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Effects of hull form parameters on seakeeping for YTU gulet series with cruiser stern

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ABSTRACT: *This study aims to identify the relations between seakeeping characteristics and hull form parameters for YTU Gulet series with cruiser stern. Seakeeping analyses are carried out by means of a computer software which is based on the strip theory and statistical short term response prediction method. Multiple regression analysis is used for numerical assessment through a computer software. RMS heave-pitch motions and absolute vertical accelerations on passenger saloon for Sea State 3 at head waves are investigated for this purpose. It is well known that while ship weight and the ratios of main dimensions are the primary factors on ship motions, other hull form parameters (C_P, C_{WP}, C_{VP}, etc.) are the secondary factors. In this study, to have an idea of geometric properties on ship motions of gulets three different regression models are developed. The obtained outcomes provide practical predictions of seakeeping behavior of gulets with a high level of accuracy that would be useful during the concept design stage.*

KEY WORDS: Ship motions; Gulets; Hull form parameters; Multiple regression method.

NOMENCLATURE

B_{OA}	Overall breadth
B_{WL}	Waterline breadth
C_B	Block coefficient
C_P	Prismatic coefficient
C_{VP}	Vertical prismatic coefficient
C_{WP}	Waterline area coefficient
D	Depth
Fn	Froude number
$H_{1/3}$	Characteristic wave height
k_{yy}	Gyration radius for pitch motion
L_{CB}	Longitudinal position of center of buoyancy
L_{CF}	Longitudinal position of center of floatation
L_{OA}	Overall length
L_{BP}	Length between perpendiculars
L_{WL}	Waterline length
T	Draught
T_m	Modal wave period
∇	Displacement volume
Δ	Displacement force
μ	Angle of encounter

ABBREVIATION LIST

ITTC	International towing tank conference
RAO	Response amplitude operator
RMS	Root mean square
SS	Sea state
STANAG	Standardization agreement
YTU	Yildiz technical university

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INTRODUCTION

Existing gulets are used for pleasure trips today. Therefore it became significant to conduct a study in order to discover their hydrodynamic characteristics. A systematic series of gulet hull forms with cruiser stern is developed in order to investigate their performance (Aydın, 2013). Certain processes could be made to understand seakeeping characteristics of the gulets by making use of several methods. Although the strip theory is the quickest and relatively most accurate one it has restrictions because of its theoretical assumptions. It has been most preferred tool during conceptual design stage. Due to its theory is linear; solutions are more realistic for slender hulls and low Froude numbers. However, strip theory has been widely accepted and a large number of computer codes are developed.

While resistance and power outputs are sensitive to local changes of hull form, seakeeping matrix is less sensitive local changes of hull form. Seakeeping performance usually depends on main dimensions and their proportions, hydrostatic values and weight distribution. For this reason, seakeeping phenomenon must be evaluated in conceptual design stage (Şaylı et al., 2007).

Several studies can be found in technical literature about effects of ship geometry on seakeeping characteristics. Bales performed a criteria free rank study for 20 displacement- normalized destroyers by using six form parameters. Based on the general definition of seakeeping rank, eight seakeeping responses were computed for each hull form. The responses were pitch, heave, ship to wave relative motion at Station 0 and 20, bottom slamming at Station 3, absolute vertical acceleration at Station 0, heave acceleration and absolute vertical motion at Station 20. Analyses were performed in long crested head seas for five speeds each for five modal periods (Bales, 1980). Kükner and Sarıöz made calculations for high speed vessels in their study. They investigated main dimensions and seconder hull form parameters effect on vertical motions (Kükner and Sarıöz, 1995). Brown conducted a study for gulet type boats in terms of resistance and seakeeping. Then he tried to present optimum hull parameters for gulets (Brown, 2005). Şaylı and others showed the effects of hull form parameters on vertical motions for fishing vessels by using multiple regression techniques (Şaylı et al., 2007). Şaylı and others, in their next study, performed the same configuration by using non-linear regression techniques (Şaylı et al., 2009). Results were very adoptable with each other. Özüm and others observed the effect of hull parameters for high speed hull forms during conceptual design stage. They explored main dimensions and secondary form parameters make the main contribution to ship motions (Özüm et al., 2011).

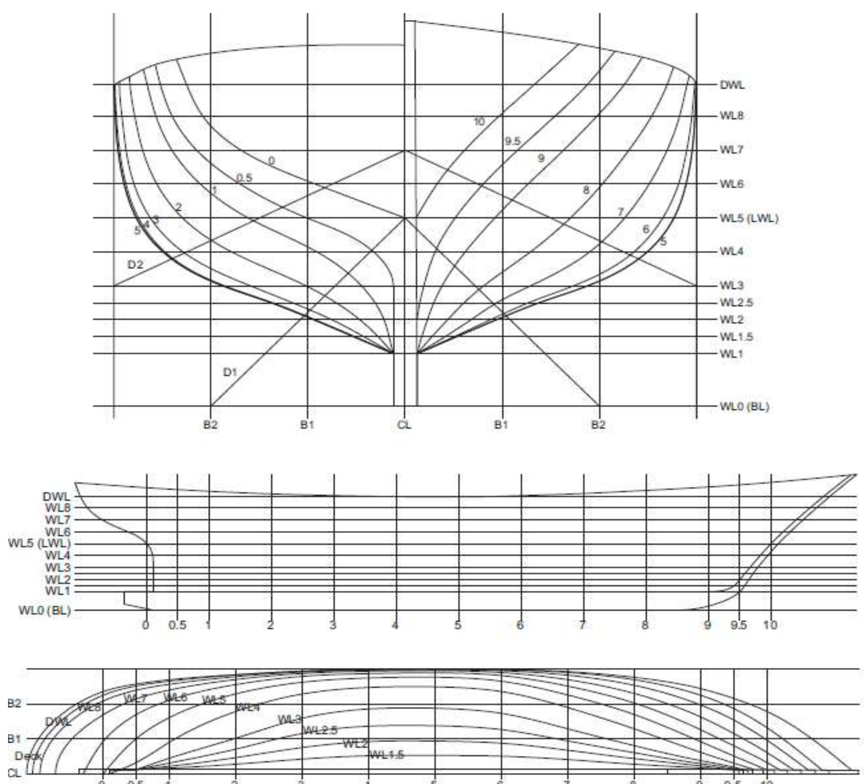

Fig. 1 Body Stations, profile and waterlines of a gulet in the series.

