DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

# PARAMETRIC WAVE EXCITATION OF TRADITIONAL TURKISH BOATS

by
Erkin YAĞCI

MAY, 2006
İZMİR

# PARAMETRIC WAVE EXCITATION OF TRADITIONAL TURKISH BOATS

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**by**
**Erkin YAĞCI**

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## M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"PARAMETRIC WAVE EXCITATION OF TRADITIONAL TURKISH BOATS"** completed by **ERKİN YAĞCI** under supervision of **Doç.Dr. Deniz ÜNSALAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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# PARAMETRIC WAVE EXCITATION OF TRADITIONAL TURKISH BOATS

## ABSTRACT

Parametric wave excitation of traditional Turkish boats in following or approaching sea states is presented. A sample hull form of a 30m. ‘‘Aynakic Gulet’’ is used for the analysis. The boat motions are computed in a computer program and the hull is subjected to the most critical form of the head or stern wave conditions. Both transverse and longitudinal loss of stability is examined by the help of the hydrostatic results and change of righting moment arm GZ.

**Keywords** :
Roll instability, parametric resonance, head wave, traditional gulet, Mathieu equation

# GELENEKSEL TÜRK TEKNELERİNDE PARAMETRİK DALGA UYARIMI

## ÖZ

Geleneksel Türk teknelerinde baştan veya kıçtan gelen deniz koşullarında parametrik dalga uyarımı incelenmiştir. Örnek olarak, 30m. boyundaki ‘’Aynakıç Gulet’’ formu söz konusu analizlerde kullanılmıştır. Teknenin baştan veya kıçtan gelen dalgalardaki hareketleri bilgisayar programları yardımıyla hesaplanmış ve en kritik koşullarda incelenmiştir. Enine ve boyuna stabilitedeki değişimler, hidrostatik sonuçların yardımıyla ve doğrultucu moment kolu GZ’in değişimi kriteri açısından incelenmiştir.

**Anahtar sözcükler** :
Yalpa dengesi, parametrik rezonans, baştan gelen dalga, geleneksel gulet, Mathieu denklemi

## CONTENTS

# CHAPTER ONE
# INTRODUCTION

## 1.1 Aim of the Study

The aim of this study is to give an general idea on the characteristic behaviour of traditional Turkish hull form of 'Gulet' with head or stern seas.

## 1.2 Historical Background

Parametric roll motion in head seas, capsizing and plunging due to the loss of stability in following or head seas are studied considering the influences of heave and pitch motions on the ship's righting lever curve in waves. Large amplitude of roll motions and capsizing of ships are reported to occur most likely in head or following seas. Although there seems no or little direct roll excitation, strong roll response can be induced by parametric resonance, and vanishing roll stability may lead to capsizing of the ship. Similarly, excessive values of pitching motions are likely to result in slamming or plunging into the waves. Firstly in the 19th century, famous scientist William Froude investigated the indirect roll excitation in head or following seas. He observed that a ship having a natural frequency in pitch twice its natural frequency in roll has undesirable seakeeping characteristics. Nearly a century later, Robb (1952) collected full-scale data on board a ship, which exhibited a continuous exchange of energy back and forth between the pitch and roll modes even though the wave motion was relatively constant. The mechanisms have been investigated comprehensively in theory and experiment by Grim (1952). The history of the work done by various researchers, together with their approches has been given by Oh, Nayfeh and Mook (2000) as follows:

> *It appears that no further research on these phenomena was pursued until Kerwin (1955) used the Mathieu equation to study wave-excited roll motions. Paulling & Rosenberg (1959) then developed a set of nonlinearly coupled*

*equations of motion to represent the motion of a vessel that was free only to pitch and roll. They neglected damping, the nonlinear efect of the roll mode on the pitch moment, and forcing terms, and derived the Mathieu equation, which they used to show that unstable roll motions can occur for certain frequency ratios. Kinney (1961) added a linear damping term to the roll equation and essentially repeated their analysis. Bass (1982) investigated the influence of heave-induced variations of the metacentric height, which depended on time and roll angle, on the response of a biased ship in large-amplitude beam waves. Blocki (1980) added nonlinear damping and a non-linear restoring moment to the roll equation and used the result to investigate the probability of capsizing. Feat & Jones (1984) used a simple Dufing-type oscillator with a softening cubic nonlinearity as a model for heave-induced roll motions.*

*Extending Blocki's work, Sanchez and Nayfeh (1990) investigated the qualitative behaviour of rolling in head or following waves. They used an analytical-numerical technique based on the method of multiple scales to predict the qualitative changes taking place as one of the parameters is slowly changed. They conformed their results, which included complicated responses, by using both analogue and digital computer simulations.*

Interesting experimental and theoretical studies into the phenomenon of parametric resonance of trimaran models were performed at the university College of London by D.C.Fellows (Zucker, 2000). A general procedure for the analytical approximation of the restoring arm in regular longitudinal waves is presented and nonlinear parametric rolling in regular waves are studied in University of Trieste (Bulian, 2004).

## 1.3 Theory

Stability in longitudinal seas is subject to a continous change because the waterplane area changes as the ship progresses through the waves. Calculations and experiments show that the maximum influence of longitudinal waves on ship stability occurs when the wave length is approximately equal to that of the ship waterline (Biran, 2003). The two edge points of the wave, while it is travelling along the ship are the wave through and wave crest. In wave trough condition, i.e., when the amidships is in wave trough, the waterplane area is much larger than the area in wave crest condition. Therefore, the $GM_T$ value is higher which results in a more stable condition. Contradictingly, when the amidships is on a wave crest, the waterplane area reaches to a minimum value and this results in smaller $GM_T$ values with respect to wave through conditions which in turn results as a decrease in stability. If this stability variation occurs twice during one natural roll period, parametric resonance starts and large angle of amplitude motions begin.

In order to tell the mathematical and phsical mechanism in the background, a single degree of freedom model can be used. Mathieu equation can be used to describe our roll motion problem. For simplicity, the damping factor of the roll motion is neglected and only longitudinal waves are taken into account. $GM_T$ is assumed to be the sum of the calm water metacenteric height and the component changing sinusoidally with the frequency of encounter (Unsalan, 2006)

$$\ddot{\varphi} + \frac{g}{k^2}(\overline{GM_{T,0}} + \delta\overline{GM_T} \cos \omega_e t)\varphi = 0 \qquad (1)$$

using the transformation $\chi = \frac{1}{2}\omega_e t$ and the relation for natural frequency of roll,

$$\omega_{n,r} = \frac{\sqrt{g.GM_{T,0}}}{k_T} \qquad (2)$$

where $k_T$ is the radius of gyration of the ship for rolling motion, the equation:

$$\frac{d^2\varphi}{d\chi^2} + \left[4\left(\frac{\omega_{n,r}}{\omega_e}\right)^2 + 4\left(\frac{\omega_{n,r}}{\omega_e}\right)^2 \frac{\delta\overline{GM_T}}{GM_{T,0}} \cos 2\chi\right]\varphi = 0 \qquad (3)$$

is obtained. This equation is a form of the Matieu differential equation

$$\frac{d^2\varphi}{d\chi^2} + (\alpha - 2\beta \cos 2\chi)\varphi = 0 \qquad (4)$$

where:

$$\alpha = 4\left(\frac{\omega_{n,r}}{\omega_e}\right)^2 \qquad (5)$$

and

$$\beta = -2\left(\frac{\omega_{n,r}}{\omega_e}\right)^2 \frac{\delta\overline{GM_T}}{GM_{T,0}} \qquad (6)$$

