TUGAS AKHIR
(KL 1702)

PREDIKSI SLAMMING PADA HYCAT AKIBAT GERAKAN KOPEL HEAVING DAN PITCHING PADA GELOMBANG ACAK

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TUGAS AKHIR

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Der Maschinist arbaitet bis zum letzten Abenzug

Der Soldat kreight bis zum letzten Atemzug

Kupersembahkan Tugas Akhir ini kepada Mama dan Papa atas segala bimbingan, doa dan kasih sayangnya sepanjang jalan dan seluas samudera

ABSTRAK

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Tugas Akhir ini memprediksikan terjadinya slamming pada HYCAT (Hydrofoil Catamaran) jika dikenai gelombang dengan arah head seas pada kecepatan operasional yang berbeda. Slamming merupakan kondisi dimana haluan menumbuk ombak dan karena gerakan tersebut terjadi secara tiba-tiba, maka akan mengakibatkan adanya gaya impact pada haluan. Impact terjadi ketika haluan membentur permukaan air selama gerakan pitching. Slamming akan terjadi apabila relatif displacement melebihi dari jarak antara wetdeck dengan permukaan air. Prosedur dari perhitungan dimulai dengan pengitungan masa tambah kapal dengan menggunakan metode strip teori, selanjutnya relatif motion dihitung setelah mendapatkan semua komponen dari persamaan gerak kopel heaving dan pitching. Dari relatif motion dirubah ke dalam graik Respon Amplitudo Operator (RAO). RAO jika dikalikan dengan spektrum gelombang akan mendapatkan relatif bow motion spektra. Selanjutnya dilakukan analisis spektra guna mendapatkan probabilitas slamming. Dari penghitungan probabilitas slamming pada kecepatan operasional 10 knot dihasilkan slamming mulai terjadi pada Hs 3 meter dengan probabilitas 1.555 %.. Sedangkan untuk kecepatan operasional 20 knot slamming mulai terjadi pada Hs 3 meter dengan probabilitas 0.05%. Pada kecepatan operasional 30 knot slamming mulai terjadi pada Hs 2 meter dengan probabilitas 0.215 %. Sedangkan kesimpulan yang dapat diambil bahwa catamaran yang dikaji layak untuk dioperasikan di perairan Indonesia dengan rata-rata Hs tidak melebihi .

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DAFTAR NOTASI

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Dp = diameter prototipe

Dm = diameter model

λ = angka nisbah

Lp = panjang prototipe

Lm = panjang model

Fa = Gaya Inersia

Fb = Gaya Redaman

Fc = Gaya Pengembali

F = Gaya Eksitasi

m = masa kapal

a_z = masa tambah

b = koefisien damping

c = koefisien pengembali

$\ddot{z}$ = percepatan vertical

$\dot{z}$ = kecepatan vertical

z = posisi vertikal

$\ddot{\theta}$ = percepatan angular

$\dot{\theta}$ = kecepatan angular

θ = simpangan angular akibat gerakan pitching

ΣF = total gaya fluida/ gaya ekstrenal.

ΣM = total momen gaya yang bekerja pada strip akibat gerak relatif terhadap gelombang.

M = massa strip dari kapal

a_z = massa tambah strip untuk gerakan heaving

Δ = displacement kapal

g = percepatan gravitasi

$\ddot{\zeta}$ = percepatan vertikal dari permukaan air

$\dot{\zeta}$ = kecepatan vertikal dari permukaan air

ζ = posisi vertikal daro permukaan air

$m_n \ddot{z}_n$ = gaya inersia yang diperlukan untuk menggerakkan masa strip

$a_n \dot{w}_r$ = gaya hidrodinamik yang diperlukan untuk menggerakkan masa tambah.

$b_n w_r$ = gaya redaman hydrodynamik akibat kecepatan relatif.

$c_n z_r$ = gaya hidrostatis akibat perubahan posisi relatif.

ut = displcement antara sumbu utama dengan titik pangkal benda untuk waktu *t* tertentu.

ξ = jarak dari origin kapal ke titik dari persamaan yang ditinjau.

e^{-kz} = faktor penurunan tekanan dihitung dari tekanan net pada gelombang sepanjang sarat strip.

Fo = amplitudo dari exciting force

σ = sudut fase antara gaya eksitasi dengan gerakan gelombang

Tm = garis sarat rata-rata tiap station .

Sn = luasan area tiap station

Bn = lebar tiap station

Ayy = massa tambah momen inersia

B = momen peredam

C = momen pengembali

D = d

E $= -\int b_n \xi d\xi - u\, a_z$

H $= -\int c_n \xi d\xi$

M = momen eksitasi

Mo = amplitudo momen eksitasi

Za = amplitudo heaving

δ = beda phase untuk heaving

Qa = amplitudo pitching

ξ = beda phase untuk pitching

ρ = masa jenis air laut

ζ_a = amplitude gelombang

E_T = Total energi dari semua komponen gelombang (kN/m)

mo = luasan dibawah kurva

$S_\zeta(\omega_w)$= energi gelombang fungsi frekuensi gelombang

ω_w = frekuensi gelombang (rad/s)

A $=8,1 \times 10^{-2} g^2$

B = $3,11 \times 10^4/Hs$

Hs = tinggi gelombang significant (m)

$S(\omega_w)$ = spektrum gelombang (m^2-sec)

V = keceptan kapal

μ = sudut pertemuan gelombang (head sea = 180 ^{0})

S_R = respon spektrum (m^2-sec)

RAO = Response Amplitude Operator

CF = faktor koreksi

Z_{cx} = jarak antara wetdeck dengan permukaan air. (m)

Z_{drel} = relatif displacement (m).

Z_{dabs} = absolute vertical motion.

ζ = tinggi gelombang pada calm water (m)

ζ_3 = heave elevation (m).

ζ_5 = pitch elevation (m).

E_d = variance dari relatif vertikal displacement.

Z_{cx} = jarak antara wetdeck dengan permukaan air. (m)

ς_w = amplitudo gelombang (m).

Ev = varian dari relatif vertikal motion.

BAB I
PENDAHULUAN

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PENDAHULUAN

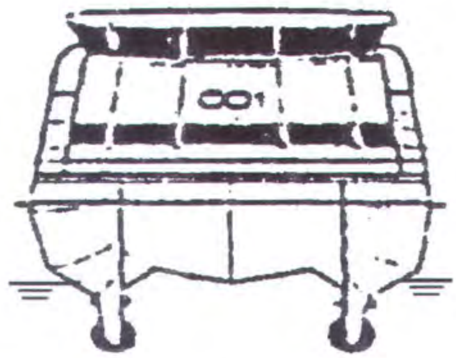
I.1 Latar Belakang

Indonesia merupakan negara dengan ratio wilayah perairan dan daratan terbesar didunia, dimana 2/3 dari wilayahnya berupa laut. Hal ini menjadikan Indonesia bangsa yang potensial dalam bidang kelautan, transportasi laut merupakan hal yang penting ketika kita bicara tentang mobilitas penduduk dari satu pulau ke pulau yang lain. Disamping itu Indonesia membutuhkan pertahanan wilayah yang dapat mencakup wilayah yang luas, hal ini dapat dipenuhi dengan pembangunan bangunan apung yang memiliki kecepatan di atas rata-rata dan dapat bermanuver dengan cepat serta tangkas. Untuk memenuhi akan bangunan apung tersebut maka diperlukan suatu studi yang diharapkan nantinya dapat menjadikan suatu referensi yang berarti dalam pengembangan selanjutnya.

Penggunaan jenis transportasi laut non konvensional atau *Advanced Marine Vehicles* (AMVs) yang mempunyai karakteristik kecepatan dan kenyamanan lebih tinggi dari pada jenis konvesional, akan menjadi alternatif kebutuhan jenis transportasi laut di masa mendatang. *Hybrid Hydrofoil Catamaran* (HYCAT) sebagai salah satu jenis AMVs mempunyai bentuk konstruksi kombinasi dari lambung catamaran dengan dua buah *fully submerged hydrofoil* seperti ditunjukkan pada gambar 1.1 (Arii et al., 1993).

Bangunan apung tipe HYCAT (Hybrid Hydrofoil Catamaran) merupakan bangunan apung non konvensional, dimana bangunan ini memiliki manuver yang lebih baik dibandingkan dengan bangunan apung konvensional lainnya

(Kawaguchi et al, 1991). Ide konsep HYCAT adalah membuat bangunan apung yang dapat berlayar di perairan bergelombang dengan penurunan kecepatan sekecil mungkin, tanpa slamming dan tanpa shipping green water (air laut mencapai geladak). Bentuk lambung HYCAT memiliki luas garis air (WPA) yang kecil, sehingga dapat memperkecil gerakan pada gelombang dan lambung tersebut didesain agar memiliki tahanan dan karakteristik operasional seastate lebih baik daripada bangunan apung hydrofoil (Djatmiko, 1996).



Gambar 1.1. Pandangan depan HYCAT (Calkins, 1991)

Meskipun teknologi penciptaan sarana transportasi laut baru telah mengalami perkembangan yang sangat cepat, dengan diciptakannya berbagai jenis tipe bangunan laut yang memiliki keunggulan bermanuver di laut, seperti misalnya Hovercraft, Superjet, catamaran dll. Sedangkan untuk tipe catamaran, di Indonesia masih belum banyak dikaji mengenai masalah hidrodinamikanya, padahal tipe catamaran memiliki keunggulan-keunggulan yang lebih jika dibandingkan dengan tipe monohull (gambar 1.2).

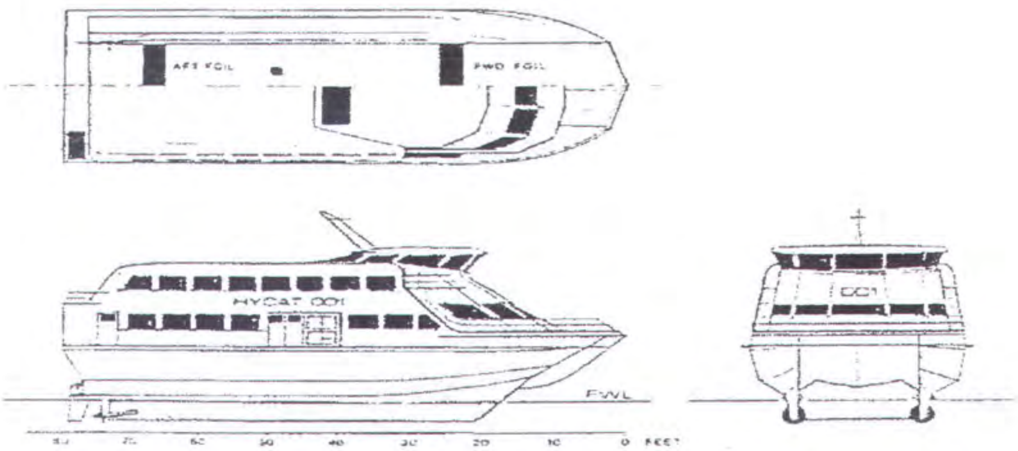
Adapun hal-hal yang perlu dipertimbangkan dalam pembangunan catamaran yaitu:

1. Catamaran merupakan bangunan laut tipe multihull, sehingga berakibat pada luas permukaan yang tercelup air (Wetted Surface Area) semakin besar.
2. Mampu melaju dengan kecepatan tinggi.
3. Ketika luas deck dan pengaruh air menjadi prioritas atau pertimbangan, maka katamaran menjadi solusi yang terbaik.