In this study, gulet type pleasure boats were examined in terms of seakeeping properties. Although gulets were built in traditional ways previously, these crafts are built with modern technics in recent years. A study was conducted with the purpose of developing an original gulet series with cruiser stern without destroying its character. First, 21 cruiser stern gulet hull forms with different geometric design block coefficients (C_B) were designed by the author with the information gained during the technical visits. These hull forms were produced by preserving conventionalism. Detailed information can be found in related paper. (Aydın, 2013) Body Stations, profile and waterlines of a gulet in the series are shown in Fig. 1.

The hull form parameters of YTU Gulets are tabulated in Table 1. For comparison purposes Table 2 is constructed to show the dimension and displacement ranges of existing gulets in Turkey and YTU Gulets.

Table 1 Main dimensions and some geometric properties of YTU gulets with cruiser stern.

Gulets	$L_{OA}(m)$	$L_{WZ}(m)$	B_{OA} (m)	$B_{WL}(m)$	$T(m)$	$D(m)$	C_B	C_M	$(W)(ton)$
G1	15	11.976	4.839	4.389	1.558	2.634	0.256	0.392	21.495
G2	16	12.774	5.036	4.571	1.612	2.741	0.262	0.403	25.278
G3	17	13.573	5.224	4.746	1.665	2.845	0.268	0.414	29.434
G4	18	14.371	5.404	4.915	1.762	2.992	0.269	0.416	34.282
G5	19	15.170	5.575	5.078	1.811	3.090	0.274	0.426	39.237
G6	20	15.968	5.739	5.237	1.859	3.185	0.280	0.435	44.601
G7	21	16.766	5.896	5.391	1.951	3.323	0.281	0.436	50.776
G8	22	17.565	6.046	5.541	1.996	3.412	0.286	0.444	57.010
G9	23	18.363	6.189	5.688	2.040	3.499	0.292	0.452	63.687
G10	24	19.162	6.327	5.832	2.129	3.629	0.292	0.452	71.307
G11	25	19.960	6.460	5.973	2.170	3.711	0.298	0.459	78.927
G12	26	20.758	6.587	6.112	2.210	3.790	0.303	0.466	87.027
G13	27	21.557	6.710	6.249	2.295	3.913	0.304	0.464	96.211
G14	28	22.355	6.828	6.385	2.333	3.989	0.309	0.470	105.330
G15	29	23.154	6.941	6.519	2.370	4.062	0.314	0.475	114.966
G16	30	23.952	7.051	6.652	2.452	4.179	0.314	0.473	125.839
G17	31	24.750	7.156	6.784	2.487	4.249	0.319	0.477	136.574
G18	32	25.549	7.258	6.916	2.522	4.317	0.324	0.481	147.866
G19	33	26.347	7.356	7.047	2.601	4.429	0.324	0.478	160.559
G20	34	27.146	7.451	7.178	2.633	4.493	0.329	0.481	173.032
G21	35	27.944	7.543	7.310	2.665	4.556	0.334	0.484	186.103

Table 2 A comparison between existing gulets and YTU gulets with cruiser stern.

	Existing gulets with cruiser stern	YTU gulets with cruiser stern
$L_{OA}(m)$	18 - 33	15 - 35
$B_{OA}(m)$	5.400 - 7.800	4.839 - 7.543
$D(m)$	2.350 - 4.10	2.634 - 4.556
$T(m)$	1.650 - 2.760	1.558 - 2.665
C_B	0.230 - 0.315	0.256 - 0.334
C_{WP}	0.705 - 0.810	0.738 - 0.823
C_p	0.646 - 0.730	0.654 - 0.689
$\Delta(kN)$	343.35 -1520.55	210.86 - 1825.67

Effects of geometrical features of 21 different YTU Gulets on their seakeeping characteristics in terms of the following three responses are investigated:

- Heave motion
- Pitch motion
- Absolute vertical acceleration at the passenger saloon

Location of the passenger saloon is shown in the Table 3:

Table 3 Location of the passenger saloon.

Longitudinal distance from after end point (m)	$L_{OA} \times 0.4$
Transverse distance from centerline (m)	0
Height from the keel (m)	$D \times 1.20$

Design database

Displacement forces of the gulets should be brought to equal level for fair comparison of effects of geometric characteristics on specified ship motions. This value is 774.27 *kN*. Thus the design database is built with the hull forms of displacement normalized YTU Gulets those are given in Table 4:

Table 4 Hull form parameters for analyses.

Gulets	L_{WL}/B_{WL}	B_{WL}/T	$L_{WL}/\nabla^{1/3}$	C_{WP}	C_P	C_{VP}	L_{CF}/L_{OA}	L_{CB}/L_{OA}
G1	2.729	2.817	4.343	0.738	0.654	0.347	0.492	0.509
G2	2.795	2.836	4.389	0.731	0.650	0.358	0.491	0.505
G3	2.860	2.850	4.432	0.725	0.647	0.369	0.484	0.497
G4	2.924	2.789	4.460	0.720	0.646	0.373	0.481	0.491
G5	2.987	2.804	4.501	0.717	0.644	0.383	0.478	0.487
G6	3.049	2.817	4.540	0.715	0.643	0.392	0.476	0.484
G7	3.110	2.763	4.565	0.714	0.644	0.393	0.473	0.480
G8	3.170	2.776	4.602	0.714	0.644	0.401	0.472	0.479
G9	3.228	2.788	4.636	0.716	0.645	0.407	0.470	0.476
G10	3.286	2.739	4.659	0.718	0.647	0.407	0.469	0.475
G11	3.342	2.753	4.692	0.722	0.648	0.412	0.468	0.475
G12	3.396	2.766	4.723	0.727	0.650	0.416	0.467	0.476
G13	3.450	2.723	4.743	0.734	0.654	0.414	0.464	0.476
G14	3.501	2.737	4.773	0.741	0.657	0.416	0.464	0.477
G15	3.552	2.751	4.801	0.750	0.660	0.418	0.468	0.479
G16	3.601	2.713	4.819	0.759	0.665	0.414	0.465	0.481
G17	3.648	2.728	4.846	0.770	0.668	0.414	0.470	0.484
G18	3.694	2.742	4.871	0.782	0.673	0.414	0.471	0.487
G19	3.739	2.709	4.888	0.794	0.679	0.408	0.473	0.490
G20	3.782	2.726	4.912	0.808	0.684	0.407	0.475	0.494
G21	3.823	2.743	4.935	0.823	0.689	0.405	0.477	0.498

SEAKEEPING CALCULATIONS

Seakeeping performance is evaluated for head waves (μ =180°) and for Fn =0:0.5:0.3 in this paper. Hydrodynamic coefficients are calculated by using Frank Close Fit Method for each gulet section. This solution is valid for arbitrary cross sections and the velocity potential is represented by a distribution of sources on the mean submerged cross section. In this method; green function satisfying the linear free surface boundary condition is used to represent the velocity potential. The density of the sources is an unknown function to be determined from integral equations obtained by applying the body boundary condition (Frank, 1967). Cross sections of the gulet 11 (G11) are shown in Fig. 2.