Mathieu equation has regions of stable and unstable solutions. In the latter case, the solution becomes unbounded. Those regions are shown in the so-called 'Strut-Ince diagram', shown in figure 1.1

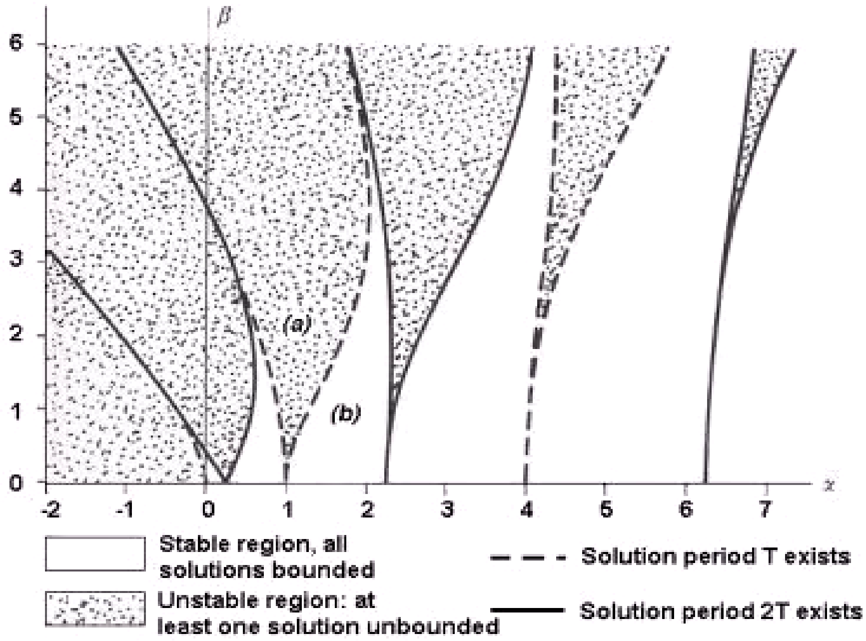


Figure 1.1. Strut-Ince diagram, showing regions of stable(shaded) and unstable(unshaded) solutions

The worst case, as demonstrated both by model tests(Oh et al, 2000) and by reported actual experience(Biran, 2003) is the case for $\alpha = 1$, or the period of encounter of the waves being half of the natural roll period.

Similar considerations also hold for the pitching and heave oscillations. Mathieu equation for the pitch becomes:

$$\frac{d^2\theta}{d\chi^2} + (\alpha - 2\beta\cos 2\chi)\theta = 0 \qquad (7)$$

where:

$$\alpha = 4\left(\frac{\omega_{n,p}}{\omega_e}\right)^2 \tag{8}$$

and

$$\beta = -2\left(\frac{\omega_{n,p}}{\omega_e}\right)^2 \frac{\delta \overline{GM_L}}{GM_{L,0}} \tag{9}$$

$$\omega_{n,h} = \frac{\sqrt{g \cdot GM_{L,0}}}{k_L} \tag{10}$$

where $GM_{L,0}$ is the longitudinal metacentric height and $\delta GM_L$ is its variation in waves and $k_L$ is the radius of gyration of the ship for pitchng motion.

The form of Mathieu equation for a pure heaving motion can, similarly be written as:

$$\frac{d^2 z}{d\chi^2} + \left[4\left(\frac{\omega_{n,h}}{\omega_e}\right)^2 + 4\left(\frac{\omega_{n,h}}{\omega_e}\right)^2 \frac{\delta A_{WL}}{A_{WL,0}} cos\, 2\chi\right] z = 0 \tag{11}$$

where $A_{WL}$ is thewaterline area and the natural frequency of heaving motion is:

$$\omega_{n,h} = \sqrt{\frac{\rho g A_{WL}}{m + m_a}} \tag{12}$$

For heaving of a fine-form vessel, added mass can be taken equal to 0.6m (Sabuncu, 1993).

# CHAPTER TWO
# SAMPLE TRADITIONAL GULET IN LONGITUDINAL SEA

## 2.1 Main Characteristics Of The Sample Vessel

Gulets are the traditional boats of Mediterranean Sea. Their origin has been an area of dispute, but it is certain that they are totally accepted and used for centuries long in Mediterranean coast. Traditionally, they were used as fishing or cargo carrying boats. However, 99 % of present day gulets are used as pleasure vessels. Their authentic and classic look attracts the classic yacht lovers, enthusiasts and tourists. Their shape may be described as a full keel motor-sailor with an exaggerated bow flare. Aynakic Gulets are newly developped forms of classic gulets, for the need of larger interior volumes for guest accomodations. Their form is nearly the same of gulets except their transom sterns.

In this study, a 30.0m. Aynakic Gulet will be used as a sample vessel. The general dimensions of the boat is as follows;

$L_{OA}$ =30.0m.
$L_{WL}$ = 25.93m.
B = 7.80m.
$B_{WL}$ = 7.33m.
T = 3.00m.
$\Delta$. = 137.8 tonnes
LCB = 12.98m. (From zero point)
$C_P$ = 0.590 (Prismatic coefficient)
$C_B$ = 0.246 (Block coefficient)
$C_M$ = 0.409 (Midship area coefficient)
$GM_{T,0}$ = 2.758 m.
$GM_{L,0}$ = 37.21 m.
Waterplane area = 138.35m$^2$
Wetted surface area = 205.8m$^2$

* All the dimensions are given according to ‘zero point’ , where zero point is located

at intersection of aft extermity and baseline.

* Sea water density taken as 1025 kg/m$^3$

*The loading condition is specified for all the calculations as follows;

Full load displacement = 137.8 tonnes

LCG = 12.98m.

VCG = 3.50m.

TCG = 0.00m.

