination for heave, pitch and vertical acceleration and preferred to give them in detail.

3.1 Collinearity

In statistics, the simple way to find the collinearity among dependent variables is to estimate the Variance Inflation Factors (VIF). The following equantion giwen above can be used to calculate the VIF and the higher the value, the higher the collinearity. A VIF for a single dependent variable is obtained using the R-squared value of the regression of that variable against all other dependent variables:

$$VIF_n = \frac{1}{1-R_n^2} \quad (1)$$

where the VIF for variable n is the reciprocal of the inverse of R_n^2 from the regression. The VIF is calculated for each dependent variable and those with high values are removed. The definition of ‘high’ is somewhat arbitrary but values in the range of 5-10 are commonly used. We preferred to use 10 in our calculations. However we also have tried 5 and several others, the results were not changed.

3.1 Backward Elimination

This backward elimination can be described in five steps as follows:

Step 1 :	Take values of the dependent (Y) and independent variables (X_1, X_2, …, X_n) from the database
Step 2:	Consider the multi-regression model as in $\hat{Y} = A_0 + A_1X_1 + A_2X_2 + ... + A_nX_n$
Step 3:	Calculate variance inflation factors (VIF) of each X variable
Step 4:	If there is more than one variable's VIF is greater than 10, then the variable with the maximum VIF is excluded from the model and go to Step 3 with the remaining variables. However if there is only one variable's VIF is greater than 10, then this variable is excluded from the model and go to step 3.

Step 5:	When the model does not have any variable with the VIF which is greater than 10, then the remaining variables are used in the final regression model in order to calculate the coefficients of the remaining variables using the least-squared method as in [1, 2]

During the automatic elimination of ship parameters to construct the regression model with less parameters, the Hull Form Database is built using Visual Basic programming language based on SQL-Server database. The data analysis is done dynamically by using the backward elimination to analyse records on a ship database and to automatically find out both the motion characteristics and their dependencies. Our software system based on the automatic elimination also works with the up-to-date information in any given database which can change at any time without any need of reconstructing the complete system [13, 14, 15].

4 Eliminated Model

We have estimated four different models for seakeeping in our previous papers [1, 2] using several parameters which are summarised in Table 3 including our last model which we are introducing as "Eliminated" that is the fifth. In this eliminated model, we first identified the weak parameter by the forward elimination in our software system and then the remaining parameter are used to have the eliminated model.

Table 3 Implemented seakeeping regression models and corresponding design variables.

Model	Description	Non-dimensional Ratios	Hull Form Parameters	Speed
I	Simple	$L/\nabla^{1/3}$, L/B, B/T	n/a	Fn, Fn^2
II	Intermediate	$L/\nabla^{1/3}$, L/B, B/T	C_{WP}, C_{VP}	*Fn, Fn2*
III	Enhanced 1	$L/\nabla^{1/3}$, L/B, B/T	C_{VP}, C_{WP}, LCF/L, LCB/L	*Fn*
IV	Enhanced 2	$L/\nabla^{1/3}$, L/B, B/T	C_{WPA}, C_{WPF}, C_{VPA}, C_{VPF}	*Fn*
V	Eliminated	L/B, B/T	C_{WPA},C_{WPF}, C_{VPA}, LCF/L, LCB/L	*Fn, Fn2*

By the use the remaining parameters and multi-parameter linear regression analysis, the calculated coefficients from our self-coded software system are given in Table 4 as follows:

Table 4 Coefficients for Eliminated Model

a) Heave

		L/B	*B/T*	*LCF/L*	*LCB/L*	*CWPF*	*CWPA*	*CVPA*	*Fn2*	*Fn*	
λ/L	A_0	A1	A2	A3	A 4	A 5	A 6	A 7	A 8	A 9	R-sq
0.50	-0.0217	0.0270	0.0083	-0.3848	0.6286	-0.0669	-0.1117	-0.0195	1.0330	-0.5502	0.7088
0.75	0.3714	0.0079	0.0256	-0.3205	-0.4043	-0.1319	0.2569	0.0128	3.0426	-1.4327	0.8690
1.00	-0.8123	0.1790	0.0509	-0.2679	2.3887	0.1927	-0.8790	-0.3905	-2.3763	-0.0872	0.7645
1.25	-1.5674	0.3587	0.0727	-0.9021	4.4497	0.1669	-1.3800	-0.5858	-12.9446	3.6513	0.8406
1.50	-1.3293	0.3526	0.0341	-1.1509	4.3628	0.1841	-1.4359	-0.3313	-9.7896	4.4911	0.8029
1.75	-0.2733	0.1810	-0.0704	-1.1231	3.0078	0.1623	-1.0609	0.1878	2.0216	2.2373	0.9225
2.00	0.4573	0.0500	-0.1209	-0.7251	1.6908	0.1538	-0.6074	0.3588	6.2817	0.7934	0.9411
2.50	0.7686	0.0163	-0.0790	-0.2609	0.7073	0.1319	-0.2733	0.1328	3.3637	0.4371	0.9158
3.00	0.8377	0.0150	-0.0463	-0.0681	0.3345	0.1003	-0.1564	0.0380	1.2317	0.4236	0.9007

b) Pitch

		L/B	*B/T*	*LCF/L*	*LCB/L*	C_{WPF}	C_{WPA}	C_{VPA}	*Fn2*	*Fn*	
λ/L	B_0	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	R-sq
0.50	0.0680	0.0045	0.0045	-0.1019	-0.0124	-0.0298	0.0432	-0.0022	0.5015	-0.2979	0.8889
0.75	-0.0462	0.0323	0.0123	-0.0622	0.5589	-0.0147	-0.2497	-0.0520	1.3033	-0.7397	0.8119
1.00	-0.0705	0.1083	0.0449	0.3991	0.6559	-0.0891	-0.4436	-0.1215	-0.3594	-1.0827	0.9430
1.25	-0.0449	0.1487	0.0807	1.2711	0.0476	-0.1057	-0.6189	-0.1520	-6.3529	0.9213	0.8766
1.50	0.2233	0.0996	0.0725	2.0596	-0.7765	-0.0008	-0.7661	-0.0249	-5.4877	1.9392	0.6185
1.75	0.7555	-0.0177	0.0002	2.6435	-1.7196	0.1376	-0.7118	0.2703	0.7746	1.1895	0.8998
2.00	1.0424	-0.0779	-0.0474	2.6514	-1.9468	0.1953	-0.5693	0.3691	3.1494	0.7191	0.9327
2.50	1.1057	-0.0604	-0.0405	1.9658	-1.4489	0.1784	-0.4589	0.2263	2.3557	0.6535	0.9458
3.00	1.1038	-0.0460	-0.0257	1.4912	-1.1089	0.1570	-0.3725	0.1346	2.0278	0.5298	0.9555