Oleh karenanya seorang perancang harus benar-benar mengetahui semua beban yang dialami akibat dari bentuk kontruksi dan kondisi lingkungan daerah operasinya. Gerakan katamaran ataupun bangunan apung lainnya dilaut yang bergelombang banyak dipengaruhi oleh efek-efek hidrodinamika, seperti gerakan heaving dan pitching katamaran ketika bertemu dengan gelombang yang pada saat-saat tertentu terdapat limpahan air pada geladak bangunan apung(deck wetness) dimana deck wetness ini sangat berpengaruh terhadap gerak bangunan apung(dalam hal ini kecepatan bangunan apung) dan juga berlebihannya deck wetness dapat mengakibatkan tenggelamnya bangunan apung. Oleh karenanya studi tentang deck wetness pada katamaran sangat penting sekali dilakukan agar katamaran dapat berfungsi sesuai dengan yang diharapkan.

Karena pentingnya peranan bangunan apung type HYCAT dimasa mendatang maka perlu dipelajari karakteristik bangunan apung type HYCAT dalam menghadapi gelombang laut, baik dengan studi teoritis maupun secara eksperimen.

Berangkat dari pertimbangan diatas PREDIKSI SLAMMING PADA HYCAT AKIBAT GERAKAN KOPEL HEAVING DAN PITCHING DIATAS GELOMBANG ACAK



Gambar 1.2. Konfigurasi bangunan apung type HYCAT (Calkins, 1991)

I.2. Perumusan Masalah

Slamming pada HYCAT merupakan kondisi dimana haluan menumbuk ombak dan karena gerakan tersebut terjadi secara tiba-tiba, maka akan mengakibatkan adanya gaya impact pada haluan..

Ketika haluan HYCAT tercelup dan ketika tiba-tiba gelombang kembali masuk dengan kecepatan yang relatif besar, slamming dapat terjadi. Slamming pada HYCAT tersebut juga dapat mengakibatkan terjadinya shipping green water (air membasahi deck), dengan adanya tumbukan antara gelombang dengan haluan kapal akan menghasilkan percikan air yang dapat membasahi deck kapal.

Hal ini terjadi jika relatif displacement lebih tinggi dari jarak antara wetdeck dengan permukaan air. Pada olah geraknya HYCAT memilki arah gerak 6 derajat kebebasan yang meliputi Sway, Heave, Roll, Pitch, dan Yaw. Dari keenam gerakan tersebut yang paling dominan mempengaruhi slamming adalah kopel antara Heaving-Pitching, dimana gerakan ini akan dikaji secara khusus dalam tahap ini. Perumusan masalah tersebut diatas mencakup :

1. Bagaimanakah karakteristik gerakan relatif HYCAT akibat gerakan kopel heaving pitching, sebagai parameter penentu dalam prediksi slamming .
2. Bagimanakah pengaruh kecepatan model dan tinggi gelombang terhadap probabilitas slamming di atas gelombang acak

I.3. Tujuan

Dari perumusan masalah diatas, dapat diambil tujuan yang dapat diambil. Adapun tujuan yang diharapkan, meliputi :

1. Menentukan karakteristik gerakan relatif (relatif motion) HYCAT sebagai parameter penentu dalam prediksi slamming akibat adanya gerakan couple heaving pitching pada gelombang acak.
2. Melakukan analisis untuk memprediksi peluang terjadinya slamming sebagai fungsi perubah intensitas gelombang dan kecepatan HYCAT

I.4. Manfaat

Beberapa manfaat yang dapat diambil dari penelitian ini adalah :

1. Memberikan masukan kepada dunia penelitian, khususnya penelitian tentang bangunan lepas pantai.

2. Menambah wacana baru mengenai perkembangan bangunan apung tipe HYCAT.

I.5 Batasan

Batasan masalah yang perlu dicermati dari penelitian ini adalah :

1. Perhitungan gerakan heave dan pitch dilakukan dengan menggunakan teori gelombang linear dengan arah gelombang dari depan (head seas) menggunakan variasi frekuensi gelombang, dan kecepatan model HYCAT.
2. Fluida yang digunakan *incompressible, irrotational, homogen* dan *inviscid.*
3. Tekanan pada permukaan air adalah konstan dan seragam.
4. Gerakan yang terjadi merupakan gerakan kopel heaving pitching.
5. Interaksi gelombang antara kedua lambung dianggap tidak ada.
6. Tahanan dan redaman yang diakibatkan adanya foil diabaikan.
7. Efek tiga dimensi seperti interfensi antara strip atau hubungan antara elemen-elemen yang berdekatan diabaikan.

BAB II
TINJAUAN PUSTAKA DAN DASAR TEORI

BAB II

TINJAUAN PUSTAKA DAN LANDASAN TEORI

2.1. Tinjauan Pustaka

Pada dasarnya ada tiga metode yang digunakan dalam melakukan estimasi gerakan bangunan apung tipe HYCAT. Metode-metode ini adalah : a) teori Morison, b) teori strip, dan c) teori difraksi.

Penerapan teori Morison dalam beberapa hal bisa diterima bilamana asumsi sehubungan dengan benda apung dalam fluida dalam beberapa hal dapat diambil secara tepat (Lamb, 1988).

Pemecahan masalah dengan teori strip pada dasarnya adalah seperti halnya dengan penerapan teori Morison, yakni lambung benam dibagi menjadi sejumlah elemen. Setiap elemen potongan diperhitungkan secara individual, sehingga interferensi antara dua potongan yang bersebelahan dapat diabaikan. Teori strip selanjutnya juga memerlukan asumsi kelangsingan longitudinal, dan dalam perhitungan gaya hidrodinamis.

Bangunan apung type HYCAT memiliki gaya buoyancy yang diperoleh dari dua lambung (twin hull). HYCAT dapat menambah kemampuan operasi karena unjuk kerja olah gerak kapal yang baik dalam pelayaran, termasuk mengurangi penurunan kecepatan pada perairan laut yang buruk. Penyusunan badan kapal yang sedemikian rupa mengakibatkan penampang garis air HYCAT lebih kecil daripada kapal konvensional sehingga gerakan HYCAT akibat gelombang dapat diperkecil.

Untuk menganalisa gerakan struktur terapung, penting diketahui terlebih dahulu tentang macam gerakan dan system koordinat. Gerakan-gerakan struktur terapung di laut mempunyai 6 (enam) macam gerakan, terdiri atas 3 (tiga) gerakan translasi yaitu surging, swaying, dan heaving , serta 3 (tiga) gerakan rotasi yaitu rolling , pitching dan yawing . Dari gerakan –gerakan struktur tersebut hanya tiga gerakan saja yang merupakan gerakan osilasi murni, jika struktur tersebut mengalami gangguan dari posisi kesetimbangannya , yaitu heaving, rolling dan pitching.

2.2. Dasar Teori

2.2.1. Hukum Kesamaan

Agar diperoleh hasil spesifik gaya-gaya yang bekerja pada model sama dengan pada protitype (full scale), maka model harus memenuhi beberapa hukum kesamaan. Kesamaan tersebut meliputi kesamaan geometri , kinematis, dinamik (Murtedjo, 2000).

2.2.1.1.Kesamaan Geometris

Kesamaan geometris adalah merupakan perbandingan antara ukuran model dengan prototype, perbandingan ini selalu menghasilkan harga yang konstan. Definisinya adalah sebagai berikut :

Sebuah model dan prototipe adalah serupa secara geometris jika dan hanya jika semua ukuran benda dalam ketiga koordinatnya mempunyai nisbah skala linier yang sama.

Perhatikan bahwa semua skala panjang harus sama. Keadaannya seperti bila memotret prototipe dan mengecilkan atau membesarkanya sampai sama besar dengan modelnya. Kalau model itu akan dibuat berukuran sepersepuluhnya prototipe, panjang, lebar dan tingginya masing-masing harus sepersepuluhnya pula. Bukan ini juga, bentuk keseluruhannya harus sepersepuluhnya bentuk prototipe. Secara teknis kita menyebut titik-titiknya *homolog* , artinya mempunyai letak nisbi yang sama. Maka syarat keserupaan geometris ialah bahwa semua titik yang homolog mempunyai nisbah skala linear yang sama. Ini berlaku untuk semua geometri fluida, maupun untuk geometri model :

Semua sudut dan semua arah aliran dipertahankan dalam keserupaan geometris. Orientasi model dan prototipe terhadap sekelilingnya harus identik.

Secara matematis hubungannya adalah :

$$\frac{Dp}{Dm} = \frac{Lp}{Lm} = \lambda = kons\tan \tag{2.1}$$

Dimana :

Dp = diameter prototipe

Dm = diameter model

λ = angka nisbah

Lp = panjang prototipe

Lm = panjang model

2.2.2. Gerakan Strktur Terapung

Setiap struktur terapung yang bergerak di atas permukaan laut selalu mengalami gerakan osilasi. Gerakan osilasi ini terdiri dari 6 macam gerakan, yaitu 3 macam gerakan lateral dan 3 macam gerakan rotasional dalam 3 arah sumbu yang ditunjukkan dalam gambar 2.1 Macam gerakan itu meliputi :

a. *Surging* : Gerakan osilasi lateral pada sumbu -x.

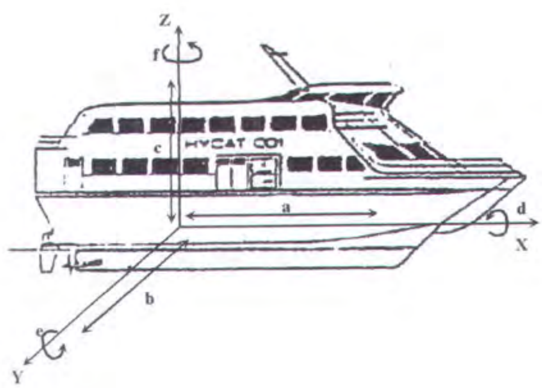
b. *Swaying* : Gerakan osilasi lateral pada sumbu -y.

c. *Heaving* : Gerakan osilasi lateral pada sumbu -z.

d. *Rolling* : Gerakan osilasi rotasional terhadap sumbu -x.

e. *Pitching* : Gerakan osilasi rotasional terhadap sumbu -y.

f. *Yawing* : Gerakan osilasi rotasional terhadap sumbu -z.



Gambar 2.1. Enam derajat kebebasan gerakan struktur *Catamaran* (Calkins, 1991)

Hanya 3 macam gerakan merupakan gerakan osilasi murni yaitu *heaving, rolling dan pitching*, karena gerakan ini bekerja dibawah gaya atau momen pengembali ketika struktur itu terganggu dari posisi kesetimbangannya. Untuk gerakan *surging, swaying* dan *yawing* struktur tidak kembali menuju posisi kesetimbangannya semula kalau diganggu, kecuali ada gaya atau momen pengembali yang menyebabkannya bekerja dalam arah berlawanan.

Pada penelitian ini akan dibahas struktur terapung yang bergerak dua derajat kebebasan dalam arah gerakan *couple heave-pitch* akibat gelombang dalam arah *head sea*. Seperti diketahui gaya osilasi teredam memiliki empat faktor penting (Bhattacharya, 1978) sebagai berikut :

a. Gaya Inersia : $Fa = (m + a_z)\ddot{z}$ (2.2)

b. Gaya Redaman : $Fb = b\dot{z}$ (2.3)

c. Gaya Pengembali : $Fc = cz$ (2.4)

d. Gaya Eksitasi : $F = FoCos\omega_e t$ (2.5)

dimana :

m = masa kapal

a_z = masa tambah

b = koefisien damping

c = koefisien pengembali

$\ddot{z}$ = percepatan vertical

$\dot{z}$ = kecepatan vertical

z = posisi vertikal

Berdasarkan hukum Newton II maka semua gaya yang bekerja pada sebuah benda (strip) adalah sama dengan perkalian antara massa strip terhadap percepatannya.