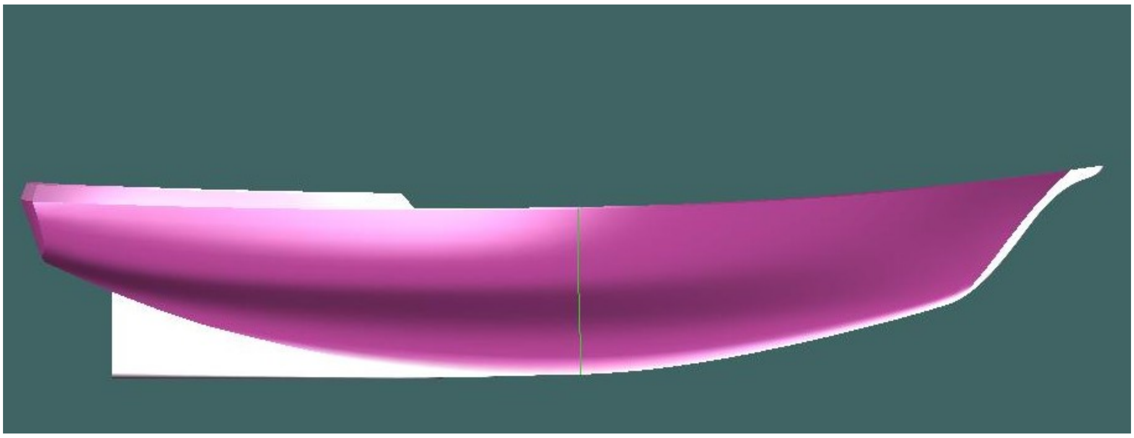


Figure 2.1 Profile view of the 3D model of the ‘Aynakic Gulet’

## 2.2 Calculation of the Parametric Wave Profile

Calculations and experiments show that the maximum influence of longitudinal waves on ship stability occurs when the wave length is approximately equal to that of the ship waterline (Biran,2003). Therefore, the extreme wave length shall be taken equal to the gulet’s waterline,

$$\lambda = L_{WL} = 25.93m. \tag{1}$$

The wave height corresponding to this length is defined by Equation (2) which is accepted by the German Navy.

$$H = \frac{\lambda}{10 + 0.05\lambda} = \frac{25.93}{10 + 0.05x25.93} = 2.295m. \tag{2}$$

The wave profile can be obtained by using the following formulation.

$$\begin{aligned} & z = T + \frac{H}{2} cos( kx - \omega_e t ) \\ & \text{where:} \\ & \omega_e .t = \Phi \\ & k = \frac{2\pi}{\lambda} = \frac{2\pi}{L_{WL}} \end{aligned} \qquad (3)$$

Here, *z* defines the height of the wave from design waterline at phase difference **Φ**. A simple and small C program is given in Appendix 1 in order to calculate the wave profile. The Calculated wave profile may be seen in Figure 2.2

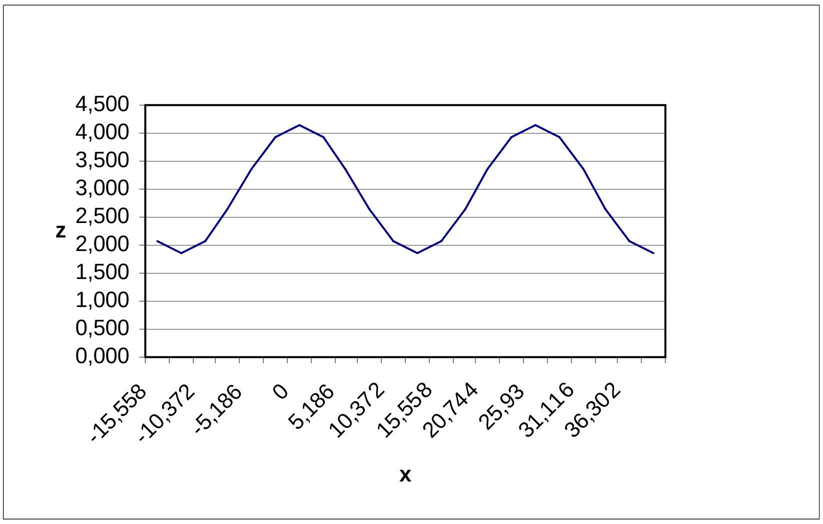
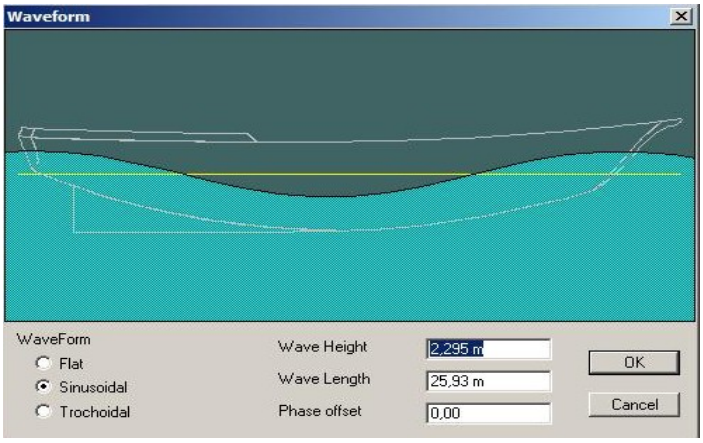


Figure 2.2 Wave profile which is generated by the program

## 2.3 Variation of $GM_T$ & $GM_L$ with the Wave Profile

An interesting feature of the longitudinal seas is that, they do not only effect the ship in longitudinal direction, but also in the transverse direction. In this section, it will be represented by graphs and tables that the transverse rightening moment arm GZ is changing by the movement of the wave through the vessel. In order to see the change in GZ, we are going to investigate the changes in GM, which is directly proportional to GZ. For the analysis, computer softwares called, Maxsurf and Hydromax were used. A graphical representation may be seen between figure 2.3 to figure 2.15



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,00

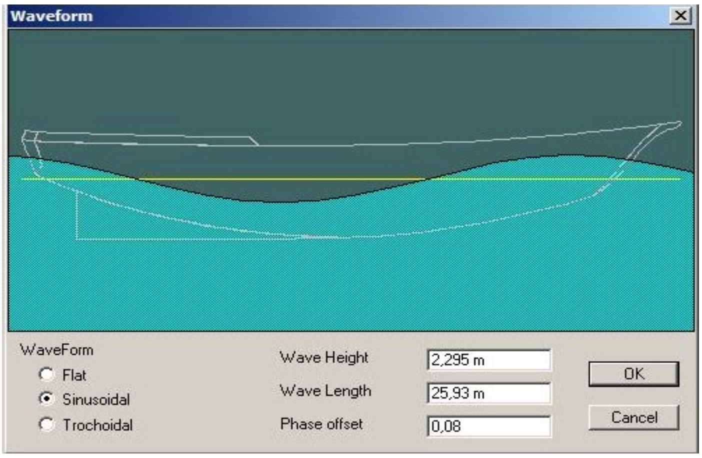
Phase Angle : $0^0$

$GM_T = 2.26$ m.

$GM_L = 61.18$ m.