c) Vertical Acceleration

		L/B	*B/T*	*LCF/L*	*LCB/L*	C_{WPF}	C_{WPA}	C_{VPA}	*Fn2*	*Fn*	
λ/L	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	R-sq
0.50	0.0680	0.0045	0.0045	-0.1019	-0.0124	-0.0298	0.0432	-0.0022	0.5015	-0.2979	0.8889
0.75	-0.0462	0.0323	0.0123	-0.0622	0.5589	-0.0147	-0.2497	-0.0520	1.3033	-0.7397	0.8119
1.00	-0.0705	0.1083	0.0449	0.3991	0.6559	-0.0891	-0.4436	-0.1215	-0.3594	-1.0827	0.9430
1.25	-0.0449	0.1487	0.0807	1.2711	0.0476	-0.1057	-0.6189	-0.1520	-6.3529	0.9213	0.8766
1.50	0.2233	0.0996	0.0725	2.0596	-0.7765	-0.0008	-0.7661	-0.0249	-5.4877	1.9392	0.6185
1.75	0.7555	-0.0177	0.0002	2.6435	-1.7196	0.1376	-0.7118	0.2703	0.7746	1.1895	0.8998
2.00	1.0424	-0.0779	-0.0474	2.6514	-1.9468	0.1953	-0.5693	0.3691	3.1494	0.7191	0.9327
2.50	1.1057	-0.0604	-0.0405	1.9658	-1.4489	0.1784	-0.4589	0.2263	2.3557	0.6535	0.9458
3.00	1.1038	-0.0460	-0.0257	1.4912	-1.1089	0.1570	-0.3725	0.1346	2.0278	0.5298	0.9555

Figure 3 for heave, Figure 4 for pitch and Figure 5 for vertical accelation are used to compare the coefficients of the five models.

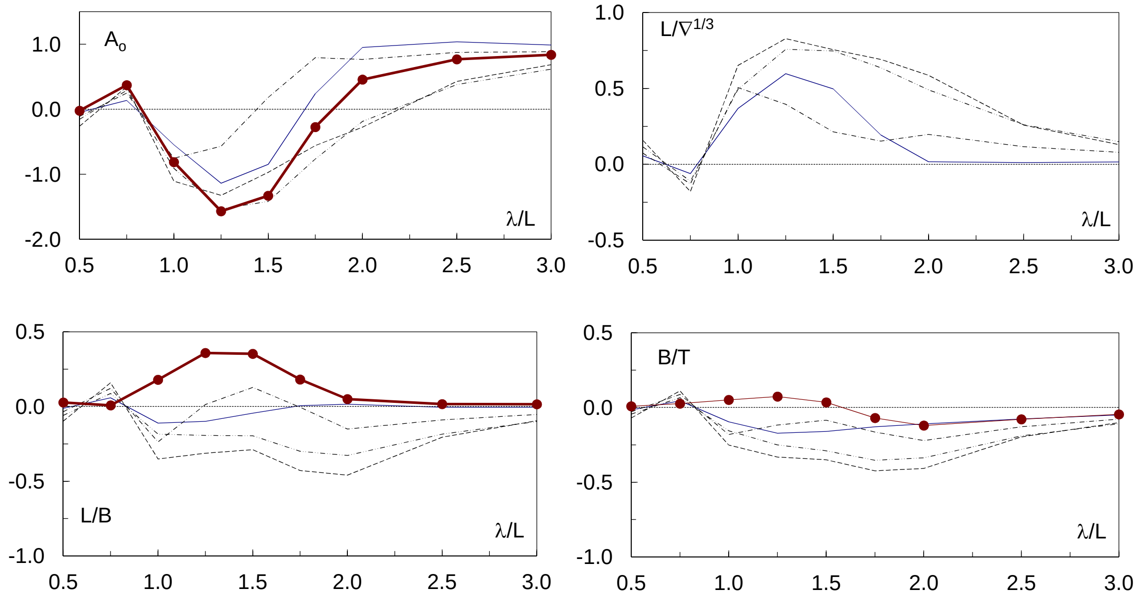


Figure 3 (continues)