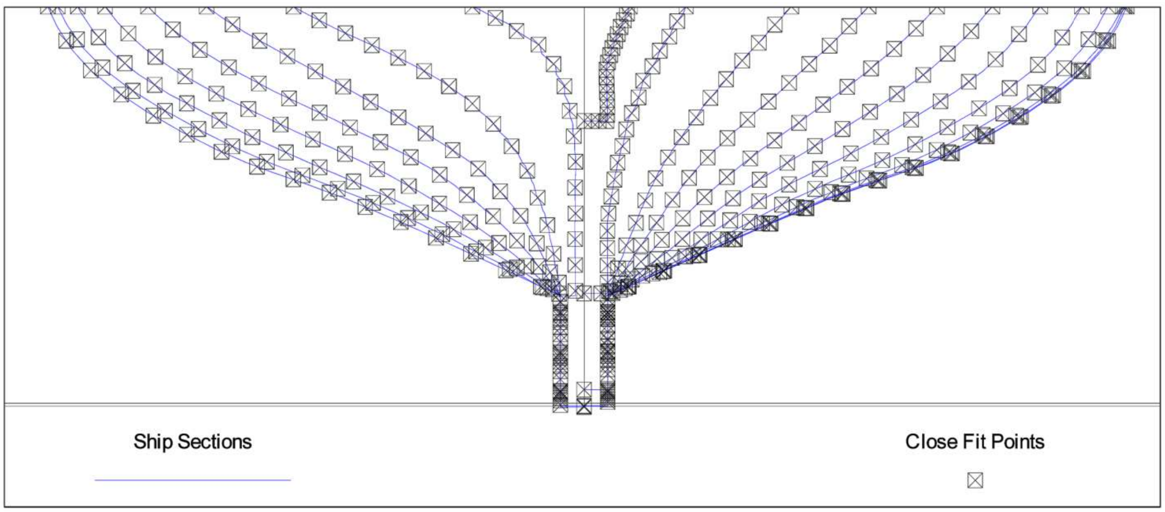

Fig. 2 Sections of the G11 and close fit points.

The assessment of seakeeping performance of a pleasure craft in a specified sea state is related to four elements:

- Ship geometry
- Weight distribution on ship
- Transfer functions (RAO) in regular waves
- Wave spectrum

As a result of these interactions, determination of ship responses can be obtained.

Gulet response characteristics

The first step for determination of the seakeeping performance is to detect the motion response amplitudes and phase lags in the frequency domain for all six degrees of freedom. Then RAOs can be executed for each specified response such as heave motion, velocity and acceleration.

RAO graph of G11 is shown in Fig. 3 in case of zero speed and head waves. It should be pointed out that there is a strong resonance danger in existence of restoring effect such as heave and pitch motion.

Definition of seaway

Ship motions in irregular waves should be investigated due to absence of regular waves in nature. It is important to get ship motions in random waves because of the complexity of sea surface. Modeling sea is possible by using some statistical methods. Irregular sea can be expressed by using wave spectra that is composed as regards to normal distribution. Spectral density function must be known to enter short term statistical parameters. This recommended function must fit characteristic of the sea environment where gulets will sail. It is used 2 parameter ITTC (Bretschnider) wave spectrum in analyses which is proposed in STANAG 4194 documents by reason of gulet type boats mostly operate in East Mediterranean Sea. Analyses are performed at sea state 3. Characteristic wave height and modal period of sea state 3 are shown in Table 5:

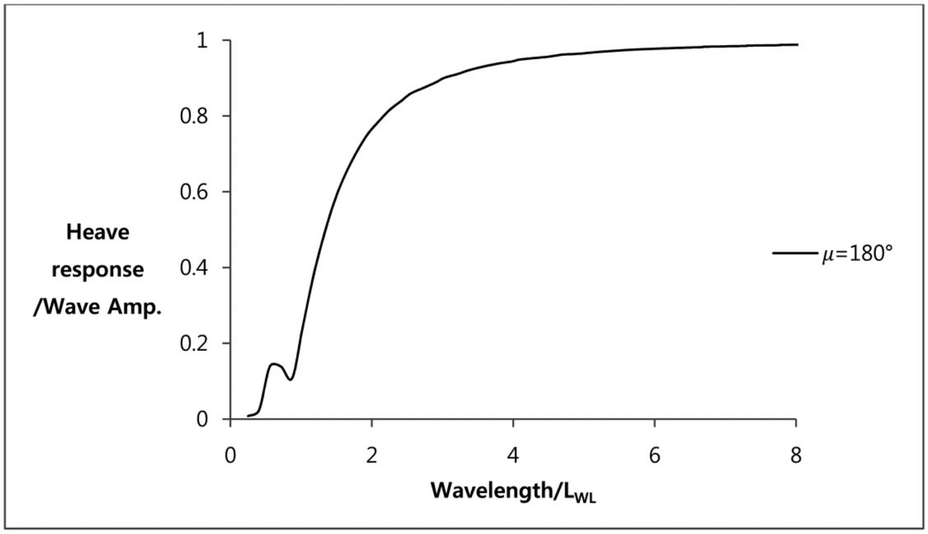

Fig. 3 Heave transfer function for Fn=0, for G11.

Table 5 Characteristics of east mediterranean sea at SS 3.

SS	$H_{1/3}(m)$	$T_m(s)$
3	0.88	6.25

Prediction of motions

It is very common to use 2D and 3D analytical methods on prediction of ship responses in operational sea environment. At the short-term analyses, average, observed and most frequent motion amplitudes are obtained by the help of response function curve which is plotted with superposition RAO and wave spectrum curve (Figs. 4-6). This procedure is applied with Eq. (1). Response function curve must be plotted in the case of head waves and vertical responses. Maximum Fn is taken as 0.3 because the gulets are displacement type boats and Fn is a limiting factor for the strip theory.