$A_{WL} = 131.02\ m^2$

Figure 2.3 Wave simulation, phase angle $0^0$



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,08

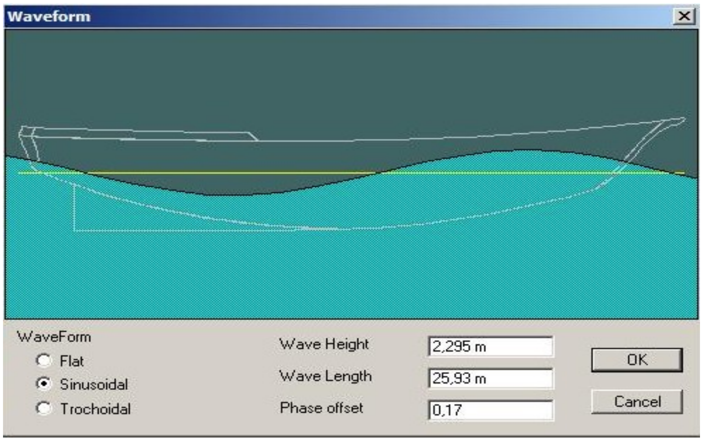
Phase Angle : $30^0$

$GM_T = 2.31$ m.

$GM_L = 65.81$ m.

$A_{WL} = 132.30\ m^2$

Figure 2.4 Wave simulation, phase angle $30^0$



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,17

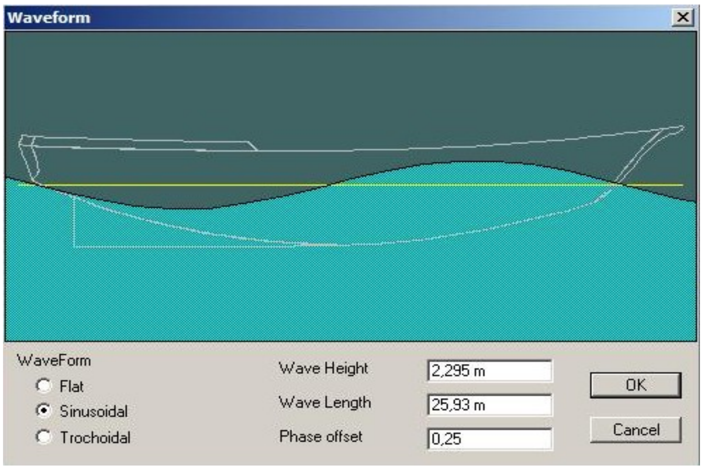
Phase Angle : $60^0$

$GM_T = 2.21$ m.

$GM_L = 52.81$ m.

$A_{WL} = 125.6\ m^2$

Figure 2.5 Wave simulation, phase angle $60^0$



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,25

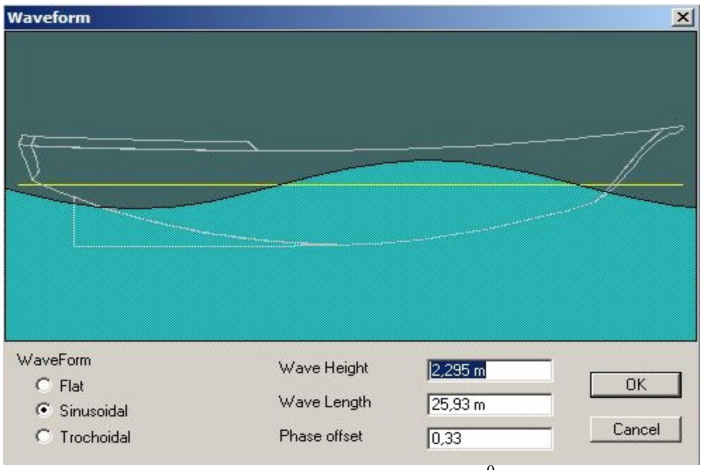
Figure 2.6 Wave simulation, phase angle $90^0$

Phase Angle : $90^0$

$GM_T = 2.10$ m.

$GM_L = 22.95$ m.

$A_{WL} = 110.3\ m^2$



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,33

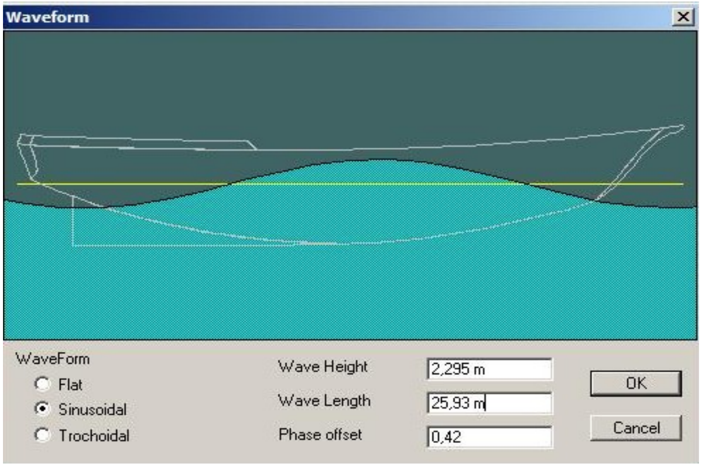
Figure 2.7 Wave simulation, phase angle $120^0$

Phase Angle : $120^0$

$GM_T = 2.16$ m.

$GM_L = 16.18$ m.

$A_{WL} = 111.9\ m^2$



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,42

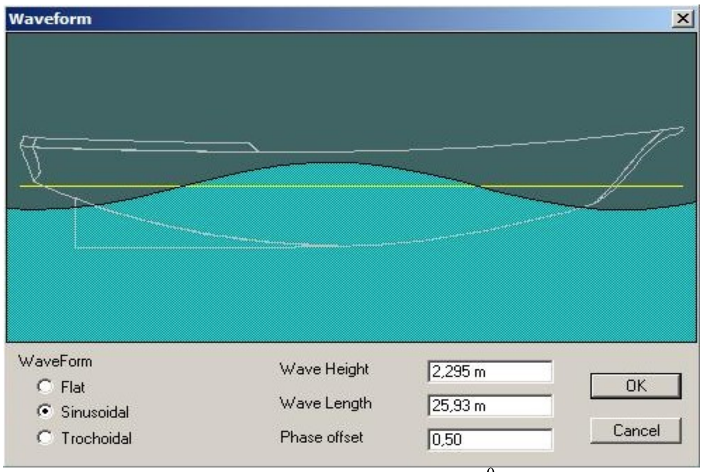
Figure 2.8 Wave simulation, phase angle $150^0$

Phase Angle : $150^0$

$GM_T = 2.17$ m.

$GM_L = 15.02$ m.

$A_{WL} = 116.3\ m^2$



WaveForm

○ Flat

● Sinusoidal

○ Trochoidal

Wave Height 2,295 m

Wave Length 25,93 m

Phase offset 0,50

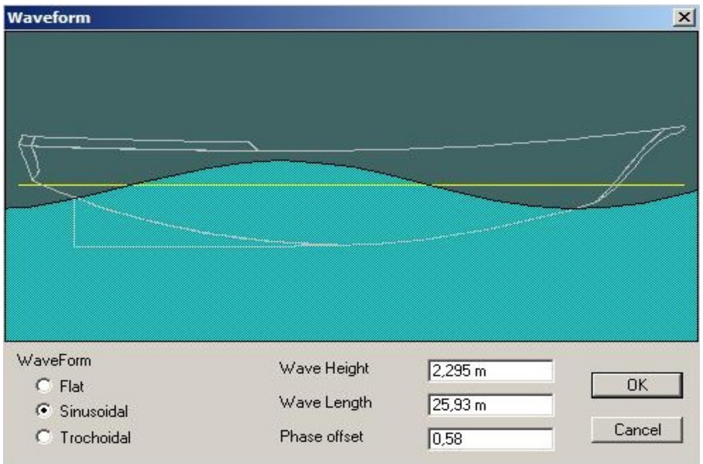
Figure 2.9 Wave simulation, phase angle $180^0$

Phase Angle : $180^0$

$GM_T = 2.16$ m.