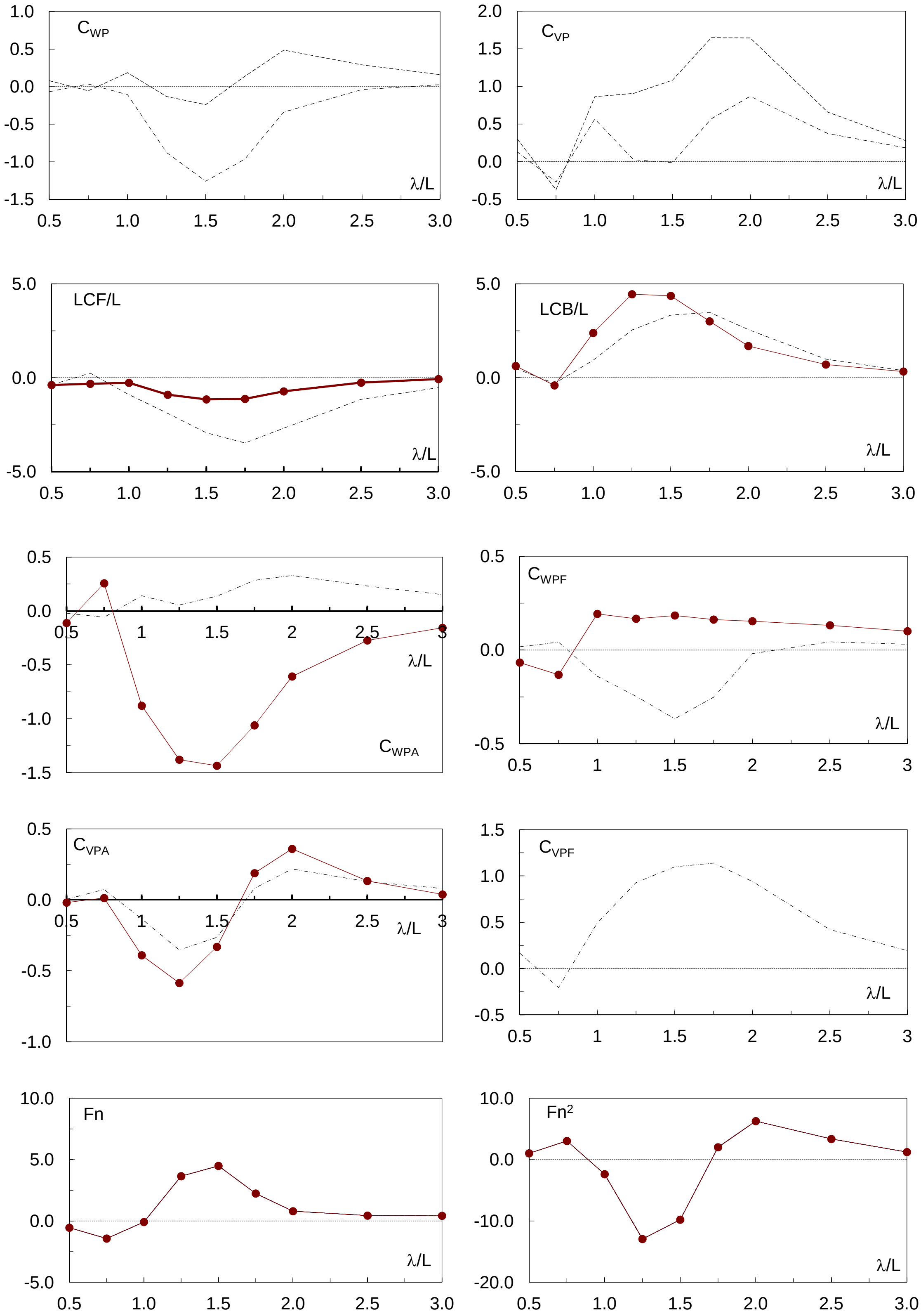


Figure 3 (continues)

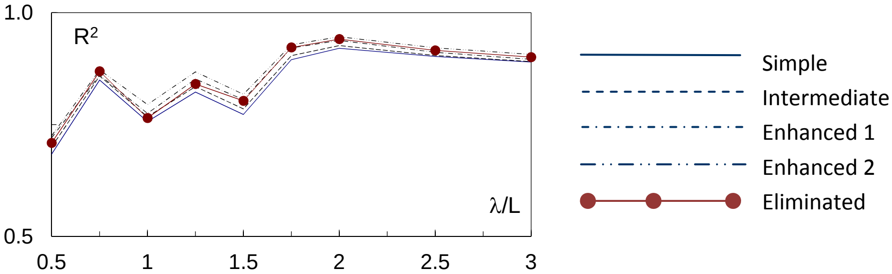
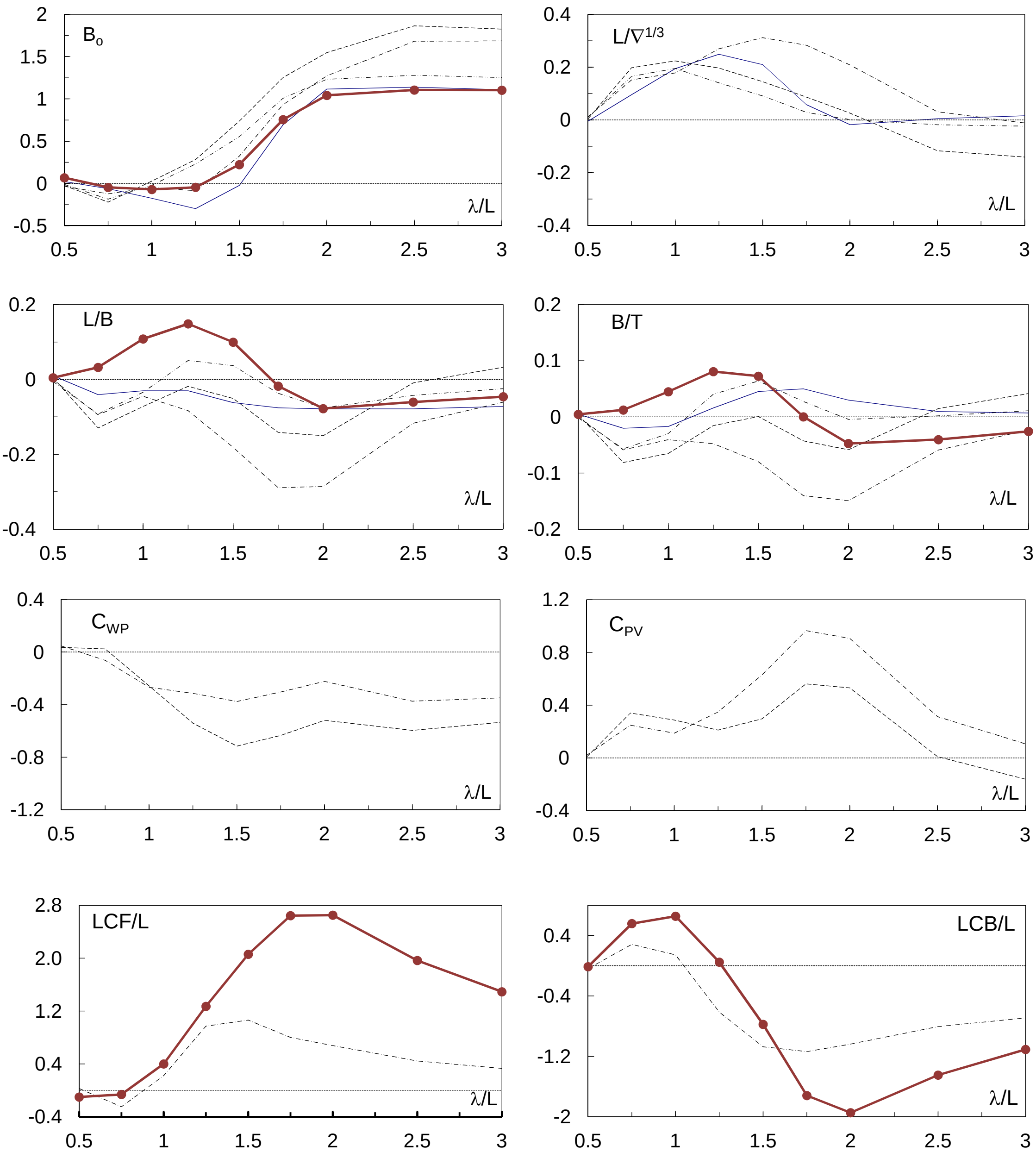