$$S_z(\omega_e) = S_\zeta(\omega_e) \times |RAO_Z|^2 \tag{1}$$

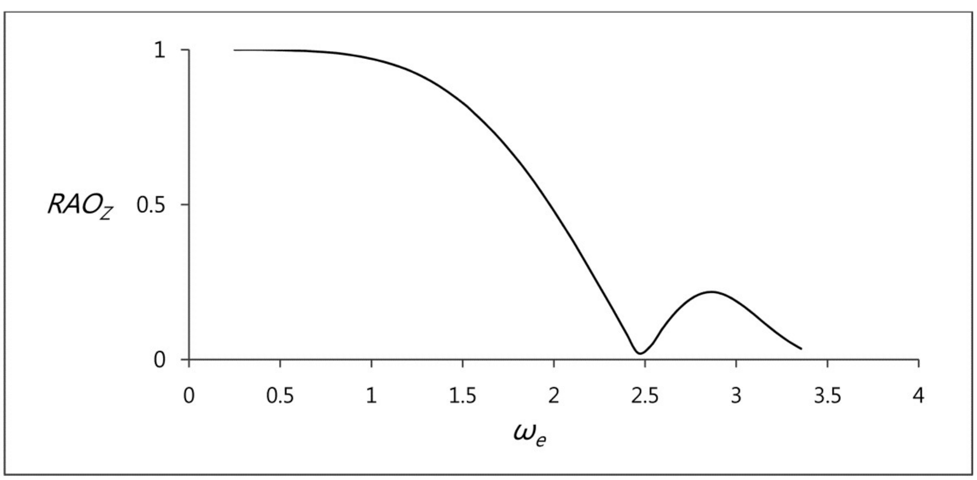

Fig. 4 Typical RAO curve.

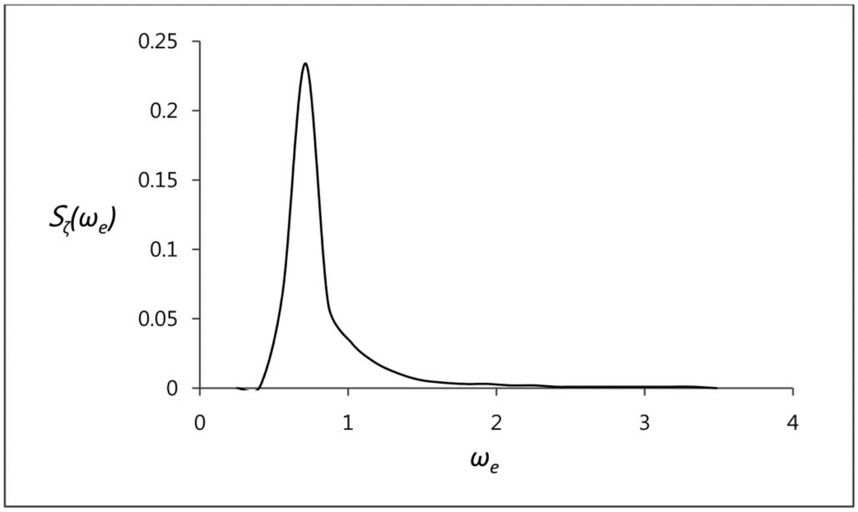

Fig. 5 Typical wave spectrum curve.

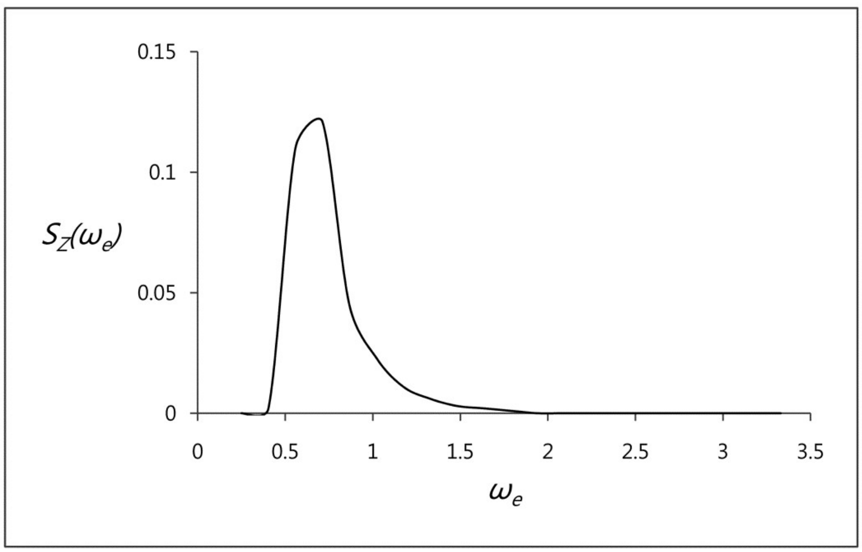

Fig. 6 Typical response curve.

MULTIPLE REGRESSION ANALYSES

The multiple regression equation is derived from the Least Squared Method and it is alike two variable regression analyses. Instead of a single independent variable, two or more independent variables are used to find a dependent variable values. The multiple regression equation is given Eq. (2):

$$P = A_0 + A_1X_1 + A_2X_2 + \cdots + A_nX_n \tag{2}$$

where P is and estimated dependent variable which represents RMS values of specified responses in case of head waves. Independent variables must represent dependent variables very well. Otherwise obtained results might be not adoptable. Used regression models are based on main dimensions and hydrostatic values since ship motions are generally are function of them. Therefore X_1, $X_2 \cdots, X_n$ independent variables represent main dimensions and their proportions, form coefficients etc. On the other hand A_1, $A_2 \cdots$, A_n coefficients are regression coefficients which shows how independent variables affects dependent variables. These all variables should be written in matrix format in Eq. (3) to calculate regression coefficients.

$$X = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1m} \\ 1 & x_{21} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & \cdots & x_{nm} \end{bmatrix} \quad P = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix}$$

$$A = \begin{bmatrix} A_0 \\ A_1 \\ \vdots \\ A_m \end{bmatrix} \tag{3}$$

Eq. (4) must be solved to find matrix of the regression coefficients.

$$A = \left(X^T X\right)^{-1} \left(X^T P\right) \tag{4}$$

while m shows number of independent variables n shows number of equation. X^T represents transpose of X matrix. Number of independent variables, m, is determined from selected regression model. In this respect, multiple regression coefficients are computed by using regression solver software with a very high R^2. 21 equations are solved for each response and regression model. Recommended regression models are given next chapter.

Recommended regression models

Three different regression models are presented for the purpose of determining effects of independent variables on dependent variables. These regression models are given in Table 6. Dependent variables which are used in regression analyses are RMS responses of specified ship motions at SS3 for displacement normalized gulets. Computed RMS values represent most frequent motion amplitudes at SS3. Besides, computations are repeated for each model for seven different Froude number (Fn =0:0.05:0.3).

Table 6 Used models for regression analyses.