Persamaan untuk *heaving* :

$$m.\ddot{z} = \Sigma F \tag{2.6}$$

Persamaan untuk *pitching* :

$$I.\ddot{\theta} = \Sigma M \tag{2.7}$$

dimana:

ΣF = Total gaya fluida/ gaya ekstrenal.

ΣM = Total momen gaya yang bekerja pada strip akibat gerak relatif terhadap gelombang.

Untuk menghitung elevasi bangunan apung terhadap MWL akibat kopel heaving dan pitching maka digunakan Teori Strip, dimana sebuah benda terapung dibagi secara transversal menjadi beberapa bagian yang selanjutnya disebut sebagai Strip.

Adanya massa tambah pada suatu benda yang bergerak relatif terhadap fluida maka persamaan (2.6) diatas dapat ditulis kembali menjadi :

$$\sum F = (m + a_z) \tag{2.8}$$

dimana: m = massa strip dari kapal

a_z = massa tambah strip untuk gerakan heaving

Pergerakan dari masa strip dan masa tambah ke arah bawah akan mengakibatkan adanya reaksi perlawanan. Reaksi tersebut sering disebut dengan gaya tahanan/gaya redaman. Sehingga dapat dirumuskan :

$$cz = (m + a_z)\ddot{z} + b\dot{z} \qquad (2.9)$$

Bila diamsusikan bahwa pada arah gaya kebawah bernilai positif sedangkan arah gaya keatas bernilai negatif, maka persamaan (2.9) menjadi:

$$cz = (m + a_z)(-\ddot{z}) + b(-\dot{z}) \qquad (2.10)$$

Pada persamaan (2.10) dapat dijabarkan sebagai fungsi dari displacement kapal, sehingga persamaannya menjadi:

$$cz = \left(\frac{\Delta}{g} + a_z\right)(-\ddot{z}) + b(-\dot{z}) \qquad (2.11)$$

Sehingga menjadi :

$$\left(\frac{\Delta}{g} + a_z\right)\ddot{z} + b\dot{z} + cz = 0 \qquad (2.12)$$

dimana :

Δ = displacement kapal

g = percepatan gravitasi

Jika diasumsikan bahwa strip diganggu oleh suatu gelombang dengan dengan amplitudo ζ_a , maka akan menyebabkan adanya gaya perlawanan yang disebabkan oleh perbedaan water level (gaya bouyancy). Lebih jauh lagi fluktuasi dari water level akan menyebabkan external force yang terus menerus, yang disebut *exciting forces* . Nilai dari gaya eksitasi ini adalah sama dengan jumlah dari percepatan relatif, velocity, dan posisi waktu antara strip dan permukaan air relatif konstan, dimana dirumuskan.

$$m\ddot{z} = F = ma_z\left(-\ddot{z} + \ddot{\zeta}\right) + b\left(-\dot{z} + \dot{\zeta}\right) + c\left(-z + \zeta\right) \tag{2.13a}$$

atau

$$m\ddot{z} + a_z\left(\ddot{z} - \ddot{\zeta}\right) + b\left(\dot{z} - \dot{\zeta}\right) + c\left(z - \zeta\right) \tag{2.13b}$$

dimana: $\ddot{\zeta}$ = percepatan vertikal dari permukaan air

$\dot{\zeta}$ = kecepatan vertikal dari permukaan air

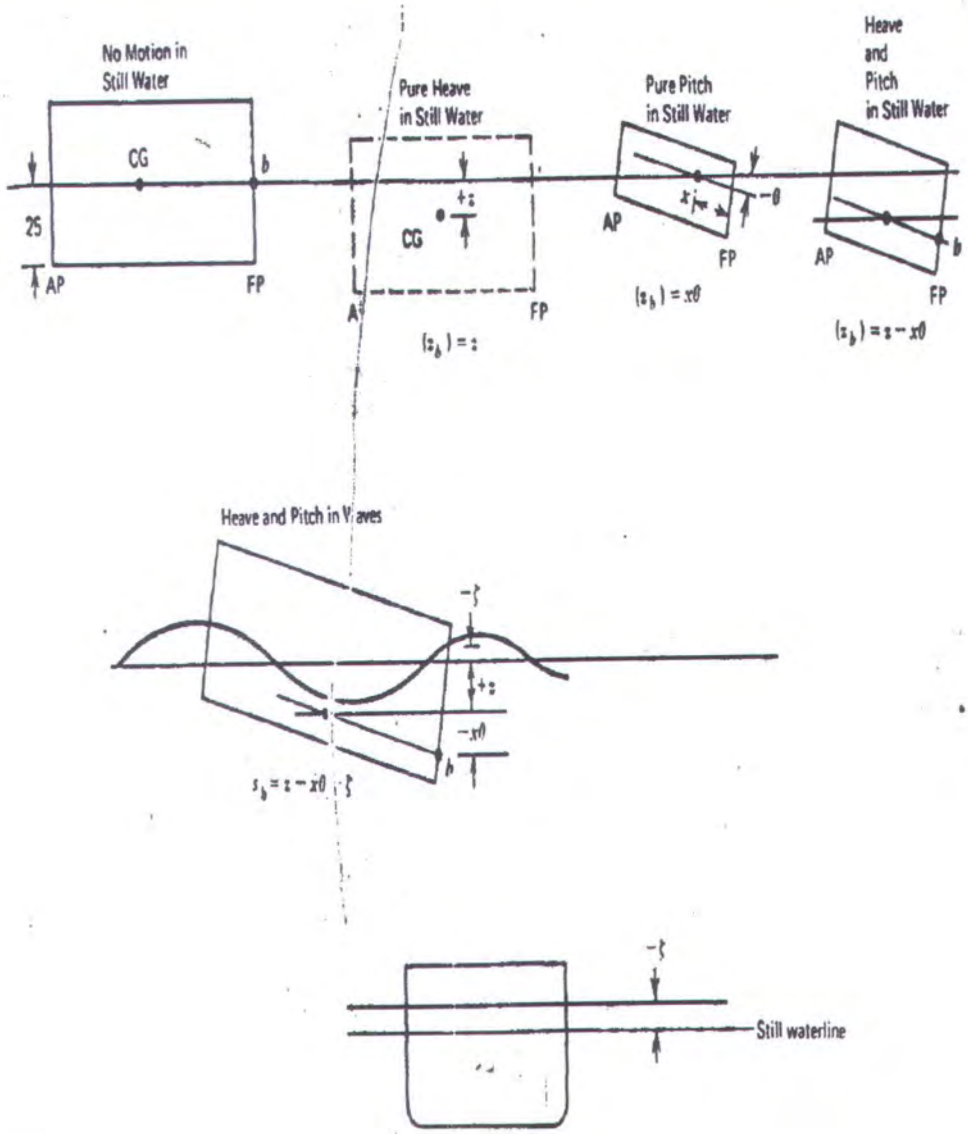
ζ = posisi vertikal daro permukaan air

Persamaan (2.13b) diatas dapat disempurnakan lagi menjadi:

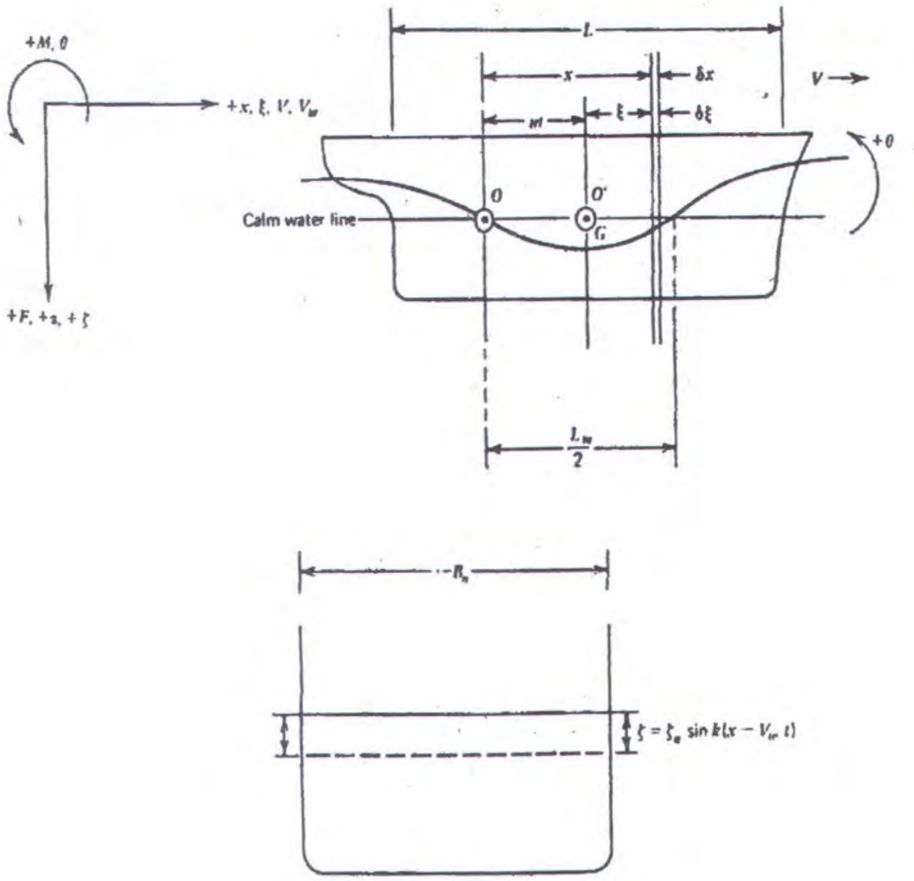
$$\left(m + a_z\right)\ddot{z} + b\dot{z} + cz = a_z\ddot{\zeta} + b\dot{\zeta} + c\zeta \tag{2.14}$$

Dimana ruas kanan disebut sebagai exciting force. Untuk mempertimbangkan gerakan kapal digelombang, salah satu yang harus digambarkan yaitu relatif motion antara kapal dan gelombang.

Posisi vertikal absolut setiap titik sepanjang kapal yang dinyatakan dalam $z - \xi\theta$ dan posisi relatif strip terhadap gelombang dinyatakan pada : $zr = z - \xi\theta - \zeta$. Untuk lebih jelasnya pada gambar 2.2 dan gambar 2.3 dibawah :



Gambar 2.2. Gerakan heaving, dan pitching pada strip (Battacharyya, R 1978)



Gambar 2.3. Koordinat sistem untuk strip teori (Battacharyya, R 1978)

$$zr = z - \xi\theta - \zeta \tag{2.15}$$

Untuk mendapatkan kecepatan relatif persamaan diatas dapat diturunkan menjadi :

$$wr = \dot{z}r = \dot{z} - \left(\xi\dot{\theta} + \theta\dot{\xi}\right) - \xi \tag{2.16}$$

Harus diingat bahwa pada titik suatu kapal yang bergerak ke depan sepanjang air pada kecepatan w mempunyai :

$$d\xi / dt = \dot{\xi} = -u$$

Sehingga percepatan relatifnya menjadi :

$$\dot{w}_r = \ddot{z} - \xi\ddot{\theta} - \dot{\theta}(-u) + u\theta - \ddot{\zeta}$$

$$= \ddot{z} - \xi\ddot{\theta} + 2u\dot{\theta} - \ddot{\zeta} \qquad (2.17)$$

Pada semua waktu gaya vertikal pada strip harus pada keadaan equilibrium. Meskipun diantara strip mungkin diseimbangkan oleh gaya geser pada struktur kapal dimana bersifat imaginar.