Figure 3 Coefficients for heave motion transfer functions



(Figure 4 continues)

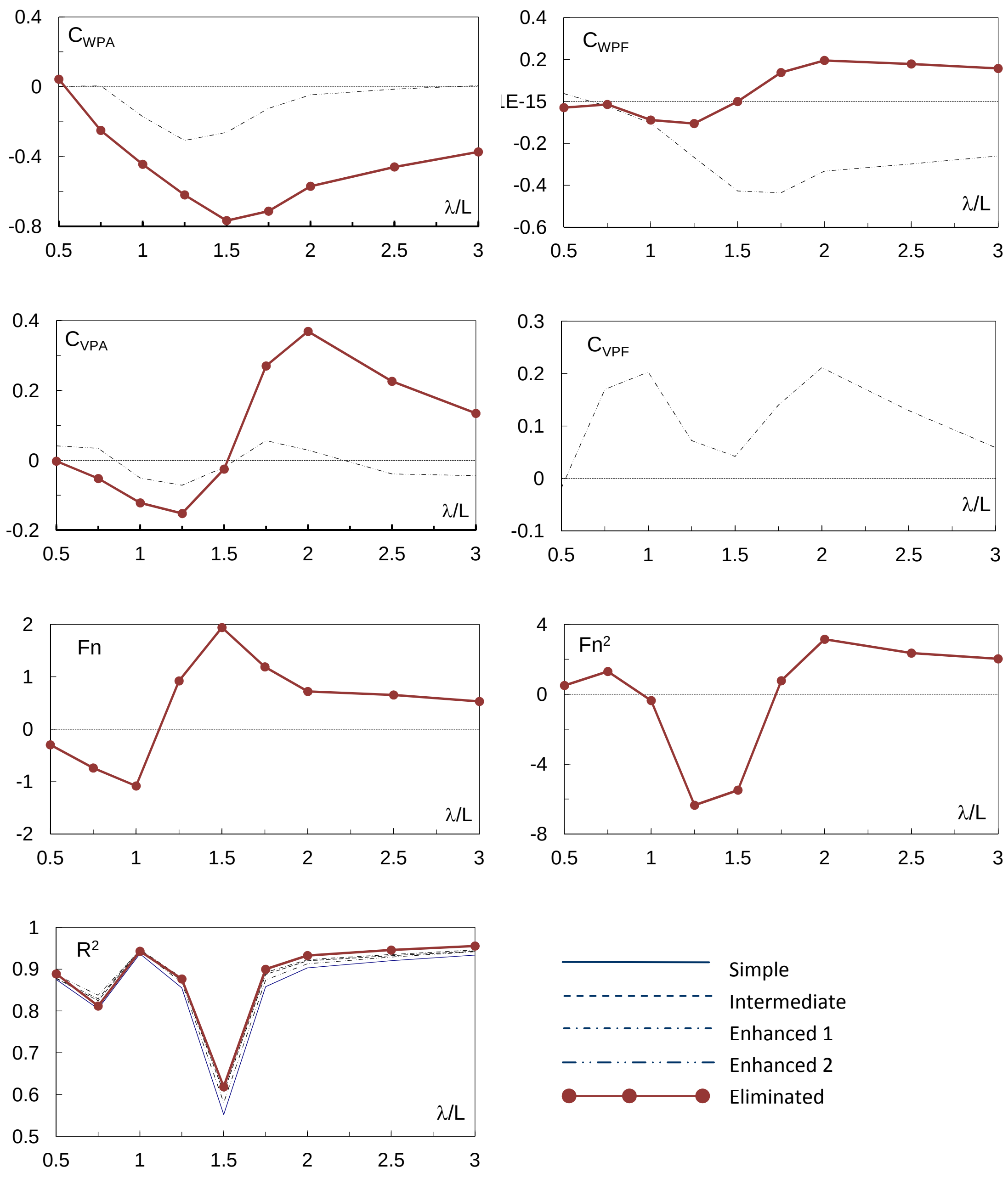
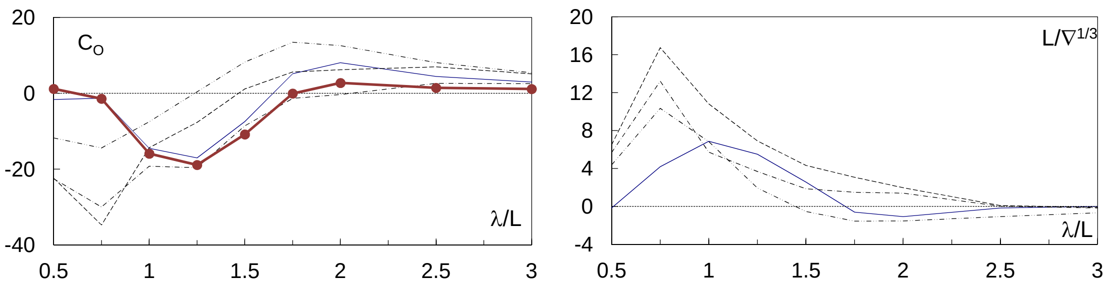
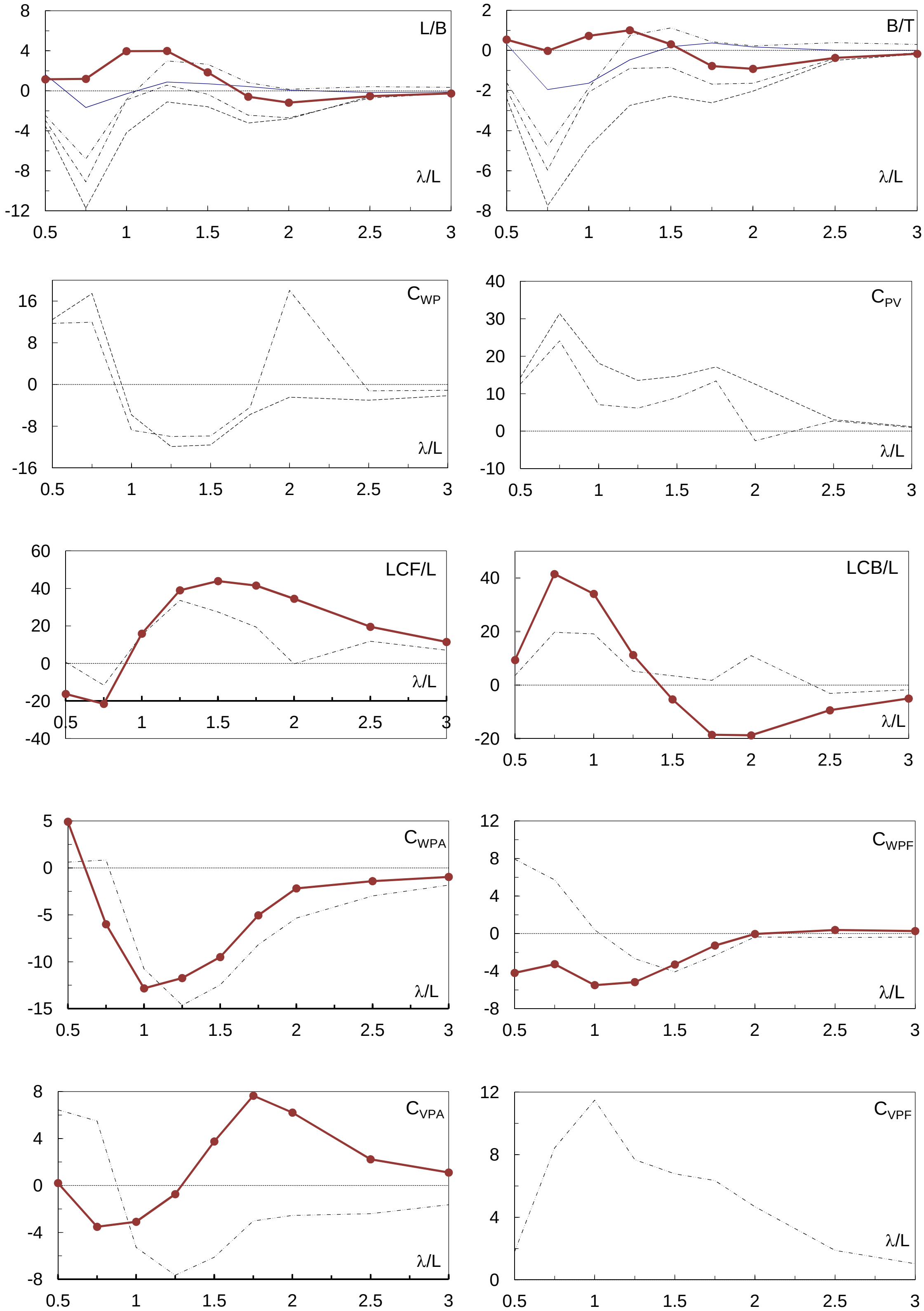