$GM_L = 14.76$ m.

$A_{WL} = 118.7\ m^2$



WaveForm

○ Flat

● Sinusoidal

○ Trochoidal

Wave Height 2,295 m

Wave Length 25,93 m

Phase offset 0,58

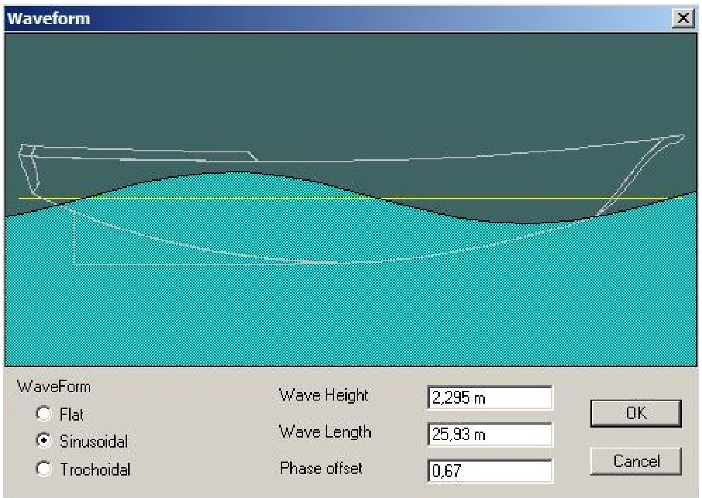
Figure 2.10 Wave simulation, phase angle $210^0$

Phase Angle : $210^0$

$GM_T = 2.18$ m.

$GM_L = 15.08$ m.

$A_{WL} = 119.8\ m^2$



WaveForm

○ Flat

● Sinusoidal

○ Trochoidal

Wave Height 2,295 m

Wave Length 25,93 m

Phase offset 0,67

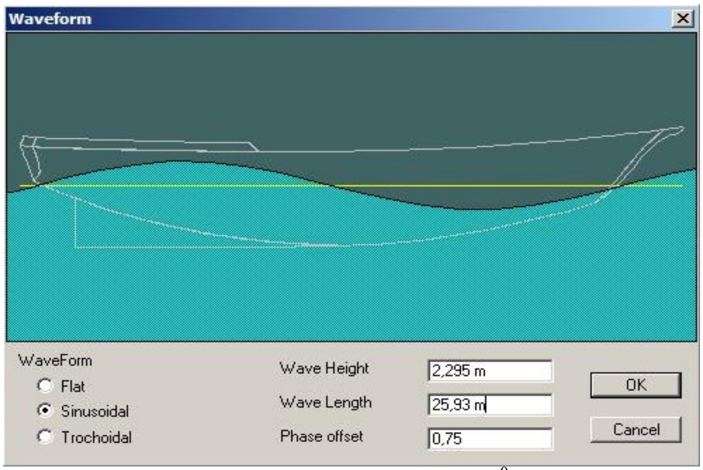
Figure 2.11 Wave simulation, phase angle $240^0$

Phase Angle : $240^0$

$GM_T = 2.23$ m.

$GM_L = 16.67$ m.

$A_{WL} = 120.1\ m^2$



WaveForm

○ Flat

● Sinusoidal

○ Trochoidal

Wave Height 2,295 m

Wave Length 25,93 m

Phase offset 0,75

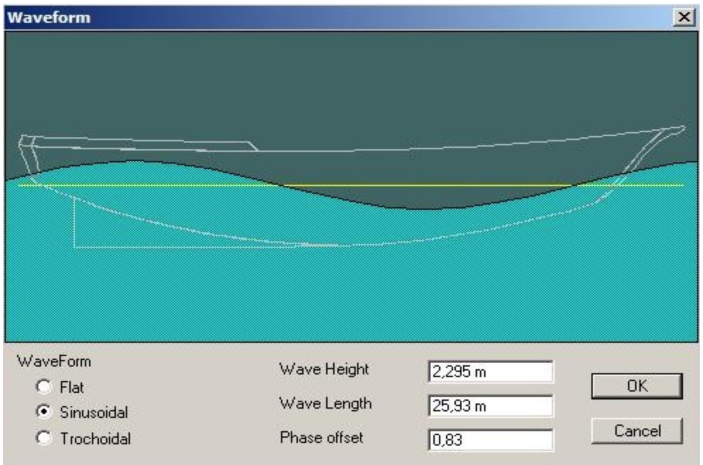
Figure 2.12 Wave simulation, phase angle $270^0$

Phase Angle : $270^0$

$GM_T = 2.28$ m.

$GM_L = 20.76$ m.

$A_{WL} = 120.8\ m^2$



WaveForm

○ Flat

● Sinusoidal

○ Trochoidal

Wave Height 2,295 m

Wave Length 25,93 m

Phase offset 0,83

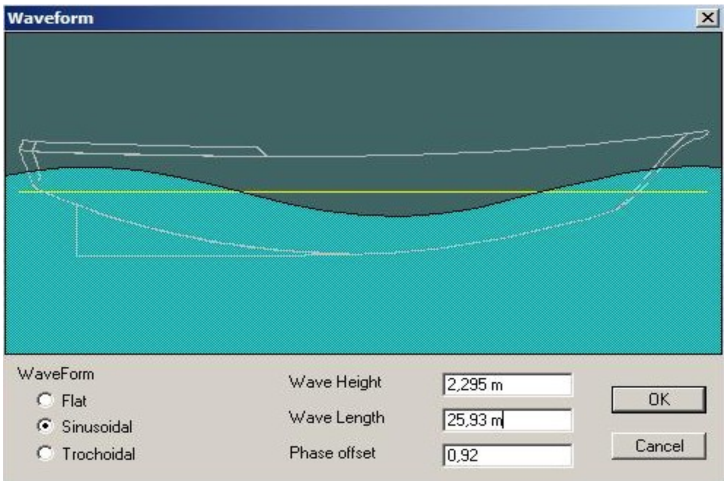
Figure 2.13 Wave simulation, phase angle $300^0$

Phase Angle : $300^0$

$GM_T = 2.30$ m.

$GM_L = 30.46$ m.