Konstribusi gaya geser pada masing-masing strip diberikan oleh $\frac{dfn}{d\xi}$ dan nilai ini sama dengan persamaan gaya yang sudah diturunkan diawal.

$$\frac{\delta fn}{\delta\xi} = -\, m_n\ddot{z}_n - (a_n\dot{w}_r + b_n w_r) - c_n z_r \qquad (2.18a)$$

dimana : $m_n\ddot{z}_n$ = gaya inersia yang diperlukan untuk menggerakkan masa strip.

$a_n\dot{w}_r$ = gaya hidrodinamik yang diperlukan untuk menggerakkan masa tambah.

$b_n w_r$ = gaya redaman hydrodynamik akibat kecepatan relatif.

$c_n z_r$ = gaya hidrostatis akibat perubahan posisi relatif.

Koefisien a_n, b_n, c_n harus dihitung untuk setiap station. Karena berubah dengan perubahan section. Selama gelombang linear melewati strip dan mengubahnya, penurunan dari $\frac{d(a_n w_r)}{dt}$ harus diperhitungkan berlawanan dengan $a_n w_r$ sehingga :

$$\frac{d(a_n w_r)}{dt} = w_r \frac{da_n}{dt} + a_n \frac{dw_r}{dt}$$

$$= w_r \frac{da_n}{dt} + a_n \dot{w}_r$$

Substitusi ke persamaan (2.18a) akan menghasilkan persamaan gaya:

$$\frac{\delta fn}{\delta \xi} = -m_n \ddot{z}_n - a_n \dot{w}_r - \left(b_n + \frac{da_n}{dt} \right) w_r - c_n z_r \qquad (2.18b)$$

Persamaan (2.18b) merupakan gaya strip untuk satu section sedangkan total dari gaya tersebut harus diintegralkan sepanjang x, dimana :

$$\frac{\delta f_n}{dt} dx = 0$$

Disini yang harus diperhatikan displacement horisontal yang terjadi adalah:

$$X = \xi + ut \qquad (2.19)$$

dimana :

ut = displcement antara sumbu utama dengan titik pangkal benda untuk waktu *t* tertentu.

ξ = jarak dari origin kapal ke titik dari persamaan yang ditinjau.

Untuk kondisi normal *ut*bernilai konstan sehingga persamaan(2.19) menjadi:

$$dx = d\xi + d(ut) = d\xi \qquad (2.20)$$

Sehingga total dari gaya menjadi :

$$\int \frac{dfn}{d\xi} d\xi = 0$$

Atau persamaan (2.18b) menjadi:

$$-\int \frac{dfn}{d\xi} d\xi = \int m_n \ddot{z}_n d\xi + \int a_n \dot{w}_r d\xi + \left(\int b_n w_r d\xi - u \int \frac{da_n}{d\xi} w_r d\xi \right) + \int c_n z_n d\xi \quad (2.21)$$

dimana : $\ddot{z}_n = \ddot{z} - \xi \ddot{\theta}$ (2.22)

Seperti pada persamaan $z_r = z - \xi\theta - \xi$. Dimana seharusnya persamaan tersebut dimodifikasi karena adanya efek pengurangan tekanan. Tidak seperti tekanan hidrostatis yang bervariasi menurut kedalaman air, tekanan air dinamik diatas puncak gelombang menurun secara eksponensial menurut kedalaman . sehingga efek penurunan tekanan akan mempengaruhi posisi relatif vertikalnya persamaannya menjadi:

$$z_r = z - \xi\theta - \zeta e^{-kz} \quad (2.23)$$

dimana:

e^{-kz} = faktor penurunan tekanan dihitung dari tekanan net pada gelombang sepanjang sarat strip.

Sehingga diperoleh persamaan kecepatan relatif dan percepatan relatif baru sebagai berikut :

$$w_r = \frac{dz_r}{dt} = \dot{z} - \xi\dot{\theta} + u\theta - \dot{\zeta} e^{-kz} \quad (2.24)$$

$$\dot{w}_r = \frac{dw_r}{dt} = \ddot{z} - \xi\ddot{\theta} + 2u\dot{\theta} - \ddot{\zeta} e^{-kz} \quad (2.25)$$

Untuk penyerdahanaan, suku-suku gerakan absolut kapal ($z, \dot{z}, \ddot{z}$ $\theta, \dot{\theta}$, $\ddot{\theta}$,) dipisahkan dari suku-suku gerakan gelombang (ξ , $\dot{\xi}$, $\ddot{\xi}$). Ruas kiri persamaan menyatakan respon natural pada displcemen awal dalam still water dan ruas kanan menyatakan kondisi gelombang yang disebut force function.Substitusi persamaan (2.22),(2.23),(2.24),(2.25) ke persamaan (2.21) .Sehingga menjadi persamaan :

$$\int m_n\left(\ddot{z}-\xi\ddot{\theta}\right)d\xi+\int a_n\left(\ddot{z}-\xi\ddot{\theta}+2u\dot{\theta}-\ddot{\zeta}e^{-kz}\right)d\xi+\left(\int b_n\left(\dot{z}-\xi\dot{\theta}+u\theta-\dot{\zeta}e^{-kz}\right)d\xi\right)$$

$$-\left(u\int\frac{da_n}{d\xi}\left(\dot{z}-\xi\dot{\theta}+u\theta-\dot{\zeta}e^{-kz}\right)d\xi\right)+\int c_n\left(z-\xi\theta-\zeta e^{-kz}\right)d\xi=0 \qquad (2.26)$$

Persamaan (2.26) disusun kembali menjadi persamaan sisi kiri dan sisi kanan , sehingga menghasilkan:

$$m_n\left(\ddot{z}-\xi\ddot{\theta}\right)+a_n\left(\ddot{z}-\xi\ddot{\theta}+2u\dot{\theta}-\right)+b_n\left(\dot{z}-\xi\dot{\theta}+u\theta\right)-\frac{da_n}{d\xi}\left(\dot{z}-\xi\dot{\theta}+u\theta\right)+c_n\left(z-\xi\theta\right)$$

$$=\ddot{\zeta}e^{-kz}a_n-\dot{\zeta}e^{-kz}b_n-u\frac{da_n}{d\xi}\dot{\xi}e^{-kz}+\zeta e^{-kz}c_n \qquad (2.27)$$

Pada persamaan (2.27) diatas, ruas kanan menyatakan exciting force untuk masing-masing strip yang disebabkan oleh gelombang, df/dx Dengan mengasumsikan gelombang reguler dan harmonik maka:

$$\xi=\xi_a\sin k(x-V_w t) \qquad (2.28)$$

masukkan persamaan $x=\xi+ut$ ke persamaan (2.28) didapatkan:

$$\zeta=\zeta a\sin k\left(\xi+\left(u+Vw\right)t\right) \qquad (2.29)$$

Karena $-k(u\text{-}Vw)=\omega e$ dan ωe merupakan frekuensi encounter maka kecepatan dan percepatan elevasi dapat dinyatakan sebagai berikut :

$$\zeta=\zeta a\sin\left(k\xi-\omega et\right) \qquad (2.30)$$

$$\dot{\zeta} = -\zeta a \omega e \cos(k\xi - \omega e t) \tag{2.31}$$

$$\ddot{\zeta} = -\zeta a \omega e^2 \sin(k\xi - \omega e t) \tag{2.32}$$

substitusi $\zeta, \dot{\zeta}, \ddot{\zeta}$ ke persamaan (2.27) menjadi :

$$m_n\ddot{z} + a_n\ddot{z} + b_n\dot{z} - u\frac{da_n}{d\xi}\dot{z} + c_n z - m_n\xi\ddot{\theta} - a_n\xi\dot{\theta} + a_n 2u\dot{\theta} - b_n\xi\dot{\theta} + b_n u\theta + u\frac{da_n}{d\xi}\xi\dot{\theta}$$

$$-u^2\frac{da_n}{d\xi} + c_n\xi\theta.$$

$$= (m_n + a_z)\ddot{z} + b_n\dot{z} - u\frac{da_n}{d\xi}\dot{z} + c_n\dot{z} - m_n\xi\ddot{\theta} - a_n\xi\ddot{\theta} + a_n 2u\dot{\theta} - b_n\xi\dot{\theta} + u^2\frac{da_n}{d\xi}\theta - c_n\xi\theta$$

$$= -\zeta_a\omega^2{}_e\sin(k\xi - \omega_e t)e^{-kz}a_n - \zeta_a\omega_e\cos(k\xi - \omega_e t)e^{-kz}\left(b_n - u\frac{da_n}{d\xi}\right)d\xi$$

$$+\zeta_a\sin(k\xi - \omega_e t)e^{-kz}c_n d\xi \tag{2.33}$$

Persamaan (2.33) tersebut dapat dipersingkat, diperoleh persamaan dasar I untuk gerakan translasi pada kopel heaving dan pitching yaitu :

$$(m + a_z)\ddot{z} + b\dot{z} + cz + d\ddot{\theta} + e\dot{\theta} + h\theta = F(t) \tag{2.34}$$

dimana : $m = \int m_n d\xi$

$a_z = \int a_n d\xi$

$b = \int b_n d\xi$

Selama diasumsikan $u\int\left(\frac{da_n}{d\xi}\right)d\xi = 0$ maka :

$$c = \int c_n d\xi \tag{2.35}$$

yang dapat dinyatakan juga sebagai $\rho g\int B_n d\xi$, dimana Bn lebar masing-masing seksi.

$$d = -\int a_n \xi d\xi \tag{2.36}$$

Karena $\int m_n \xi d\xi = 0$, yaitu momen dari masa total disekitar titik beratnya harus sama dengan nol maka :

$$e = -\int b_n \xi d\xi + 2u\int a_n d\xi + u\int \left({da_n}/{d\xi} \right) \xi d\xi$$

$$= -\int b_n \xi d\xi + ua_z \tag{2.37}$$

Jika $\int \xi \left({da_n}/{d\xi} \right) d\xi = \int \xi$ dan = -a_z, maka :

$$h = -\int c_n \xi d\xi + u\int b_n d\xi$$

$$= -\int c_n \xi d\xi + ub \tag{2.38}$$

dan karena $u^2 \int \left({da_n}/{d\xi} \right) d\xi = 0$ maka:

$$F(t) = \int \frac{dF}{dx} dx = \xi a e^{-kz} \int \left(-\omega e^2 a_n + c_n \right) \sin\left(k\xi - \omega e t \right) d\xi$$

$$- \zeta a e^{-kz} \omega e \int \left(b_n - u {da_n}/{d\xi} \right) \cos\left(k\xi - \omega e t \right) d\xi \tag{2.39}$$

Exciting force (f) yang timbul sebagai akibat gerakan heaving merupakan kurva sinusoidal dan secara umum dinyatakan sebagai berikut :

$$Fo = F1 \cos \omega e t + F2 \sin \omega e t$$

$$= F0 \cos\left(\omega e t + \sigma \right) \tag{2.40}$$

dimana Fo merupakan amplitudo dari exciting force yang dinyatakan sebagai berikut : $Fo = \sqrt{F1^2 + F2^2}$

Sedangkan σ merupakan sudut fase antara gaya eksitasi dengan gerakan gelombang yang dinyatakan sebagai berikut :

$$\sigma = -\tan^{-1}\left(F1/_{F2}\right)$$

Fo dan σ diperoleh dari penyelesaian *Forcing Force* ,F1 dan F2 dapat diperoleh melalui persamaan berikut :

$$F1 = \int \frac{dF1}{dx} dx$$

dimana:

$$\frac{dF1}{dx} = \zeta a e^{-kz}\left(-\omega e^2 a_n + c_n\right)\sin k\xi + \zeta a e^{-kz}\omega e\left(b_n - u\, {}^{da_n}/_{d\xi}\right)\cos k\xi$$