Figure 4 Coefficients for pitch motion transfer functions.



(Figure 5 continues)



(Figure 5 continues)

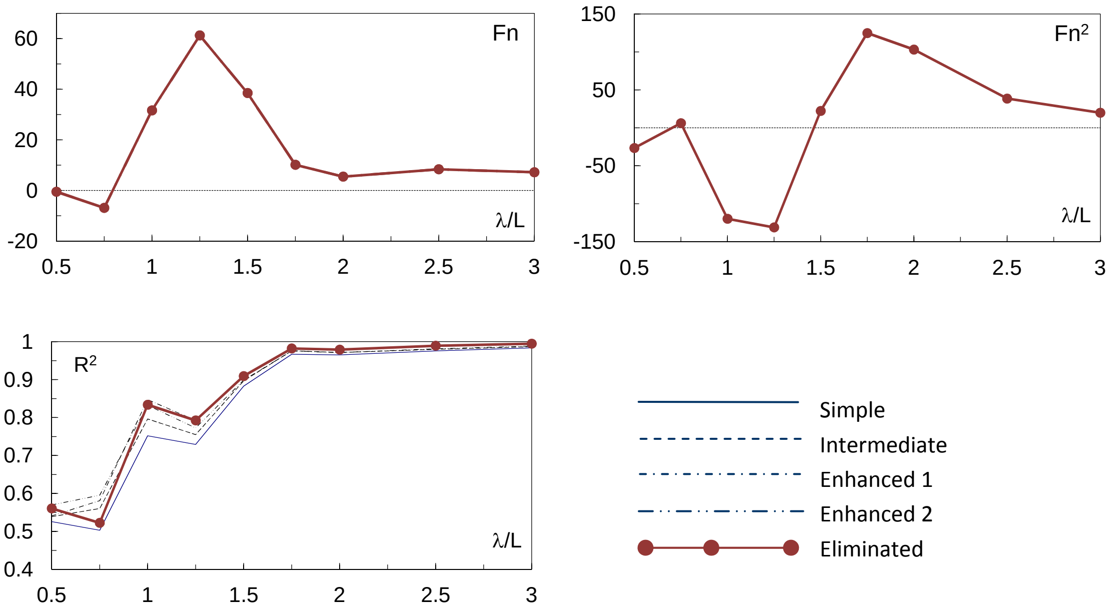


Figure 5 Coefficients for vertical acceleration transfer functions.