Model number	Used parameters
1	L_{WL}/B_{WL}, B_{WL}/T, $L_{WL}/\left(\nabla^{1/3}\right)$
2	L_{WL}/B_{WL}, B_{WL}/T, $L_{WL}/\left(\nabla^{1/3}\right)$, C_{WP}, C_{VP}, C_P
3	L_{WL}/B_{WL}, B_{WL}/T, $L_{WL}/\left(\nabla^{1/3}\right)$, C_{WP}, C_{VP}, C_P, L_{CB}/L_{OA}, L_{CF}/L_{OA}

while Model 1 consists of only main dimension proportions, Model 2 additively consist of C_{WP}, C_{VP} and C_P hydrostatic form coefficients. Model 3 contains main dimension proportions, hydrostatic form coefficients and L_{CB} - L_{CF} locations as addition. Adequate consideration of models is extremely important to evaluate multiple form parameters at this kind of analyses. Therefore number of models is selected as three.

Multiple regression equations for Model 1;

$$\text{RMS Heave} = A_0 + \frac{L_{WL}}{B_{WL}} A_1 + \frac{B_{WL}}{T} A_2 + \frac{L_{WL}}{\nabla^{1/3}} A_3 \tag{5}$$

$$\text{RMS Pitch} = B_0 + \frac{L_{WL}}{B_{WL}} B_1 + \frac{B_{WL}}{T} B_2 + \frac{L_{WL}}{\nabla^{1/3}} B_3 \tag{6}$$

$$\text{RMS Vertical Acce. At the Saloon} = C_0 + \frac{L_{WL}}{B_{WL}} C_1 + \frac{B_{WL}}{T} C_2 + \frac{L_{WL}}{\nabla^{1/3}} C_3 \tag{7}$$

Multiple regression equations for Model 2;

$$\text{RMS Heave} = A_0 + \frac{L_{WL}}{B_{WL}} A_1 + \frac{B_{WL}}{T} A_2 + \frac{L_{WL}}{\nabla^{1/3}} A_3 + C_{WP} A_4 + C_{VP} A_5 + C_P A_6 \tag{8}$$

$$\text{RMS Pitch} = B_0 + \frac{L_{WL}}{B_{WL}} B_1 + \frac{B_{WL}}{T} B_2 + \frac{L_{WL}}{\nabla^{1/3}} B_3 + C_{WP} B_4 + C_{VP} B_5 + C_P B_6 \tag{9}$$

$$\text{RMS Vertical Acce. At the Saloon} = C_0 + \frac{L_{WL}}{B_{WL}} C_1 + \frac{B_{WL}}{T} C_2 + \frac{L_{WL}}{\nabla^{1/3}} C_3 + C_{WP} C_4 + C_{VP} C_5 + C_P C_6 \tag{10}$$

Multiple regression equations for Model 3;

$$\text{RMS Heave} = A_0 + \frac{L_{WL}}{B_{WL}} A_1 + \frac{B_{WL}}{T} A_2 + \frac{L_{WL}}{\nabla^{1/3}} A_3 + C_{WP} A_4 + C_{VP} A_5 + C_P A_6 + L_{CB} A_7 + L_{CF} A_8 \tag{11}$$

$$\text{RMS Pitch} = B_0 + \frac{L_{WL}}{B_{WL}} B_1 + \frac{B_{WL}}{T} B_2 + \frac{L_{WL}}{\nabla^{1/3}} B_3 + C_{WP} B_4 + C_{VP} B_5 + C_P B_6 + L_{CB} B_7 + L_{CF} B_8 \tag{12}$$

$$\text{RMS Vertical Acce. At the Saloon} = C_0 + \frac{L_{WL}}{B_{WL}} C_1 + \frac{B_{WL}}{T} C_2 + \frac{L_{WL}}{\nabla^{1/3}} C_3 + C_{WP} C_4 + C_{VP} C_5 + C_P C_6 + L_{CB} C_7 + L_{CF} C_8 \tag{13}$$

Computed regression coefficients can be found Tables 7-15. While Tables 7-9 show regression coefficients for Model 1, Tables 10-12 show regression coefficients for Model 2. Finally Tables 13-15 present regression coefficients for Model 3.

Table 7 Regression coefficients for heave motion for Model 1.

$\text{RMS Heave} = A_0 + \frac{L_{WL}}{B_{WL}} A_1 + \frac{B_{WL}}{T} A_2 + \frac{L_{WL}}{\nabla^{1/3}} A_3$					
Fn	A_0	A_1	A_2	A_3	R_2
0	0.0545	-0.0517	-0.0186	0.0736	0.9927
0.05	0.0856	-0.0472	-0.0200	0.0648	0.9906
0.1	0.0575	-0.0517	-0.0186	0.0736	0.9927
0.15	-0.0330	-0.0716	-0.0255	0.1120	0.9918
0.20	-0.0893	-0.0858	-0.0334	0.1396	0.9702
0.25	-0.3042	-0.1328	-0.0497	0.2293	0.9668
0.30	-0.4800	-0.1709	-0.0638	0.3029	0.9504

Table 8 Regression coefficients for pitch motion for Model 1.

$\text{RMS Pitch} = B_0 + \frac{L_{WL}}{B_{WL}} B_1 + \frac{B_{WL}}{T} B_2 + \frac{L_{WL}}{\nabla^{1/3}} B_3$					
Fn	B_0	B_1	B_2	B_3	R^2
0	-7.3040	-2.3830	-0.8588	4.0664	0.9839
0.05	-9.7393	-2.9762	-1.1268	5.1677	0.9748
0.1	-11.9409	-3.4966	-1.3631	6.1437	0.9654
0.15	-26.7037	-6.0890	-1.4295	11.1711	0.8807
0.20	-14.3716	-4.0955	-1.6998	7.2662	0.9578
0.25	-14.7846	-4.2065	-1.7856	7.4688	0.9574
0.30	-13.3589	-3.8644	-1.6367	6.8177	0.9168

Table 9 Regression coefficients for vertical acceleration at saloon for Model 1.

$\text{RMS Vertical Acce. At the Saloon} = C_0 + \frac{L_{WL}}{B_{WL}} C_1 + \frac{B_{WL}}{T} C_2 + \frac{L_{WL}}{\nabla^{1/3}} C_3$					
Fn	C_0	C_1	C_2	C_3	R^2
0	-0.0517	-0.1355	-0.0367	0.1950	0.9950
0.05	-0.2011	-0.1994	-0.0779	0.3031	0.9952
0.1	-0.4558	-0.2758	-0.1069	0.4356	0.9939
0.15	-0.6609	-0.3546	-0.1571	0.5726	0.9884
0.20	-1.0424	-0.4574	-0.2004	0.7615	0.9830
0.25	-1.4407	-0.5643	-0.2498	0.9613	0.9709
0.30	-1.8442	-0.6769	-0.3054	1.1698	0.9515

Table 10 Regression coefficients for heave motion for Model 2.