(2.41a)

dengan cara yang sama diperoleh:

$$F2 = \int \frac{dF2}{dx} dx$$

$$\frac{dF2}{dx} = \zeta a e^{-kz}\left(-\omega e^2 a_n + c_n\right)\cos k\xi - \zeta a e^{-kz}\omega e\left(b_n - u\, {}^{da_n}/_{d\xi}\right)\sin k\xi$$

(2.41b)

Hal yang perlu diperhatikan dari persamaan (2.41b) diatas bahwa z dirubah menjadi Tm, diukur dari garis sarat rata-rata tiap station .

$$Tm = \frac{s_n}{B_n}$$

dimana :

Sn = luasan area tiap station

Bn = lebar tiap station

Persamaan dasar II merupakan persamaan yang menggambarkan perilaku gerakan pitching akibat gerakan kopel heaving dan pitching, yaitu :

$$(Iyy + Ayy)\theta + B\theta + C\theta + Dz + Ez + Hz = M(t) \tag{2.42}$$

dimana :

Ayy = massa tambah momen inersia

$= \int a_n \xi^2 d\xi$

B = momen peredam

$= \int b_n \xi^2 d\xi$

selama $2u \int a_n \xi d\xi = -u \int \left(\frac{da_n}{d\xi} \right) \xi^2 d\xi$

C = momen pengembali

$= \int c_n \xi^2 d\xi - uE$

Sedangkan D,E,dan H merupakan bentuk kopel yang dinyatakan sebagai berikut:

D = d

E $= -\int b_n \xi d\xi - u\, a_z$

H$= -\int c_n \xi d\xi$

M = momen eksitasi

$= Mo\cos(\omega e + \tau) = \int \frac{dF}{d\xi} \xi d\xi$

Amplitudo momen eksitasi Mo dapat diperoleh melalui persamaan berikut :

$Mo = \sqrt{M1^2 + M2^2}$

Sudut fase τ akibat momen eksitasi terhadap gerakan gelombang adalah:

$$\tau = -\tan^{-1}\left(M1 / M2\right) \qquad (2.43)$$

dimana : $M1 = \int \frac{dM1}{dx} d\xi$

$$M2 = \int \frac{dM2}{dx} d\xi$$

$$\frac{dM1}{dx} = \xi\left(\frac{dF1}{dx}\right)$$

$$\frac{dM2}{dx} = \xi\left(\frac{dF2}{dx}\right)$$

Semua variabel pada persamaan (2.34) dan(2.42) dari a_z sampai h dan dari Ayy sampai H tergantung pada bentuk hull kapal, kecepatan, dan frekuensi.

Pengembangan persamaan-persamaan diatas digunakan untuk menyelesaikan masalah strip teori.

Karena penyelesaian persamaan gerak meliputi kedua amplitudo dan perbedaan phase, persamaan tersebut ditulis dalam persamaan complex, dimana $\overline{M}$ dan $\overline{F}$ menunjukkan *Forcing Function* dalam persamaan komplex :

$$\overline{F} = Fo.e^{i\sigma} \qquad (2.44)$$

$$\overline{M} = Mo.e^{i\tau} \qquad (2.45)$$

Koefisien-koefisien pada persamaan (2.34) dan (2.42) dapat diperoleh dengan mengasumsikan pendekatan gerak kopel untuk calm water sehingga ruas kanan pada masing-masing persamaan sama dengan nol. Dimana koefisien-

koefisien tersebut dapat diganti variabelnya untuk memperoleh penyelesaian dari displacement, sebagai berikut :

$$P = -(m + a_z)\omega^2 + iB\omega + c \tag{2.46}$$

$$Q = -d\omega^2 + ie\omega + h \tag{2.47}$$

$$S = -(Iyy + Ayy)\omega^2 + iB\omega + c \tag{2.48}$$

$$R = -D\omega^2 + iE\omega + H \tag{2.49}$$

Jika $\bar{z}$ menyatakan seluruh komponen z dan $\bar{\theta}$ menyatakan seluruh komponen θ ,maka persamaan (2.34) dan (2.42) dapat ditulis kembali dalam bentuk berikut :

$$P\bar{F} + Q\bar{\theta} = \bar{F} \tag{2.50}$$

$$S\bar{Q} + R\bar{z} = \bar{M} \tag{2.51}$$

Sehingga untuk persamaan heaving adalah :

$$\bar{z} = \frac{\bar{F} - Q\bar{\theta}}{P} \tag{2.52}$$

$$\bar{\theta} = \frac{\bar{F} - P\bar{z}}{Q} \tag{2.53}$$

Sedangkan untuk persamaan pitching adalah :

$$\bar{z} = \frac{\bar{M} - S\bar{\theta}}{R} \tag{2.54}$$

$$\bar{\theta} = \frac{\bar{M} - R\bar{z}}{S} \tag{2.55}$$

Jika persamaan diatas disubtitusikan akan diperoleh persamaan berikut:

$$\frac{\bar{F} - Q\bar{\theta}}{P} = \frac{\bar{M} - S\bar{\theta}}{R} \quad \text{dan} \quad \frac{\bar{F} - P\bar{z}}{Q} = \frac{\bar{M} - R\bar{z}}{S} \tag{2.56}$$

$$\bar{z} = \frac{\overline{M}Q - \overline{F}S}{QR - PS} \qquad (2.57)$$

$$\bar{\theta} = \frac{\overline{F}R - \overline{M}P}{QR - PS} \qquad (2.58)$$

Simpangan dan sudut fase untuk $\bar{z}$ dan $\bar{\theta}$ dapat diperoleh melalui persamaan berikut :

$$\bar{z} = z_a e^{i\delta} = z_a(\cos\sigma + i\sin\sigma) \qquad (2.59)$$

$$\bar{\theta} = \theta_a e^{i\xi} = \theta_a(\cos\xi + i\sin\xi) \qquad (2.60)$$

dimana :

Za = amplitudo heaving

δ = beda phase untuk heaving

Qa = amplitudo pitching

ξ = beda phase untuk pitching

2.2.3. Gerakan Relatif Bow

Ketika terjadi gerakan kopel heaving - pitching yang diketahui memiliki amplitudo dan fase yang berhubungan dengan permukaan gelombang , gerakan relatif dapat di tentukan dengan menggunakan persamaan berikut :

$$s_\xi = z_\xi - \zeta_\xi \qquad (2.61)$$

dimana : s_ξ adalah gerakan relatif dari titik yang ditanyakan dimana berada pada jarak sumbu x; z_ξ adalah gerakan vertical dari titk ($z + \xi_\theta$); dan ζ_ξ adalah gerakan gelombang dari titik yang ditentukan dan ξ adalah jarak bow terhadap

CG. Kemudian posisi dari bow yang berhubungan dengan gelombang ditentukan dengan persamaan :

$$s_b = z_b - \zeta_\xi \tag{2.62}$$

$$= (z_b)_a \cos(\omega_e t + \varepsilon_b) - \zeta_a \cos(k_e \xi - \omega_e t)$$

$$= (z_b)_a \cos(\omega_e t + \varepsilon_b) - \zeta_a \cos\left(\frac{2\pi\xi}{L_w} + \omega_e t\right) \text{ untuk kondisi head seas.}$$

ketika $z_b > \zeta_b$ kita akan mendapatkan $s_b > 0$ hal ini menunjukkan bahwa deck tidak tercelup kedalam air (+), tetapi apabila $z_b < \zeta_b$ kita akan mendapatkan $s_b < 0$ hal ini menunjukkan bahwa deck tercelup kedalam air (-).

2.2.4. Response Amplitude Operator

Amplitude respon secara umum dipengaruhi oleh amplitudo gelombang. Pada sistem linear, respon berada dalam varian dengan amplitudo gelombang pada frequensi gelombang. Fungsi respon terbentuk ketika frekensi gelombang yang mengenai struktur maka hal inilah yang disebut dengan Response amplitude Operator (RAO) atau disebut juga dengan fungsi transfer, karena terdapat transfer *exciting wave* terhadap respon struktur. Berbagai variasi dari respon itulah yang menyebabkan RAO unik.

Banyak sekali yang menyebutkan dalam praktiknya bahwa RAO didefinisikan sebagai *response amplitude per unit wave height*. Tetapi untuk lebih mudah dalam pemahaman bahwa **RAO didefinisikan sebagai amplitudo respon per amplitudo gelombang** $\left(\frac{s_b}{\zeta_a}\right)$**.** Dalam perhitungan RAO gelombang selalu dianggap sebagai gelombang regular dan frekuensi gelombang yang dipilih dimasukkan kedalam range frekuensi yang dipakai dalam membuatspektrum gelombang. Apabila dalam perhitungan menemui kesulitan dan atau membutuhkan verifikasi asumsi matematika sangat diperlukan maka, perlu dilakukan percobaan terhadap struktur dengan kondisi gelombang regular yang dikontrol didalam laboraturium. Kemudian hasil test model RAO diskala menjadi RAO yang sesunguhnya.

2.2.5. Spektrum Gelombang

Pada gelombang irregular, sejumlah gelombang sinusoidal dengan perbedaan panjang gelombang dan tinggi gelombang membentuk gelombang irregular dengan superposisi.

Dimana energi gelombang sinusoidal deberikan dengan persamaan:

$$\frac{1}{2}\rho g \zeta_a^2 \text{ (per meter persegi dari permukaan gelombang)} \quad (2.63)$$

dimana :

ρ = masa jenis air laut

g = percepatan gravitasi

ζ_a = amplitude gelombang

Sehingga total dari energi per meter persegi untuk semua panjang dan tinggi gelombang.

$$E_T = \frac{1}{2}\rho g\left[\zeta^2_{a1} + \zeta_{a2}^2 + ... + \zeta_{an}^2\right] \quad (2.64)$$

dimana :

E_T = Total energi dari semua komponen gelombang (kN/m)

Adapun gelombang-gelombang tersebut dapat digambarkan oleh distribusi energi terhadap frekuensi atau periode dengan bermacam-macam komponen .