$A_{WL} = 123.2\ m^2$



WaveForm

○ Flat

● Sinusoidal

○ Trochoidal

Wave Height 2,295 m

Wave Length 25,93 m

Phase offset 0,92

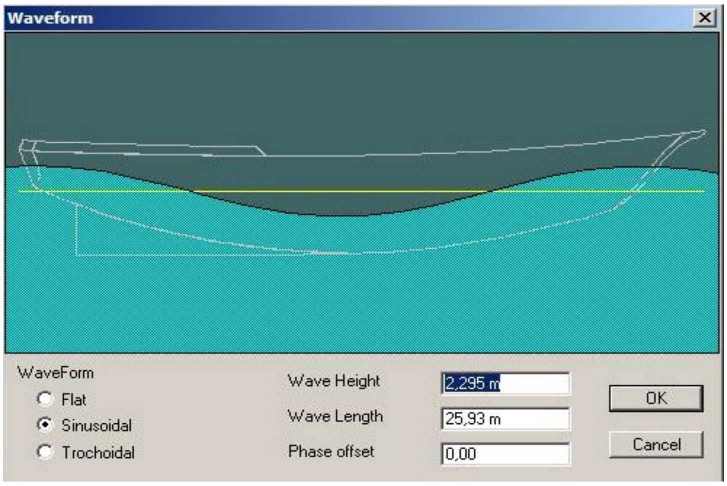
Figure 2.14 Wave simulation, phase angle $330^0$

Phase Angle : $330^0$

$GM_T = 2.25$ m.

$GM_L = 46.93$ m.

$A_{WL} = 126.8\ m^2$



WaveForm
○ Flat
● Sinusoidal
○ Trochoidal

Wave Height 2,295 m
Wave Length 25,93 m
Phase offset 0,00

Phase Angle : $360^0$

$GM_T = 2.26$ m.

$GM_L = 61.18$ m.

$A_{WL} = 131.02\ m^2$

Figure 2.15 Wave simulation, phase angle $360^0$

In the discussion above, a visual representation of wave encounter has given the reader an idea of the shape of the effective hull form at specified phase angles. A graphical comparison between the calm sea condition of $GM_T$, $GM_L$ and $A_{WL}$ can be seen in a graphical form in figures 2.16, 2.17 and 2.18, respectively.. As it may be absorved from the values and from the graph below, the most transversely stable condition for a boat is calm sea condition. If all the results are compared, it is possible to say that least stable case for a boat is 90° phase after the longitudinal encounter. In other words, the transverse stability reaches its minimum value when the wave crest is between the forward perpendicular and the midship. On the other hand, it may be easily observed that $GM_L$ finds its minimum at 180° phase angle which means just on the wave crest.