$\text{RMS Heave} = A_0 + \frac{L_{WL}}{B_{WL}} A_1 + \frac{B_{WL}}{T} A_2 + \frac{L_{WL}}{\nabla^{1/3}} A_3 + C_{WP} A_4 + C_{VP} A_5 + C_P A_6$								
Fn	A_0	A_1	A_2	A_3	A_4	A_5	A_6	R^2
0	0.1892	-0.0040	0.0039	-0.0088	-0.0881	0.0036	0.1437	0.9950
0.05	0.0664	-0.0322	-0.0124	0.0205	-0.0536	0.1073	0.2320	0.9929
0.1	0.1922	-0.0040	0.0039	-0.0088	-0.0881	0.0036	0.1437	0.9950
0.15	0.3340	0.0032	-0.0001	-0.0094	-0.0104	-0.0453	-0.1414	0.9933
0.20	0.2877	0.0002	-0.0122	-0.0523	0.0322	0.2468	0.0813	0.9826
0.25	-0.1677	-0.0806	-0.0352	0.0892	-0.0254	0.2872	0.3187	0.9853
0.30	-0.3592	-0.1025	-0.0361	0.1399	-0.1188	0.2617	0.4888	0.9813

Table 11 Regression coefficients for pitch motion for Model 2.

$$\text{RMS Pitch} = B_0 + \frac{L_{WL}}{B_{WL}} B_1 + \frac{B_{WL}}{T} B_2 + \frac{L_{WL}}{\nabla^{1/3}} B_3 + C_{WP} B_4 + C_{VP} B_5 + C_P B_6$$

Fn	B_0	B_1	B_2	B_3	B_4	B_5	B_6	R^2
0	-8.6818	-2.4191	-1.0390	2.9659	0.8044	0.8044	5.9203	0.9929
0.05	-10.0274	-2.8042	-1.3376	3.2939	1.5473	9.0038	6.5744	0.9904
0.10	-9.9209	-2.8825	-1.5042	3.2330	2.1334	10.5508	6.3092	0.9877
0.15	-16.4370	-1.9344	2.3919	11.873	-21.8250	-44.4930	-5.9979	0.9389
0.20	-9.5078	-2.8879	-1.6999	3.0911	2.4810	11.9083	6.1655	0.9872
0.25	-7.1874	-2.5469	-1.6897	2.4699	3.0336	12.1330	4.4162	0.9882
0.30	1.6896	-0.0944	-0.3091	-0.2735	-2.0444	-0.2735	3.1700	0.9533

Table 12 Regression coefficients for vertical acceleration at saloon for Model 2.

$$\text{RMS Vertical Acce. At the Saloon} = C_0 + \frac{L_{WL}}{B_{WL}} C_1 + \frac{B_{WL}}{T} C_2 + \frac{L_{WL}}{\nabla^{1/3}} C_3 + C_{WP} C_4 + C_{VP} C_5 + C_P C_6$$

Fn	C_0	C_1	C_2	C_3	C_4	C_5	C_6	R^2
0	-0.8767	-0.2279	-0.0393	0.3510	-0.3338	0.0333	0.9812	0.9960
0.05	-1.1753	-0.3420	-0.1212	0.4669	-0.1189	0.4796	1.0641	0.9966
0.10	-0.8529	-0.3270	-0.1451	0.3768	0.1060	0.8430	0.8108	0.9965
0.15	-0.1670	-0.2458	-0.1562	0.2189	0.2373	0.9433	0.3705	0.9926
0.20	-0.1075	-0.2496	-0.1839	0.1506	0.3412	1.4354	0.5476	0.9940
0.25	0.2188	-0.2129	-0.2041	0.0341	0.4746	1.8202	0.4603	0.9917
0.30	0.8309	-0.1650	-0.2583	-0.1820	0.9271	2.6512	0.1039	0.9877

Table 13 Regression coefficients for heave motion for Model 3.

$$\text{RMS Heave} = A_0 + \frac{L_{WL}}{B_{WL}} A_1 + \frac{B_{WL}}{T} A_2 + \frac{L_{WL}}{\nabla^{1/3}} A_3 + C_{WP} A_4 + C_{VP} A_5 + C_P A_6 + L_{CB} A_7 + L_{CF} A_8$$

Fn	A_0	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	R^2
0	-0.1561	-0.0543	-0.0205	0.0753	-0.1341	0.1031	0.2632	0.1370	0.0792	0.9961
0.05	-0.3961	-0.1203	-0.0552	0.1697	-0.0452	0.2393	0.215	0.3003	-0.0360	0.9950
0.10	-0.1532	-0.0543	-0.0203	0.0756	-0.1342	0.1036	0.2632	0.1370	0.0790	0.9961
0.15	0.4710	0.0064	0.0026	-0.0130	0.0640	-0.0855	-0.3313	0.0400	-0.1461	0.9952
0.20	0.3501	-0.0211	-0.0210	-0.0132	0.1430	0.228	-0.2001	0.1473	-0.2240	0.9890
0.25	0.0462	-0.0661	-0.0274	0.0660	0.0590	0.225	0.1025	0.0092	-0.1640	0.9908
0.30	0.1936	-0.0195	0.0041	0.0006	-0.0501	0.102	0.3206	-0.2337	-0.1088	0.9876

Table 14 Regression coefficients for pitch motion for Model 3.

RMS Pitch = $B_0 + \frac{L_{WL}}{B_{WL}} B_1 + \frac{B_{WL}}{T} B_2 + \frac{L_{WL}}{\nabla^{1/3}} B_3 + C_{WP} B_4 + C_{VP} B_5 + C_P B_6 + L_{CB} B_7 + L_{CF} B_8$									
Fn	B_0	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	R^2
0	-2.1020	-1.4951	-0.5810	1.4210	1.8001	4.7609	3.3661	-2.4189	-1.7430	0.9954
0.05	-2.4291	-1.7502	-0.8150	1.5330	2.7422	6.8176	3.5105	-2.7178	-2.1051	0.9938
0.10	-0.8902	-1.6291	-0.8821	1.1391	3.5515	7.9525	2.6737	-3.2341	-2.4976	0.9922
0.15	-45.7332	-8.2382	-0.6640	22.5910	-18.8145	-36.1001	-13.2181	23.1042	-7.2955	0.9660
0.20	-0.1130	-1.5673	-1.0452	0.8821	3.8981	9.2055	2.5299	-3.4613	-2.4797	0.9914
0.25	1.0620	-1.4254	-1.1320	0.5960	4.4055	9.7587	0.9026	-2.8271	-2.4375	0.9917
0.30	-23.8902	-4.7725	-2.5941	7.6390	-2.2612	10.7251	3.8911	15.516	-0.6811	0.9873

Table 15 Regression coefficients for vertical acceleration at saloon for Model 3.