Distribusi frekuensi energi disebut *Spectrum Energi*. Total energi spectrum digambarkan oleh luasan dibawah kurva untuk semua komponen gelombang. Dimana luasan dibawah kurva dirumuskan dengan persamaan.

$$mo = \int_0^{\infty} S_{\zeta}(\omega_w) d\omega_w$$

dimana:

mo = luasan dibawah kurva

$S_{\zeta}(\omega_w)$= energi gelombang fungsi frekuensi gelombang

Sedangkan untuk memperoleh Hs dari gelombang yang terjadi dapat dirumuskan dengan.

$$(h_w)_{1/3} = 4\sqrt{area} \qquad \text{atau} \qquad (h_w)_{1/3} = 4\sqrt{mo}$$

2.2.5.1.Spektrum Gelombang ITTC

Ketika spectrum gelombang pada laut normal tidak bisa diwakili oleh suatu spectrum yang memadai, maka International Towing Tank Conference (ITTC) bisa digunakan sebagai persamaan:

$$S(\omega_w) = \frac{A}{\omega_w^5} e^{-B/\omega^4_w} \qquad (2.65)$$

dimana :

ω_w = frekuensi gelombang (rad/s)

A =8,1 x $10^{-2}g^2$

g = percepatan gravitasi (m/s^2)

B = 3,11 x 10^4/Hs

Hs = tinggi gelombang significant (m)

$S(\omega_w)$ = spektrum gelombang (m^2-sec)

Untuk mengubah spektrum gelombang kedalam spektrum gelombang encountering maka frekuensi gelombang (ω_w)juga harus diubah kedalam bentuk frekuensi encountering (ω_e) yakni :

$$\omega_e = \omega_w - \frac{\omega_w V}{g}\cos\mu \qquad (2.66)$$

dimana : V = keceptan kapal

μ = sudut pertemuan gelombang (head sea = 180 ^{0})

Karena energi spektrum total pada permukaan air adalah sama maka :

$$\int S_\zeta(\omega_e)d\omega_e = \int S_\zeta(\omega_w)d\omega_w \qquad (2.67)$$

dengan $\omega_e = \omega_w - \frac{\omega_w V}{g}\cos\mu$ maka

$\frac{d\omega_e}{d\omega_w} = 1 - \frac{2\omega_w}{g}\cos\mu$ sehingga

$$S_\zeta(\omega_e)d\omega_e\left(1-\frac{2\omega_w}{g}\cos\mu\right)=S_\zeta(\omega_w)d\omega_w$$

$$\text{atau } S_\zeta(\omega_e)=\frac{S_\zeta(\omega_w)}{1-\left(2\omega_w V/g\right)\cos\mu} \tag{2.68}$$

dan apabila ditulis dalam ω_e maka persamaan diatas menjadi :

$$S_\zeta(\omega_e)=S_\zeta(\omega_w)\frac{1}{\left[1-(4\omega_e V/g)\cos\mu\right]^{1/2}} \tag{2.69}$$

dimana : $S_\zeta(\omega_e)$ adalah spektrum gelombang encountering (m^2-sec)

2.2.6. Response Spectra

Respon spektra didefinisikan sebagai density respon energi dari struktur akibat input energi gelombang dan density sepektrum energi. Pada sistem linear, respon spektra didapat dengan mengkuadratkan RAO yang kemudian dikalikan dengan spektrum gelombang, yang secara persamaan ditulis :

$$S_R(\omega)=[RAO(\omega)]^2 S(\omega) \tag{2.70}$$

dimana :

S_R = Respon spektrum (ft^2-sec)

$S(\omega)$ = Spektrum gelombang (ft^2-sec)

RAO = Response Amplitude Operator

ω = frekuensi gelombang (rad/sec)

Untuk membantu dalam menganalisa probability dari deckwetness perlu didapat terlebih dahulu amplitudo signifikan respon spektra dengan menggunakan persamaan :

$$(s_a)_{1/3} = 2x\sqrt{m_0}\,xCF \qquad (2.71)$$

dimana : $\int S_\zeta(\omega_e)d\omega_e = m_0$

CF = Faktor koreksi

$= \left(1-\varepsilon^2\right)^{1/2}$

$\varepsilon^2 = \dfrac{m_0 m_4 - m_{2s}^2}{m_0 m_4}$ sedangkan $\int \omega_e^2 S_\zeta(\omega_e)d\omega_e = m_2$

$\int \omega_e^4 S_\zeta(\omega_e)d\omega_e = m_4$

2.2.7. Slamming

Slamming merupakan kondisi dimana haluan menumbuk ombak dan karena gerakan tersebut terjadi secara tiba-tiba, maka akan mengakibatkan adanya gaya impact pada haluan.

Karena adanya gerakan bangunan apung, maka akan mengakibatkan 2 macam tekanan impact:

1. Impact terjadi ketika haluan membentur permukaan air selama gerakan pitching.
2. Impact terjadi pada beberapa bagian lambung ketika beam sea, astern sea, diagonal sea, dan gerakan lainnya.

Ketika haluan bangunan apung tercelup dan ketika tiba-tiba gelombang kembali masuk dengan kecepatan yang relatif besar, slamming dapat terjadi. Selanjutnya ada 3 kondisi kinematis untuk menjelaskan slamming:

1. Haluan tercelup.

   Pada umumnya, slamming berhubungan dengan tercelupnya haluan, didefinisikan sebagai perpotongan titik perpendicular depan dan perpanjangan dari keel , selama gaya impact maximum terjadi oleh bagunan apung, maka gaya impact terjadi secara tiba-tiba.

2. Perbedaan phase antara gerakan gelombang dan gerakan haluan.

   Jika gerakan ke bawah haluan bertemu dengan gerakan keatas gelombang (perbedaan antara gerakan gelombang dan haluan adalah 180^0), maka kondisi kritis untuk slamming terjadi.

3. Magnitude kecepatan relatif haluan.

   Jika kecepatan relatif haluan lebih besar dari harga kritis, bangunan apung kemungkinan akan mengalami slamming. Selama harga kecepatan relatif tergantung pada kecepatan bagunan apung, perubahan kecepatan akan menambah atau mengurangi slamming.

2.2.7.1 Probabilitas Slamming

Slamming akan terjadi apabila relatif displacement melebihi dari jarak antara wetdeck dengan permukaan air, dirumuskan dengan:

$$|Z_{drel}| > Z_{cx} \tag{2.72}$$

Dimana Z_{cx} = Jarak antara wetdeck dengan permukaan air. (m)

Z_{drel} = Relatif displacement (m).

Maximum relatif vertical displacement di titik permukaan gelombang dapat dicari dengan persamaan:

$$Z_{drel}(x) = Z_{dabs}(x) - \zeta(x) \tag{2.73}$$

$$Z_{dabs}(x) = \zeta_3(t) - x\zeta_5(t) \tag{2.74}$$

Dimana Z_{dabs} = Absolute vertical motion.

ζ = Tinggi gelombang pada calm water (m)

ζ_3 = Heave elevation (m).

ζ_5 = Pitch elevation (m).

Pendekatan secara probabilitas untuk menentukan peluang kejadian slamming bisa digunakan untuk memprediksi karakteristik slamming. Pendekatan probabilitas hanya bisa digunakan bila prediksi motion dengan domain frekuensi tersedia.

Pada konteks ini, karakteristik slamming HYCAT mengacu pada 3 perbedaan, tetapi masih ada korelasi, kualitas kejadian slamming, frekuensi kejadian slamming, jumlah kejadian slamming per unit time dan magnitudo impact terbesar yang diharapkan terjadi pada bagian dasar deck selama waktu operasi. Seperti pada perhitungan probabilitas slamming pada kapal monohull, faktor dominan yang harus diperhatikan untuk menghitung probabilitas slamming disamping relatif vertikal motion, juga harus diperhatikan syarat kapal, dimana slamming akan diamati. Pada kasus HYCAT faktor syarat ditentukan dengan clearance antara dasar deck dengan water level.

Dari pertimbangan kedua faktor diatas, maka probabilitas kejadian slamming dapat dirumuskan menjadi.

$$\Pr(\text{slam impact}) = \exp\left\{-\frac{Z_{cx}^{\ 2}}{2E_d}\right\} \qquad (2.75)$$

Dimana E_d = Variance dari relatif vertikal displacement.

Z_{cx} = Jarak antara wetdeck dengan permukaan air. (m)

Ed dapat dihitung dengan mengambil RAO relatif motion yang diambil dari spektrum gelombang,

$$E_d = \int_0^\infty (Z_{drel}/\zeta_w)^2 S(\omega) d\omega \qquad (2.76)$$

Dimana Z_{drel} = Relatif displacement (m).

ς_w = Amplitudo gelombang (m).

$S(\omega)$ = Spektrum gelombang.

Probabilitas slamming pada persamaan (2.75) lebih mempunyai arti, apabila jumlah kejadian slamming terjadi pada per satuan waktu. Formula diatas digunakan untuk menghitung slamming per satuan waktu :

$$n_s = \frac{1}{2\pi}\sqrt{\frac{E_v}{E_d}}\exp\left\{-\frac{Z_{cx}{}^2}{2Ed}\right\} \qquad (2.77)$$

Dimana Ev = Varian dari relatif vertikal motion.

$$E_v = \int_0^\infty (\omega Z_{drel} / \zeta_w)^2 S(\omega) d(\omega) \qquad (2.78)$$

Pada persamaan (2.75) dapat dikembangkan untuk menghitung kejadian slamming pada T jam, dengan persamaan :

$$N_s = \frac{3600T}{2\pi}\sqrt{\frac{E_v}{E_d}}\exp\left\{-\frac{Z^2{}_{cx}}{2E_d}\right\} \qquad (2.79)$$

Mengacu pada persamaan (2.75) yang digunakan pada keadaan ideal, dimana setiap kontak antara wetdeck dan water surface dianggap sebagai slamming.

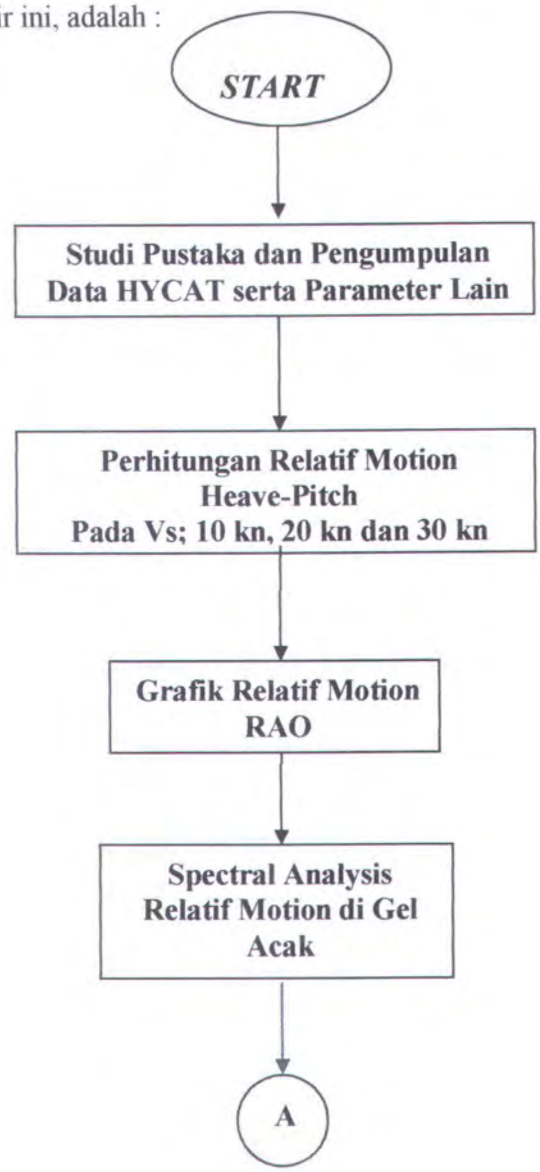
BAB III
METODOLOGI PENELITIAN

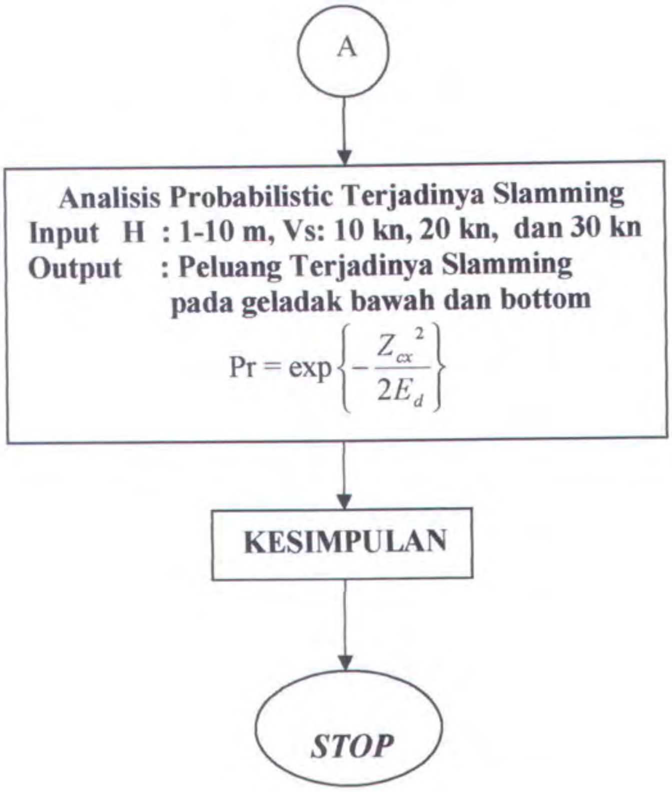
BAB III

METODOLOGI PENELITIAN

3.1. Diagram Alir

Adapun urutan kegiatan atau diagram alir dari penelitian dan penulisan laporan tugas akhir ini, adalah :