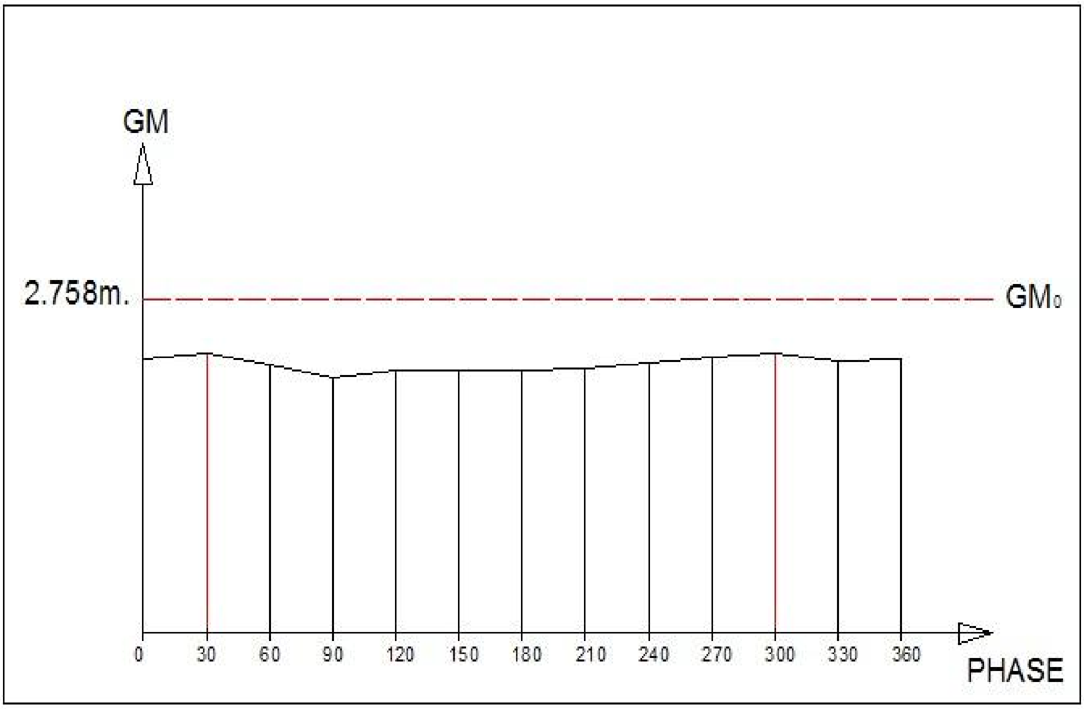


Figure 2.16 $GM_T$ (φ) with respect to $GM_{T0}$

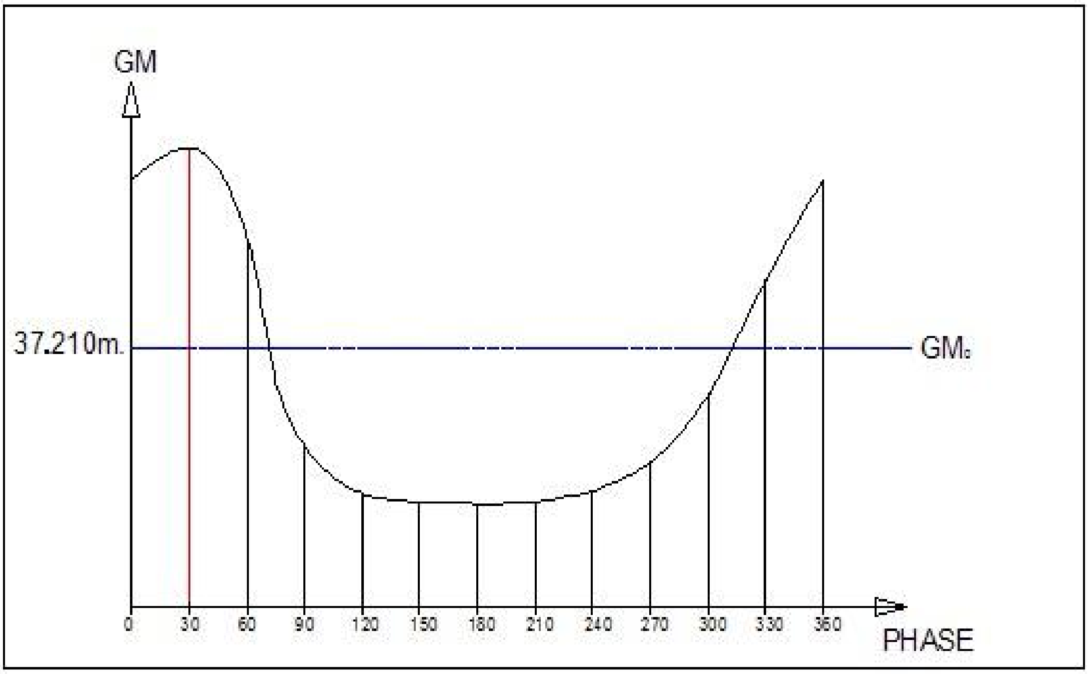


Figure 2.17 $GM_L$(φ) with respect to $GM_{L0}$

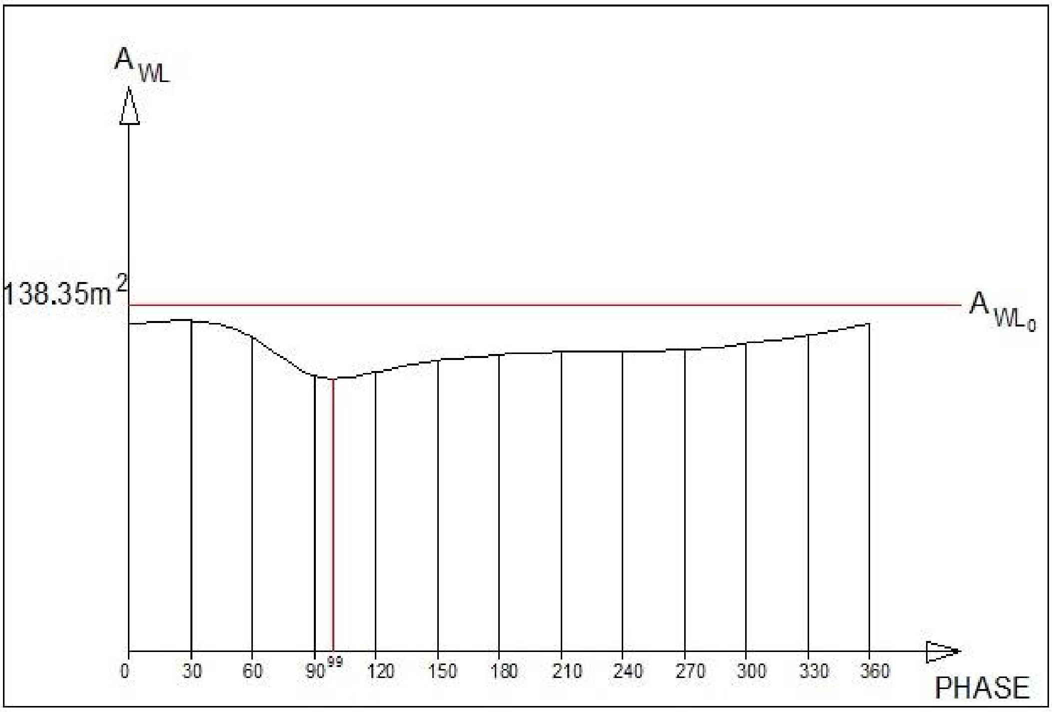


Figure 2.18 Change of waterplane area with respect to phase angle.

A tabular form of the data changing with the wave motion through the vessel is given below on table 2.1 as;

Table 2.1 Change of GM values with respect to phase angle

| $\phi$ | $GM_T(\phi)$ | $GM_T(\phi)$ / $GM_{T0}$ | $GM_L(\phi)$ | $GM_L(\phi)$ / $GM_{L0}$ | waterplane area(m2) | Wetted Surface area(m2) |
|---|---|---|---|---|---|---|
| 30 | 2.308 | 0.837 | 65.810 | 1.769 | 132.3 | 202.37 |
| 60 | 2.209 | 0.801 | 52.810 | 1.419 | 125.57 | 195.92 |
| 90 | 2.102 | 0.762 | 22.950 | 0.617 | 110.3 | 182.53 |
| 120 | 2.162 | 0.784 | 16.178 | 0.435 | 111.88 | 187.149 |
| 150 | 2.166 | 0.785 | 15.015 | 0.404 | 116.279 | 192.403 |
| 180 | 2.165 | 0.785 | 14.764 | 0.397 | 118.73 | 195.97 |
| 210 | 2.181 | 0.791 | 15.075 | 0.405 | 119.83 | 197.44 |
| 240 | 2.228 | 0.808 | 16.674 | 0.448 | 120.12 | 195.62 |
| 270 | 2.280 | 0.827 | 20.755 | 0.558 | 120.756 | 196.076 |
| 300 | 2.304 | 0.835 | 30.455 | 0.818 | 123.209 | 198.555 |
| 330 | 2.252 | 0.817 | 46.929 | 1.261 | 126.761 | 200.585 |
| 360 | 2.255 | 0.818 | 61.183 | 1.644 | 131.02 | 202.81 |

Fourier analysis for the periodic variation of $GM_T$, $GM_L$ and $A_{WP}$ were made by the help of IMSL subroutine FFTRF, which uses a fast Fourier transform algorithm:

$$g(t)=\frac{1}{N}\left[c_1+2\sum_{n=2}^{N+1/2}c_{2n-2}\,cos\frac{2\pi(n-1)t}{T}+2\sum_{n=2}^{N+1/2}c_{2n-1}\,sin\frac{2\pi(n-1)t}{T}\right] \tag{12}$$

where T is the period.

The harmonic coefficients $c_1$ to $c_{13}$ per Equation 12 are tabulated below:

Table 2.1 Harmonic coefficients

| Harmonic number | $GM_T$ | $GM_L$ | $A_{WP}$ |
|---|---|---|---|
| 1 | $-1.907\times10^{-6}$ | 0.00000 | $-0.45776\times10^{-5}$ |
| 2 | 0.2767 | 170.9371 | 44.59610 |
| 3 | 0.36656 | 5.9142 | 24.30971 |
| 4 | 0.04016 | 48.6982 | 29.99996 |
| 5 | -0.10230 | -2.33726 | -7.060555 |
| 6 | 0.08749 | -10.9190 | -3.328276 |
| 7 | -0.224399 | -13.5734 | -13.29013 |
| 8 | -0.06293 | -20.58318 | -10.43605 |
| 9 | -0.082809 | -0.02358 | -0.9989203 |
| 10 | -0.083190 | -9.894455 | -4.164115 |
| 11 | 0.046319 | 7.37081 | 5.712129 |
| 12 | -0.034264 | -0.43957 | 1.074902 |
| 13 | 0.0462594 | 4.07812 | 2.895056 |

As can be seen, the dominant values of the variations are the first harmonics ($c_2$ and $c_3$) for all three parameters.