For each Froude number and Vessel V_051, the comparison between computed and predicted heave transfer functions is given in Figure 6, the comparison between computed and predicted pitch transfer functions is given in Figure 7 and finally the comparison between computed and predicted vertical acceleration transfer functions is given in Figure 8 (see Appendix 1).

5 Discussion

According to the new results given in Figure 3, Figure 4 and Figure 5, the following Table 5 can be set up by integrating the former Table 8 in our paper (Sayli et al., 2007) where the related regression models were based on the linear regression analysis ("linear" expression in Table 5 shows the parameters' influences) and the former Table 7 in our paper (Sayli et al., 2010) where the related regression models were based on the non-linear regression analysis ("non-linear" expression in Table 5 shows the parameters' influences). In Table 5, "Eliminated" column gives the results of our current eliminated method and we have assigned the notation of "H" if the coefficient has a constant sign with a significant value, the notation of "L" if the coefficient has a constant sign with a disregardable value, the notation of "?" if the sign of the coefficient is changing in the examined range, and the notation of "-" if the parameter is eliminated.

After comparing the columns of Table 5, the major results can be summarised as follows:

$L/\nabla^{1/3}$ – low influence and eliminated;

L/B – contradictory influence;

B/T – contradictory influence;

C_{WP} – high influence and eliminated;

C_{VPF} – low influence and eliminated;

C_{WPF} – influence is reduced or questionable;

C_{WPA} – high influence is confirmed;

C_{VPF} – low influence and eliminated;

C_{VPA} – influence is questionable;

LCF/L – contradictory influence;

LCB/L – contradictory influence.

Table 5 Hull form requirements for good seakeeping.

Motion	Heave			Pitch			V.A.@Stern		
Variable	Linear	Non-linear	*Eliminated*	Linear	Non-linear	*Eliminated*	Linear	Non-linear	*Eliminated*
$L/\nabla^{1/3}$	L	L	-	L	L	-	L	L	-
L/B	H	H	*L*	H	H	*?*	?	?	*?*
B/T	H	H	*L*	?	?	*?*	H	H	*?*
C_{WP}	H	H	-	H	H	-	H	H	-
C_{VP}	L	L	-	L	L	-	L	L	-
C_{WPF}	H	L	*H*	H	H	*?*	H	H	*?*
C_{WPA}	L	H	*H*	H	H	*H*	H	H	*H*
C_{VPF}	L	?	-	L	H	-	L	H	-
C_{VPA}	?	?	*?*	?	L	*?*	H	L	*H*
LCF/L	H	H	*L*	L	L	*H*	L	L	*H*
LCB/L	L	L	*H*	H	H	*H*	L	L	*?*

From the above, some conclusions can be made:

- The regression analysis is certainly a good tool for the data analyses of ship motion transfer functions. In general, if the regression analysis is done using the all possible variables, the results get closer to the computed values and the better – the more sensitive estimations which can be used for engineering concept design cases. In this paper this is also observed because some cases of mentioned variables above were behaved very clearly in our previous paper but now using the eliminated method they were not acting as clear as before and they caused some questions about their interference on the ship motions. On the other hand, some variables acted in the opposite ways and they become more important such as *LCB/L* and *LCF/L*.
- Automatic elimination could help to eliminate some of the insignificant variables ($L/\nabla^{1/3}$ and C_{VPF} in our case).
- It can be said that if the engineers do not have enough time to analyse the data in this case it can be better to use less parameters in the data analysis. But if the investment has high commercial worth then the engineers must consider and analyse all variables and their effects in the concept design to minimise the risks of the further stages of design. Moreover, it may be possible to dismiss to analyse a variable thinking no-effects on the conceptual design stage but in the implementation this may cause other hydrodynamic circumstances that would also effect the ship motion transfer function

as well. Ideally it can be suggested that any engineer should analyse any evidence in the data that she/he can have, before making any design decision.

- During this research our implemented software can be easily used for any kind and size of any database such as Oracle or SQL server, which is fast and effective to make the elimination of many parameters. Therefore, naval architects should consider to have their own implemented software with high technology and encourage to do specific data collections and analyses.

6 Conclusion

This paper presents the results of applying the regression analysis for implementing meta-models suitable for predictions in early design stage. An automatic eliminated method has been applied to a family of Mediterranean fishing vessels and to the related hydrodynamic database of motion and acceleration responses in regular waves (RAO's). The results clearly show that even by automatic elimination of selected design variables, the computed predictions are good and comparable with those obtained by more "rational" regression models. In other terms, independently of the preferred design parameters, different regression models could be used with the same reliability for obtaining predictions in early design stage.

We can say that, after having Table 5 by the use of eliminated method, going back to the seakeeping models in our previous works [1, 2], our arguments were probably too ambitious and in reality, we perhaps never can obtain what we hope, in this way, clear indications on the role of single variables, but only on few of them, for example C_{WPA}. In a case of having a real time database (for example sensored based measurements) that can be used to build higher level of meta-models for the initial design stage issues as well as the further stages.