Gambar 3.1 Diagram Alir Metodologi

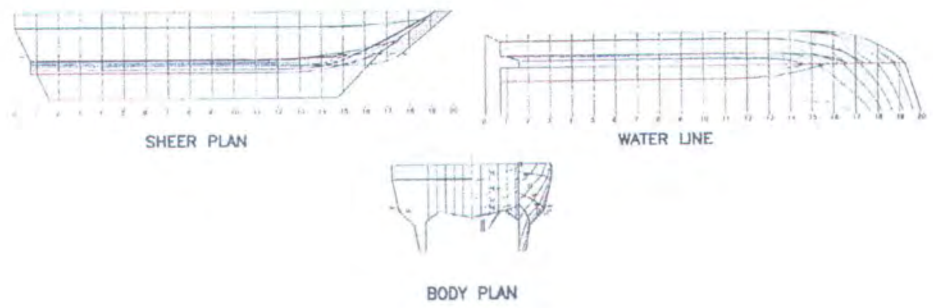
3.2. Metodologi Penelitian

Metodologi yang dilakukan dalam studi ini ada beberapa tahapan ,dimana tahapan-tahapan tersebut merupakan langkah yang digunakan dalam proses perhitungan. Adapun langkah tersebut ialah :

1. Pengumpulan data serta studi literatur. Data kapal diperoleh dari Laboratorium Hidrodinamika Indonesia (LHI), yang merupakan principal dimension dari model yang selanjutnya dikonversikan menjadi ukuran prototype (full scale). Dimensi kapal dapat dilihat pada gambar 3.2, dengan principal dimension sebagai berikut :

Tabel 3.1 Principal Dimension

Bagian	Ukuran
LOA	24,6 m
Lebar	9,1 m
Sarat	2,5 m
Displacement	330 ton



Gambar 3.2 Geometri HYCAT

2. Langkah selanjutnya menghitung relatif motion untuk gerakan kopel heaving-pitching pada kecepatan kapal 10 knot, 20 knot, dan 30 knot dengan memvariasikan frekuensi gelombang.
3. Mempresentasikan relatif motion tersebut dalam grafik RAO.
4. Melakukan Spectral Analisis Relatif Motion, dengan mengalikan spektrum gelombang menggunakan spektrum ITTC dengan RAO pada $H_{1/3}$ = 1 m – 10 m.
5. Menghitung probabilitas kejadian slamming pada daerah yang ingin ditinjau dengan melihat Spectral Analisis Relatif Motion. Untuk lebih jelasnya dapat dilihat pada flowchart dibawah.
6. Melakukan pengkajian dan pembahasan terhadap hasil analisa untuk akhirnya dapat mengambil kesimpulan studi.

3.3 Sistematika Penulisan

Dalam penyelesaian penyusunan Tugas Akhir ini, telah disusun sistematika sebagai berikut :

BAB I Pendahuluan

Diuraikan mengenai dasar pemikiran dan latar belakang yang melandasi penelitian ini, perumusandan batasan permasalahan serta tujuan yang hendak dicapai.

BAB II Tinjauan Pustaka dan Landasan Teori

Diuraikan mengenai tinjauan pustaka yang dipakai dalam penelitian, hukum kesamaan, dan pemilihan teori gelombang yang sesuai, gerakan struktur terapung, formulasi tahanan secara teoritis.

BAB III Metodologi Penelitian

Berisi penjelasan dan uraian tentang persiapan model HYCAT, serta diagram alir dari penulisan.

BAB IV Hasil dan Pembahasan

Diuraikan mmengenai perhitungan teoritis, dimana hasil tersebut ditampilkan dalam bentuk garfik-grafik.

BAB V Kesimpulan dan Saran.

Berisi kesimpulan hasil percobaan , hasil perbandingan serta saran untuk penyempurnaan hasil penelitian.

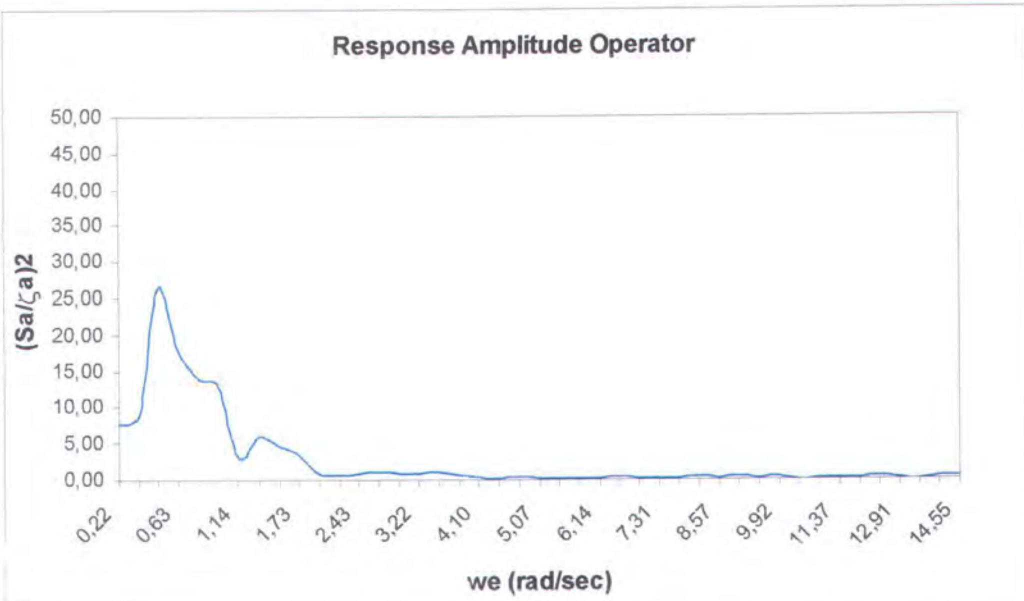
BAB IV
ANALISIS DATA DAN PEMBAHASAN

BAB IV

ANALISA DATA DAN PEMBAHASAN

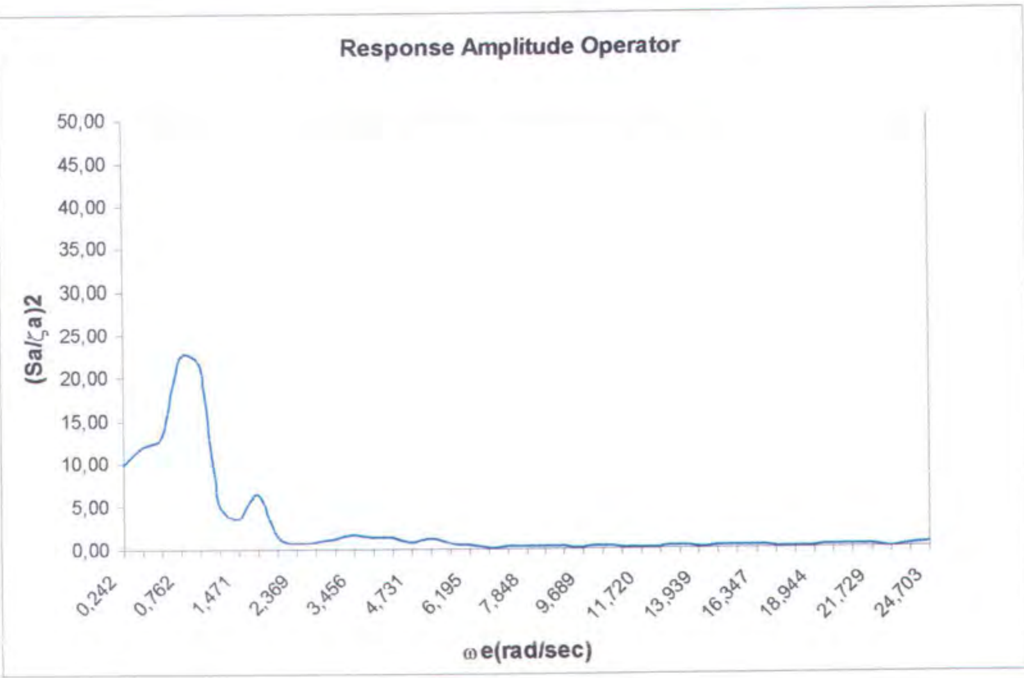
4.1 Hasil Perhitungan

Dari perhitungan yang dilakukan dengan memvariasikan kecepatan HYCAT dan tinggi gelombang significant yang berbeda dapat dihasilkan Respon Amlitudo Operator. Dengan menggunakan persamaan $\left(\frac{s_b}{\zeta_a}\right)$ maka dapat dihasilkan grafik Respon Amplitudo Operator dengan sumbu axis frekuensi encountering :



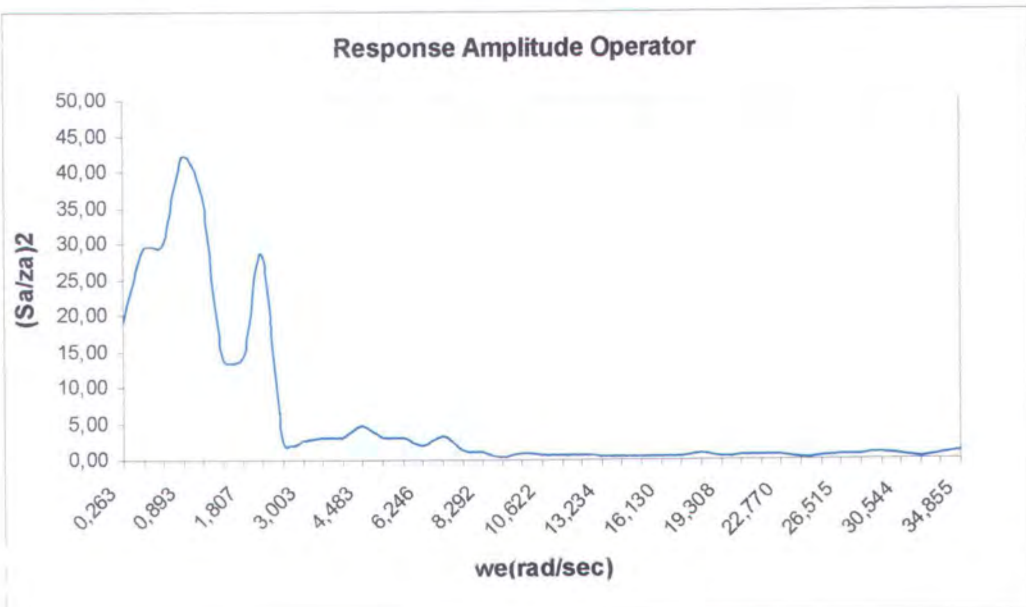
Gambar 4.1 Grafik RAO untuk Vs=10 knot

Pada gambar 4.1 untuk kecepatan 10 knot memiliki nilai rasio tertinggi pada nilai berkisar 26,382 dengan frekuensi encountering pada 0,484 mulai pada frekuensi diatas 1,95 nilai rasio mulai melandai.