RMS Vertical Acce. At the Saloon = $C_0 + \frac{L_{WL}}{B_{WL}} C_1 + \frac{B_{WL}}{T} C_2 + \frac{L_{WL}}{\nabla^{1/3}} C_3 + C_{WP} C_4 + C_{VP} C_5 + C_P C_6 + L_{CB} C_7 + L_{CF} C_8$									
Fn	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	R^2
0	-0.7530	-0.2061	-0.0290	0.3151	-0.3271	-0.0021	0.9641	-0.0659	-0.0077	0.9960
0.05	-1.2521	-0.3500	-0.1251	0.4812	-0.1382	0.5022	1.1131	0.0154	0.0364	0.9966
0.10	-1.5782	-0.4671	-0.2134	0.6141	0.1241	1.0501	0.7682	0.4813	-0.0698	0.9970
0.15	-0.1812	-0.2630	-0.1645	0.2496	0.2872	0.9472	0.2431	0.0934	-0.1036	0.9927
0.20	-0.6751	-0.3907	-0.2512	0.3907	0.4591	1.5971	0.2535	0.5504	-0.2660	0.9949
0.25	0.0293	-0.2991	-0.2459	0.1839	0.6470	1.8736	0.0268	0.4057	-0.3603	0.9928
0.30	0.7680	-0.2490	-0.2971	-0.0354	1.1700	2.6677	-0.5107	0.4464	-0.5001	0.9896

DISCUSSION

After researching recommended regression models it is now possible to evaluate the effects of hull geometry on seakeeping characteristics. R-squared values which specify goodness of fit are around 0.95. It is a very good prediction on determining dependent variables. It means that independent variables represent dependent variables very well. However, when Table 8 is examined; one can see a slight decreasing R-squared value. It is determined around 0.88 and corresponds to Fn=0.15 case. This situation leads to a slight difference between strip theory and recommended models that can be seen in Figs. 6(b) and Fig. 8(b). There is no specific reason for this state due to calculation of motions is dependent of so many parameters. Hull form requirements for good seakeeping for the gulets are given in Table 16:

When regression coefficients of Model 1 are investigated the effects of main dimension proportions on ship motions are seen clearly. Increasing of L_{WL} / B_{WL} and B_{WL} / T values, decreasing of $L_{WL} / \nabla^{1/3}$ values became useful to reduce heave-pitch motions and absolute vertical acceleration at saloon. In particular, being positive or negative value of regression coefficient is a solid symptom that shows how it affects. The role of the parameters given with question marks is not clear. When Model 2 is examined it is understood that higher C_{WP} lower C_{VP} and C_P values are better for heave motion. It is also seen from tables that lower C_{VP} and C_P values are better for pitch motion and vertical acceleration. Model 3 has to be checked to obtain the influence of L_{CB} and L_{CF}. These points are should be closer to bow for pitch motion. In other respects, while L_{CB} should be closer stern L_{CF} should be closer bow for the sake of heave motion and vertical acceleration. If the regression coefficient tables are observed in detail the rate of influence of parameters also could be understood. Comparing rate of influence is simply possible when each parameter is grouped each other such as separation of comparing form coefficients and L_{CB} and L_{CF}. Figs. 7-9 shows the comparison between strip theory and multiple regression calculation for gulet 11. While Fig. 7 shows respectively heave- pitch motions and vertical acceleration for Model 1, Fig. 8 shows respectively heave-pitch motions and vertical acceleration for Model 2, Fig. 9 shows respectively heave-pitch motions and vertical acceleration for Model 3. It could be easily seen from Figs. 7-9 that RMS strip theory values for heave-pitch motions and vertical acceleration are predicted very close to multiple regression computations.

Table 16 Requirement for good seakeeping.

Parameters	Heave	Pitch	Vert. Acce. At Saloon
L_{WL} / B_{WL}	High	High	High
B_{WL} / T	High	High	High
$L_{WL} / \nabla^{1/3}$	Low	Low	Low
C_{WP}	High	?	?
C_{VP}	Low	Low	Low
C_P	Low	Low	Low
L_{CB}	Aft from mid-ship	Forward from mid-ship	Aft from mid-ship
L_{CF}	Forward from mid-ship	Forward from mid-ship	Forward from mid-ship

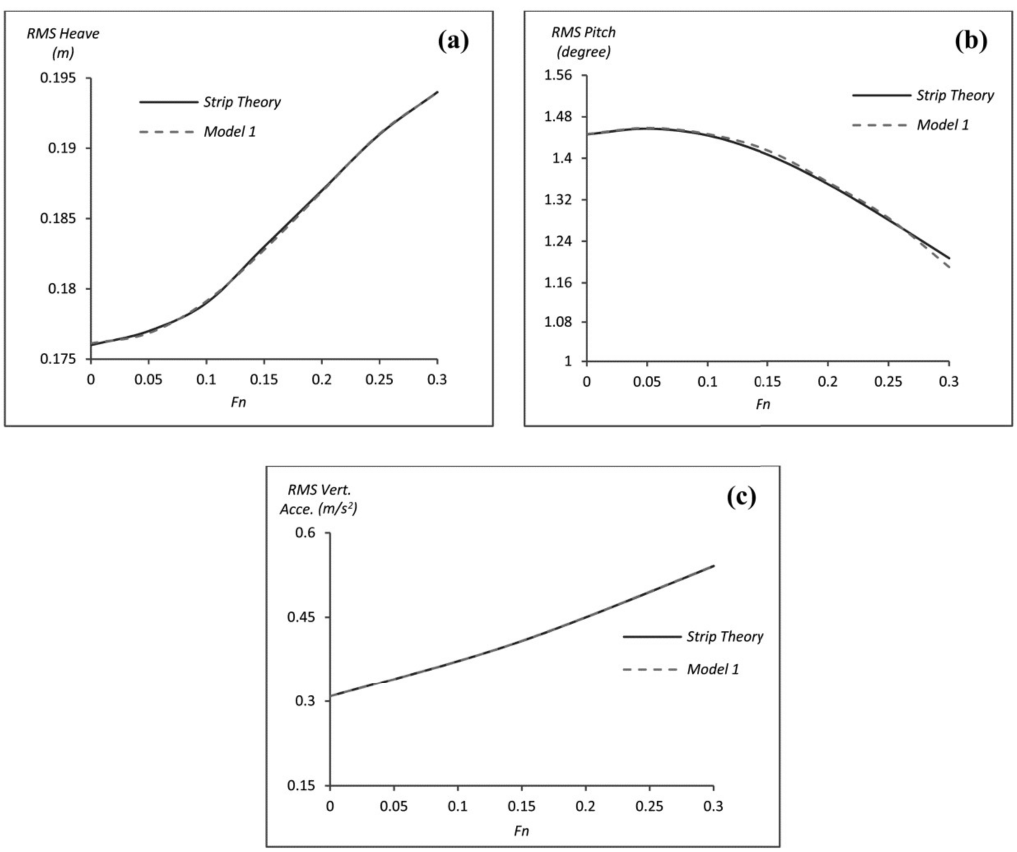

Fig. 7 (a) Model 1- heave comparison between strip theory and regression. (b) Model 1- pitch comparison between strip theory and regression. (c) Model 1- vert. acce. comparison between strip theory and regression.