The relative variation of the stability parameter, $\beta$ can be found from the first harmonics. Therefore, for the case of $\alpha = 1$ and for the rolling motion:

$$\beta=4\left(\frac{\omega_n}{\omega_e}\right)^2\frac{\delta GM_T}{GM_{T0}}=4\left(\frac{\omega_n}{\omega_e}\right)^2\frac{\sqrt{c_2^2+c_3^2}}{GM_{T0}}=\frac{\sqrt{0.2767^2+0.3666^2}}{2.758}=0.167 \tag{13}$$

For the pitching motion:

$$\beta=4\left(\frac{\omega_n}{\omega_e}\right)^2\frac{\delta GM_L}{GM_{L0}}=4\left(\frac{\omega_n}{\omega_e}\right)^2\frac{\sqrt{c_2^2+c_3^2}}{GM_{L0}}=\frac{\sqrt{170.937^2+5.914^2}}{27.210}=6.285 \tag{14}$$

and for the heaving motion:

$$\beta=4\left(\frac{\omega_n}{\omega_e}\right)^2\frac{\delta A_{WL}}{A_{WL0}}=4\left(\frac{\omega_n}{\omega_e}\right)^2\frac{\sqrt{c_2^2+c_3^2}}{A_{WL0}}=\frac{\sqrt{44.60^2+24.31^2}}{138.35}=0.367 \tag{15}$$

are calculated.

This analysis indicates that the "Aynakıç Gulet" hullform is susceptible to parametric resonance mainly in the pitching motion. Pitching to extreme angles can result in the plunging of the vessel into the waves or can result in slamming. Parametric excitations in rolling and heaving motions are of negligible importance, and possibly be atenuated by damping. The analysis above can be verified by towing tank results.

In order to see the critical direction (head or following) and speed at which the ship is prone to pitching, the natural frequency of pitchng has to be calculated. Radius of gyration of pitching motion can be obtained from the simple relation (Peach and Brook, 1987):

$$k_p = 0.27 L_{BP} = 7.00\, m. \tag{16}$$

Therefore, the natural period of pitchng shall be:

$$T_P = \frac{2\pi K_p}{\sqrt{g \cdot GM_L}} = 2.302\, s \tag{17}$$

Therefore, parametric resonance is likely to occur when the ship encounters waves with a period equal to half this natural period, i.e., at $T_e$ = 1.151 s. The celerity of waves expected to cause parametric excitation are, from he linear wave theory:

$$c = \sqrt{\frac{g\lambda}{2\pi}} = 6.363\, m/s \tag{18}$$

Using this equation for the period of encounter,

$$T_e = \frac{\lambda}{c - v \cdot \cos\alpha} \tag{19}$$

One gets the result $v \cos \alpha$ = -16.2 m/s, or, following waves for a ship velocity of about 31 knots- a condition which is beyond the design velocities of the gulet forms.

# CHAPTER THREE
# CONCLUSIONS

A sample Aynakic Gulet model is used to observe the effects of following or approaching seas on ship stability. The most critical form of the wave profile and frequency is selected to see the most severe condition in head or stern seas, which is defined as the wave length equal to the length waterline of the vessel and the wave encounter equal to that of twice the natural frequency of the boat. Software simulations have shown that transverse stability of the boat is not effected as much as the longitudinal stability. The $GM_T$ values are slightly decreased and show little disturbance with the effect of the longitudinal seas. However, when $GM_L$ is examined, a sudden jump was seen at $30^0$ phase angle and $GM_L$ reaches its maximum value here. A more suprising and effective phenomenon occurs just after this peak: The minimum value of $GM_L$ is observed just after this sudden increase, at $180^0$ phase angle which may result in parametric wave resonance. Another negative factor is also added in this critical area the minimum waterplane area occurs in 99 degrees of phase angle. The waterplane area comes 20 percent less with respect to the calm sea condition and makes the boat unstable for a small period of time.

The analysis of the Fourier coefficients of the three modes of motions indicate that pitching parametric resonance is the most important parametric excitation mode. However, the period of encounter of waves to excite parametric pitching resonance are likely to occur at about 31 knots- a condition that is not likely to occur under practical conditions.

If the shape of a classical gulet is examined there is a big bow flare can be seen, which may also be a damping system for longitudinal motion of the boat. As a result it may be proved that the shape of these boats are optimised in passing decades according to Mediterranean sea conditions.

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## NOMENCLATURE

| | |
|---|---|
| $A_{WL}$ | Waterplane area |
| B | Beam |
| $B_{WL}$ | Beam of the boat at waterline level |
| $C_b$ | Block coefficient |
| $C_m$ | Midship area coefficient |
| $C_P$ | Prismatic coefficient |
| g | Gravitational acceleration |
| $GM_T$ | Transverse metacentric height |
| $GM_L$ | Longitudinal metacentric height |
| H | Wave height |
| $k_p$ | Radius of gyration of pitching motion |
| $L_{AP}$ | Aft perpendicular |
| $L_{BP}$ | Forward Perpendicular |
| LCB | Longitudinal center of buoyancy |
| LCG | Longitudinal center of gravity |
| $L_{OA}$ | Over all length of the boat |
| $L_{WL}$ | Waterline lenght of the boat |
| $T_e$ | Period of encounter |
| $T_p$ | Natural pitching period |
| T | Mean draft of the boat |
| TCG | Transverse center of gravity |
| VCG | Vertical center of gravity |
| $\omega_e$ | Frequency of encounter |
| $\omega_n$ | Natural frequency of the boat |
| z | Height of the wave at different phase angles |
| $\Delta$ | Displacement of the boat |
| $\lambda$ | Wave length |
| $\phi$ | Phase difference |

| | |
|---|---|
| $\beta$ | Stability parameter |

## APPENDIX 1

A simple and small C program may be written in order to calculate the wave profile.

```
pi=4.*atan(1.)
        open(10.file= ‘e : vessel’)
        do 200 j=0 , 13
                phi=j*pi/6
                write(10,*) ‘phi= ’, phi
                print*i, ‘phi=  ’ , phi
                do 100 i=-1,20
                en=i/2
                x=2,593*en-12,965
                z=3.0+1.148*cos((2.*pix/29.53)+phi
                write(10,*)x,z
                print *,x,z
100 continue
200 continue
        close(10)
        read*,dummy
        stop
        end
```

**APPENDIX 2**

A sample program to calculate Fourier coefficients in Fortran77 programing language is listed below:

```
   USE NUMERICAL_LIBRARIES
   DIMENSION GIRDI(13),COEF(13),SEQ(13)
        GIRDI(1)=131.02
        GIRDI(2)=132.3
        GIRDI(3)=125.57
        GIRDI(4)=110.3
        GIRDI(5)=111.88
        GIRDI(6)=116.279
        GIRDI(7)=118.73
        GIRDI(8)=119.83
        GIRDI(9)=120.12
        GIRDI(10)=120.756
        GIRDI(11)=123.209
        GIRDI(12)=126.761
        GIRDI(13)=131.02
       SUM=0.0
       DO 100 K=1,13
        SUM=SUM+GIRDI(K)
100  CONTINUE
    AVG=SUM/13.
        PRINT *, "AVERAGE = ",AVG
       DO 200 L=1,13
        GIRDI(L)=GIRDI(L)-AVG
200  CONTINUE
        CALL FFTRF(13,GIRDI,COEF)
        DO 10 I=1,13
          PRINT *, I, COEF(I)
 10 CONTINUE
       READ *,DUMMY
        STOP
        END
```