APPENDIX 1 – (Figures 6, 7 and 8)

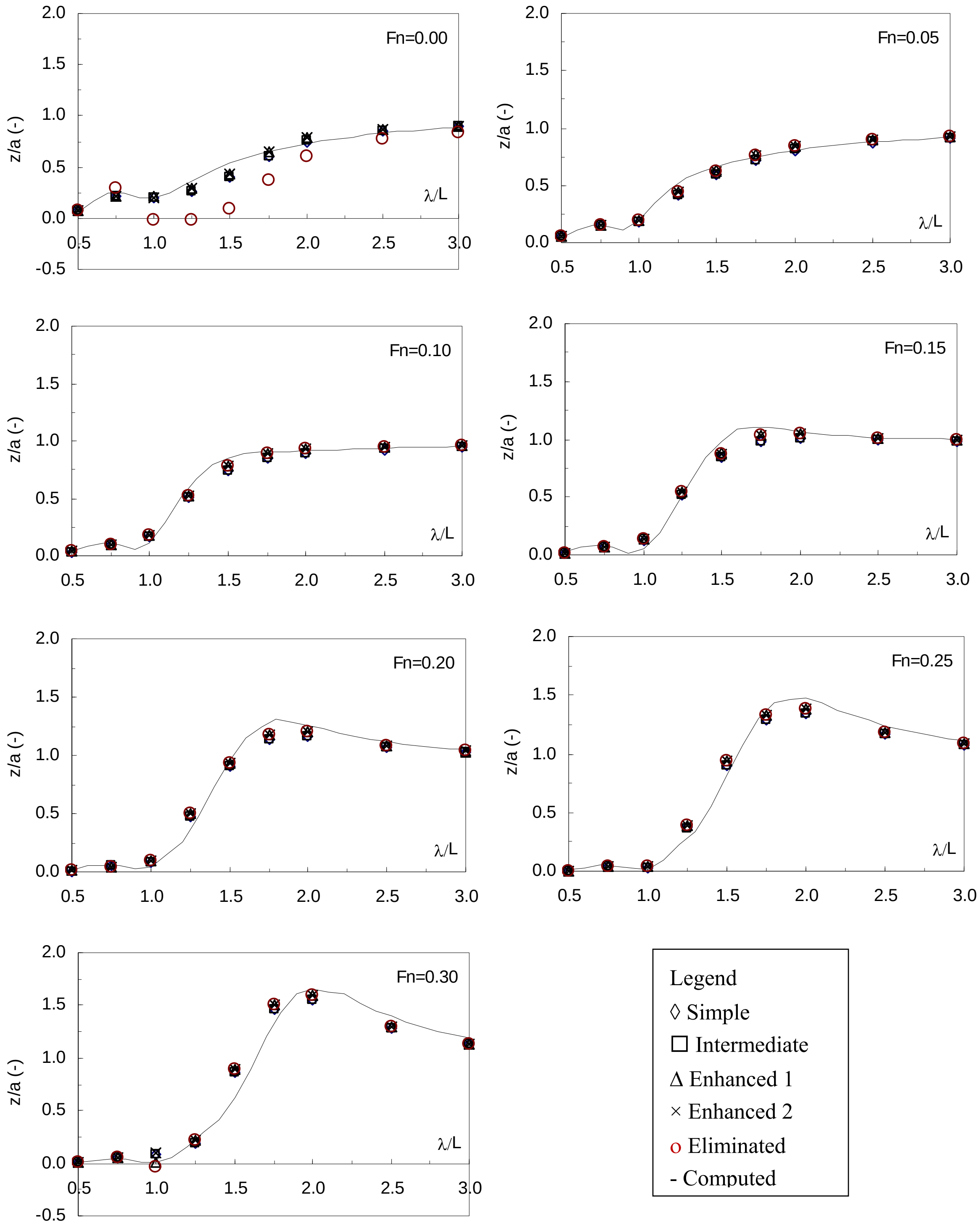


Figure 6 For each Froude number, comparison between computed and predicted heave transfer functions (*z/a*) for Vessel V_051.