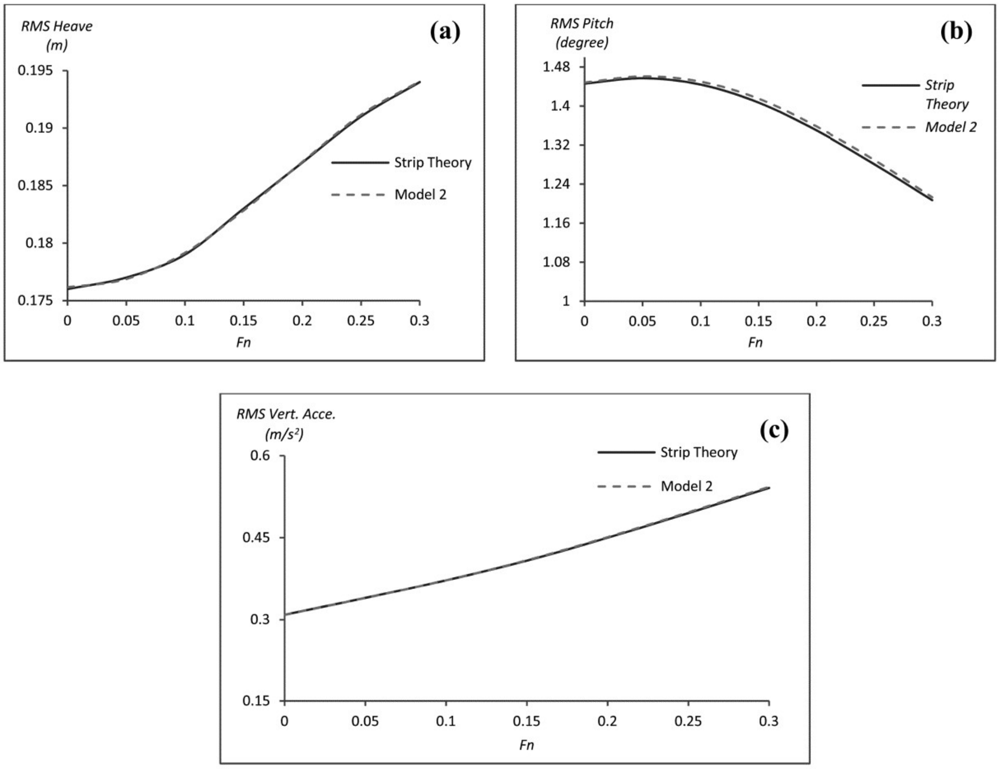

Fig. 8 (a) Model 2- heave comparison between strip theory and regression. (b) Model 2- pitch comparison between strip theory and regression. (c) Model 2- vert. acce. comparison between strip theory and regression.

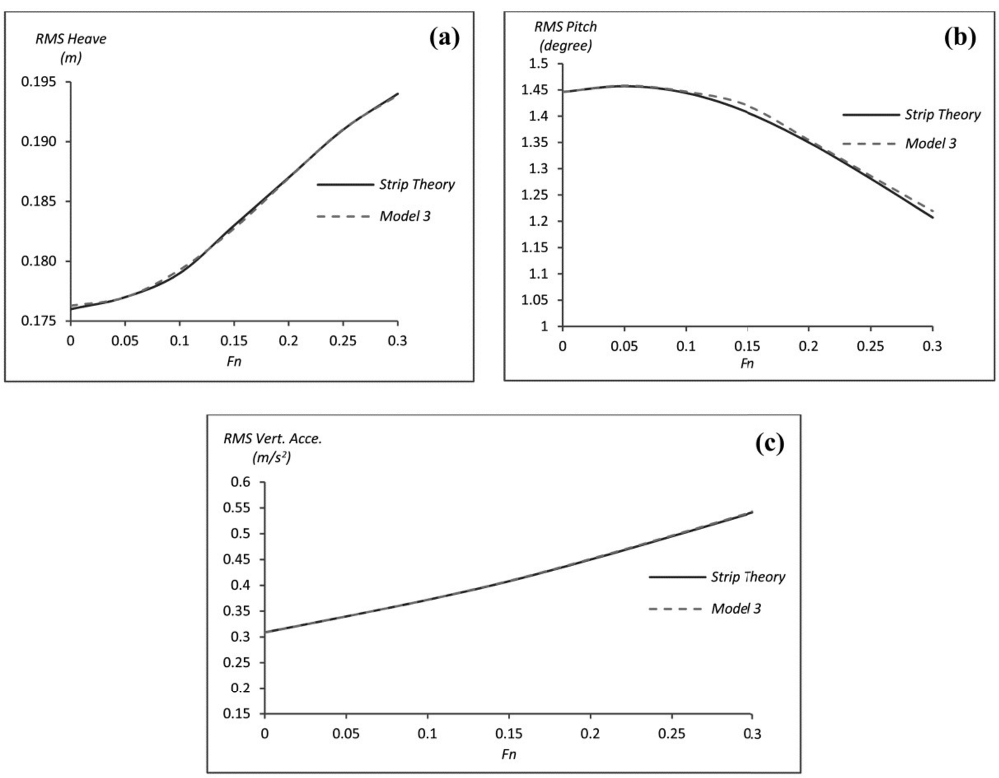

Fig. 9 (a) Model 3- heave comparison between strip theory and regression. (b) Model 3- pitch comparison between strip theory and regression. (c) Model 3- vert. acce. comparison between strip theory and regression.

CONCLUSION

The development of the effect of hull form parameters of YTU Gulets on ship motions is presented in this paper with several processes. The process started with prediction of transfer functions for 21 different gulet forms for different Froude numbers. Then these transfer functions are combined with specified spectral curve. Finally, the effects of hull form parameters are determined by the help of multiple regression method. At the end of the study, hull form requirements for good seakeeping for the gulets are determined. The comparison between strip theory and multiple regression calculations for gulet 11 is shown in figures. The obtained results ensure practical predictions of form parameter contribution to motions with a high level of accuracy that would be useful during the concept design stage. As a future work, the habitability indices of gulet type pleasure hulls will be investigated in terms of comfort on board.

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