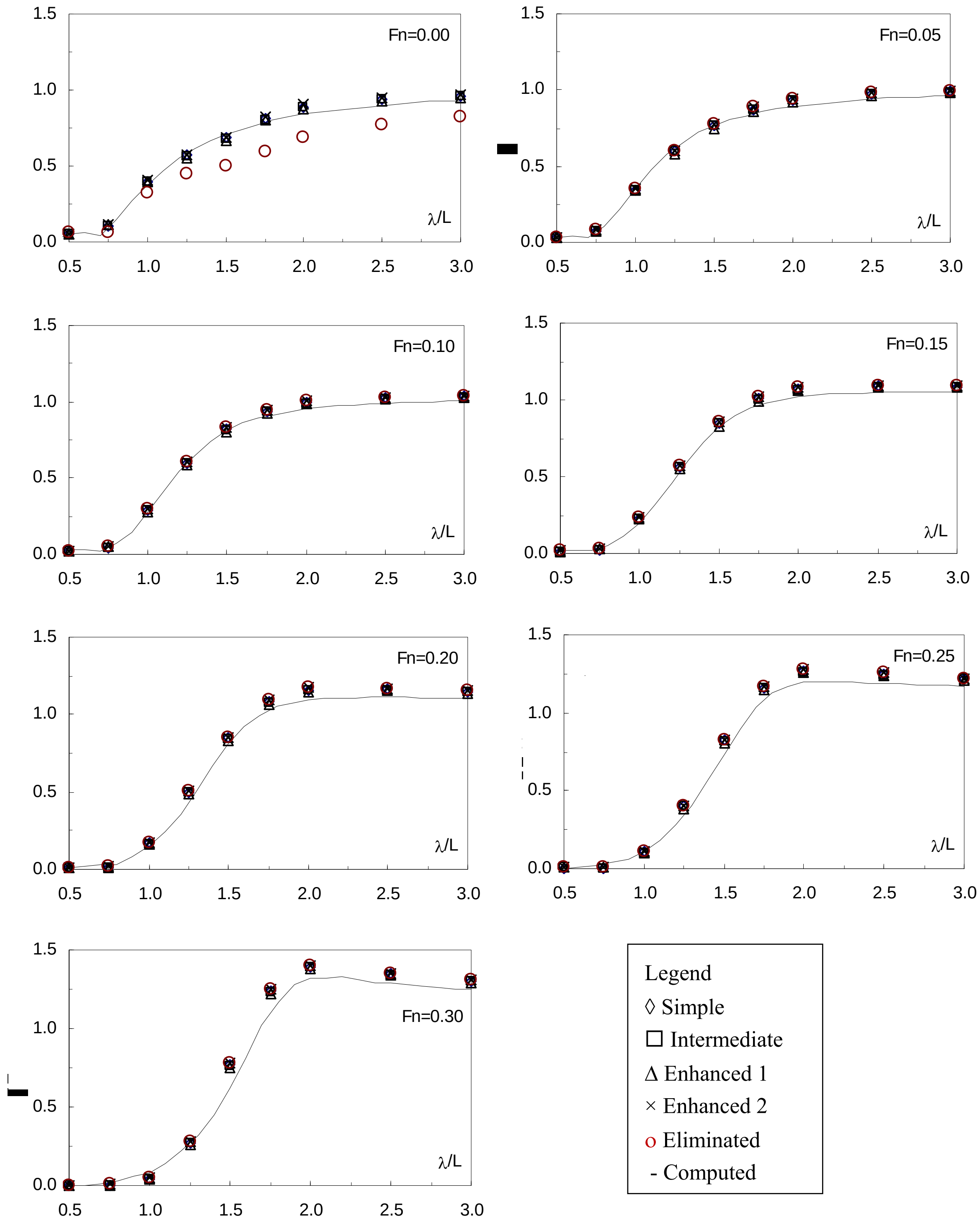


Figure 7 For each Froude number, comparison between computed and predicted pitch transfer functions (θ/α) for Vessel V_051.

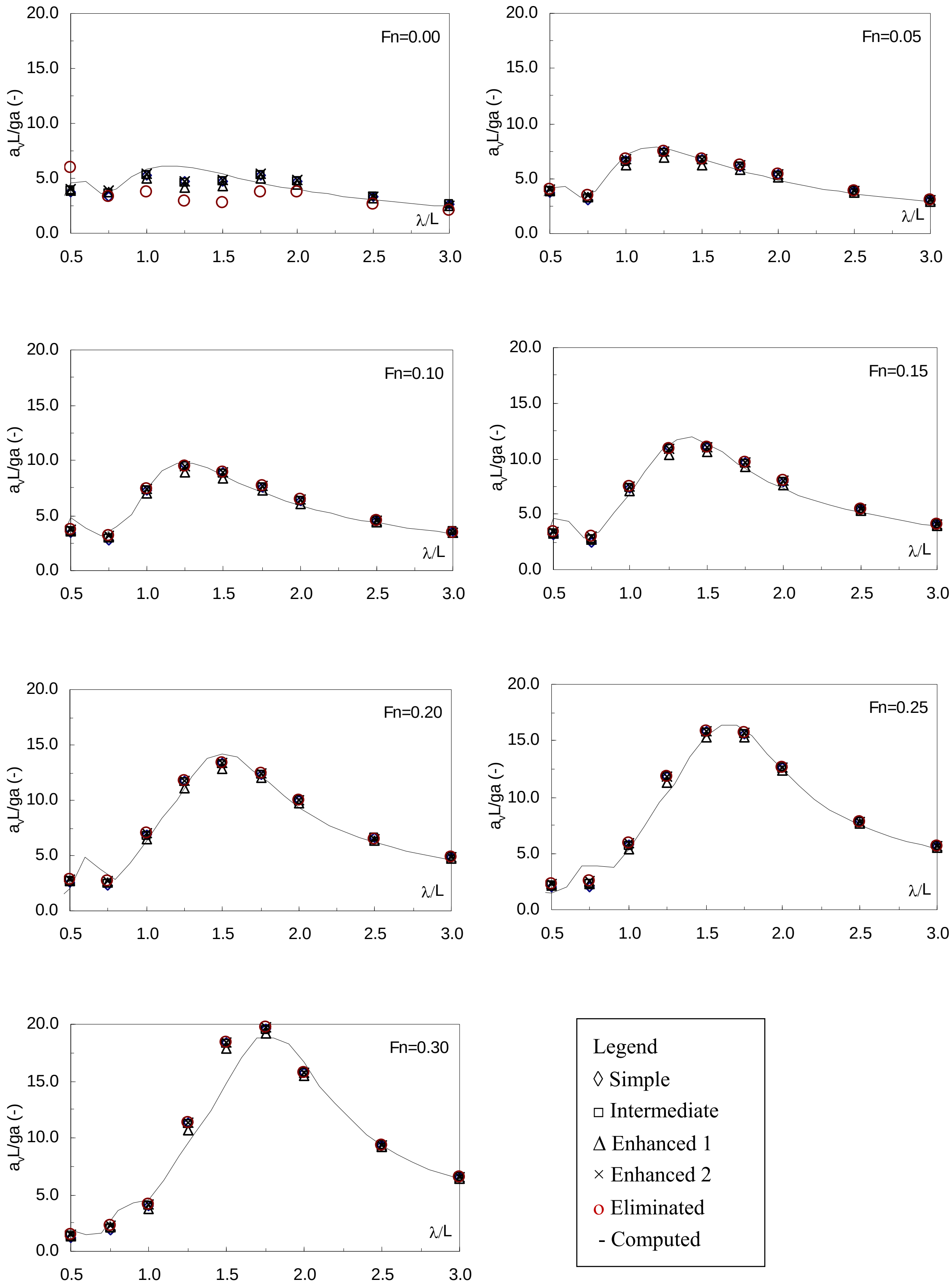


Figure 8 For each Froude number, comparison between computed and predicted vertical acceleration transfer functions ($a_v L/g\,a$) for Vessel V_051.

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