Gambar 4.2 Grafik RAO untuk Vs=20 knot

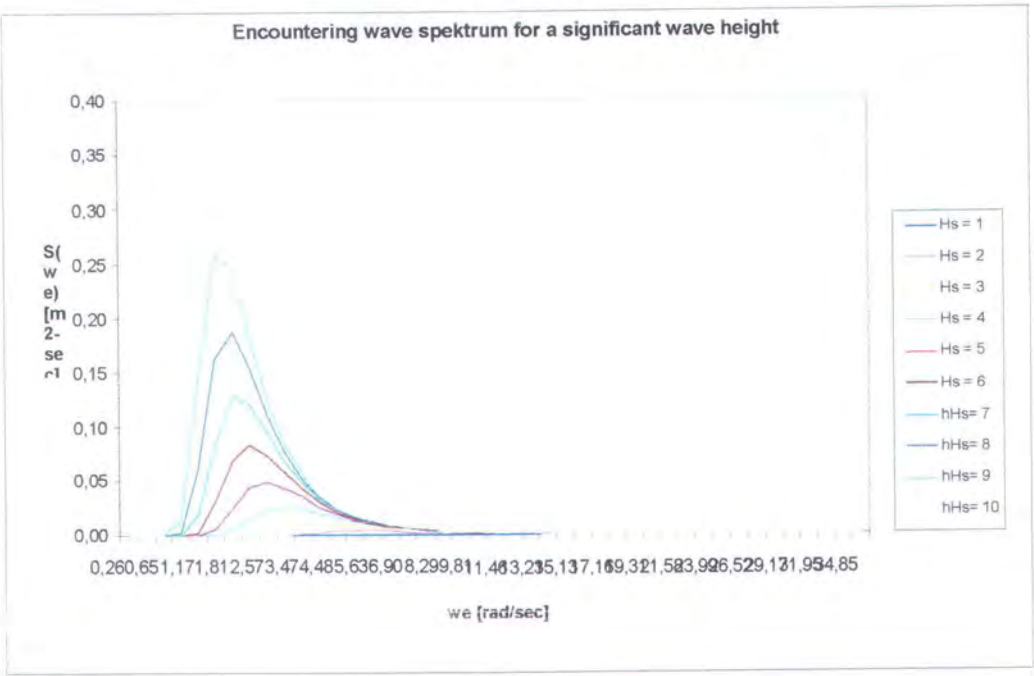
Sedangkan untuk gambar 4.2 kecepatan catamaran pada Vs= 20 knot memiliki nilai rasio tertinggi pada 22,427 dengan frekuensi encouentering pada 0,762. Sedangkan pada nilai rasio diatas 5,868 trend grafik mulai melandai.



Gambar 4.3 Grafik RAO untuk Vs=30 knot

Untuk kecepatan catamaran Vs= 30 knot pada gambar 4.3 memiliki rasio tertinggi pada nilai 42,192 dengan frekuensi encountering 0,893. Sedangkan trend grafik mulai melandai pada frekuensi encountering diatas 9,037.

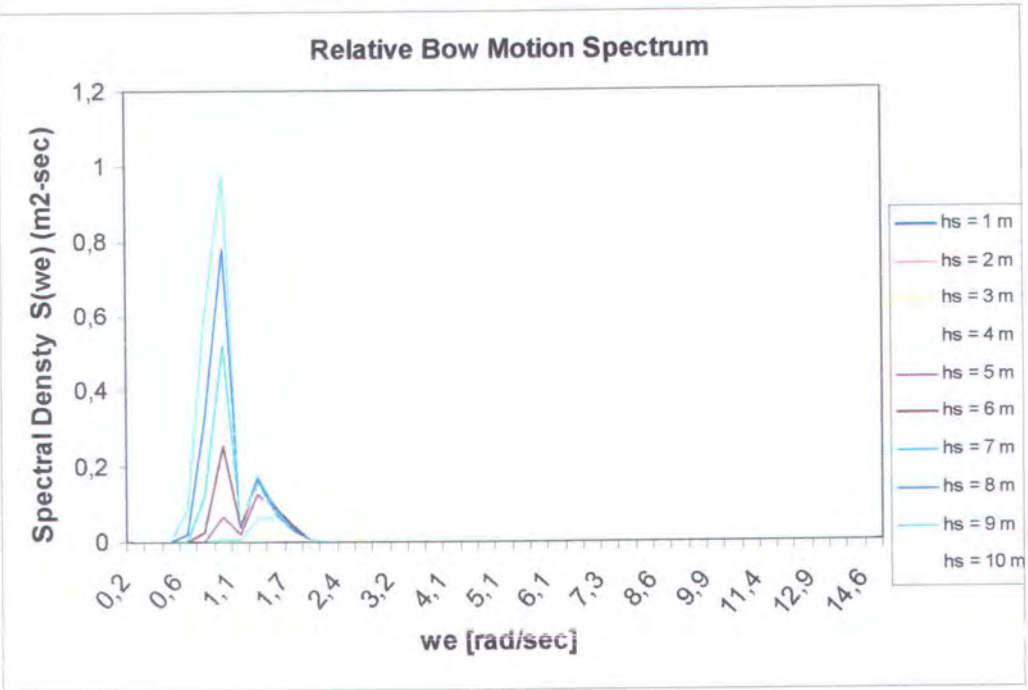
Apabila Respon Amplitudo Operator dari suatu gerakan benda apung bekerja pada suatu daerah perairan dimana memiliki spectrum gelombang , maka akan dihasilkan suatu respon spektra. Pendekatan spektrum gelombang yang digunakan adalah ITTC.



Gambar 4.4 Spektrum Gelombang ITTC dengan Variasi Hs

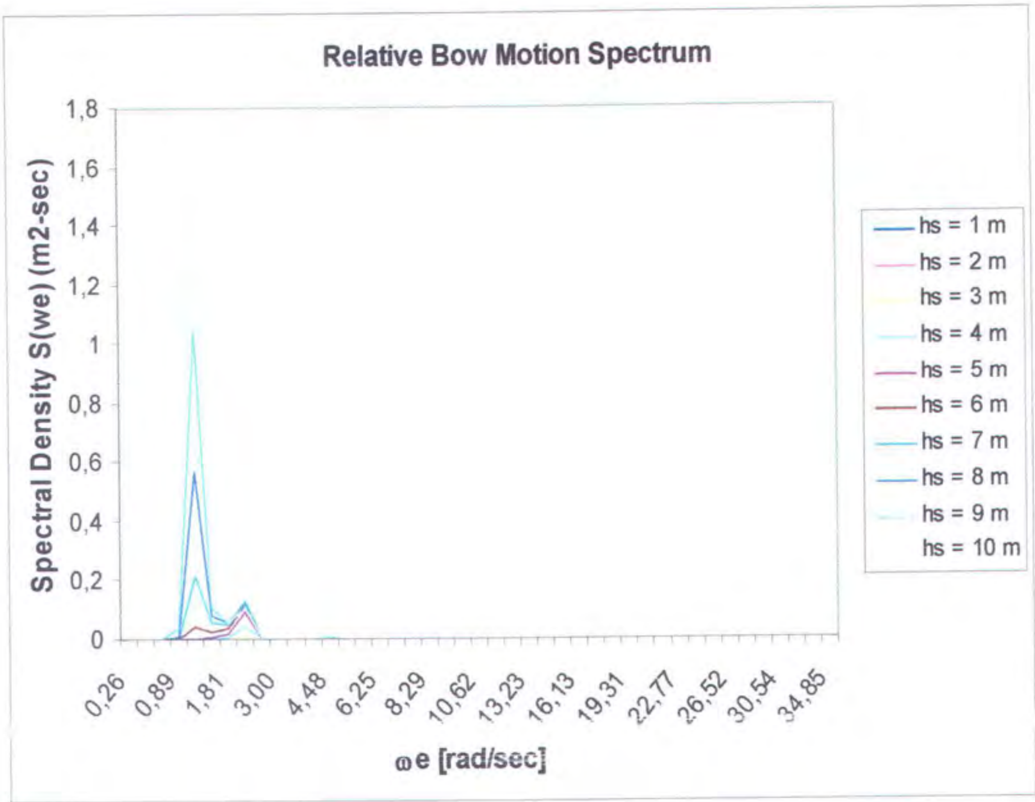
Pada gambar 4.4 spectrum gelombang yang dipakai ITTC (International Towing Tank Conference) dengan $\Delta\omega$=0,1. Dengan Hs mulai dari 1-10 meter, sehingga didapatkan grafik diatas dengan peak frekuensi encountering berkisar 3.

Respon spektra adalah $S_R(\omega) = [RAO(\omega)]^2 S(\omega)$. Dari perhitungan diperoleh grafik Respon Spektra untuk variasi kecepatan sebagai berikiut.



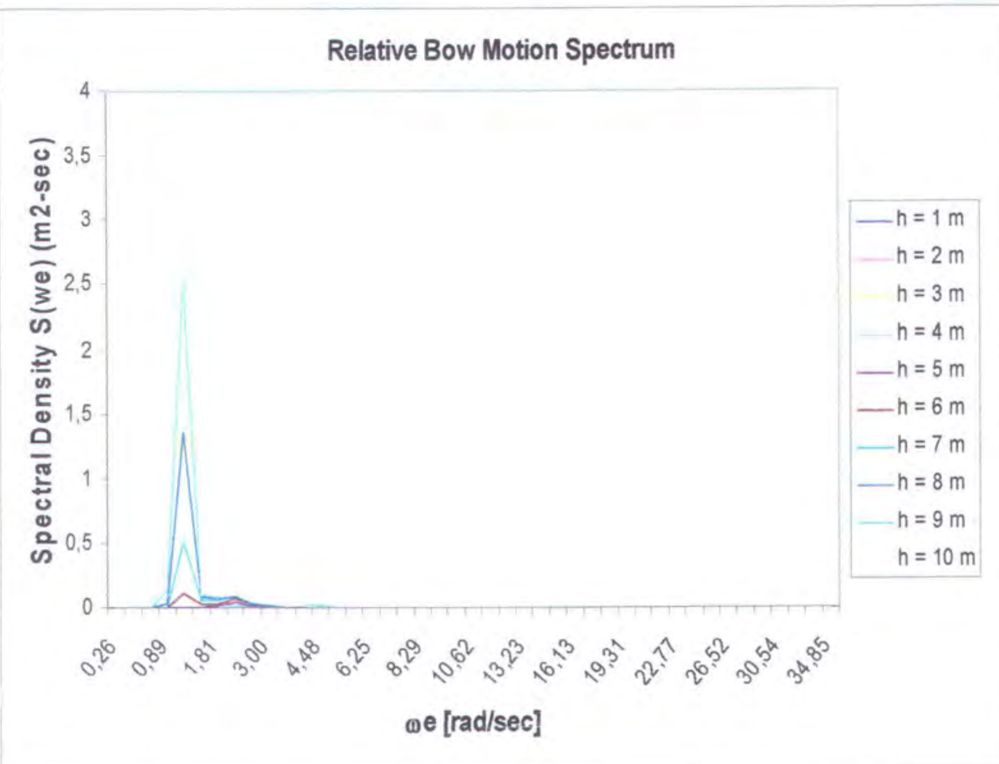
Gambar 4.5 Relatif Bow Motion Spektrum untuk Vs = 10 knot

Pada gambar 4.5 adalah Relarif Bow Motion Spektrum untuk 10 knot, didapatkan peak berkisar pada 1,1 pada frekuensi encountering 1,1. Pada frekuensi encountering 2,4 grafik mulai melandai .



Gambar 4.6 Relatif Bow Motion Spektrum untuk Vs =20 knot

Pada gambar 4.6 merupakan Relatif Bow Motion untuk kecepatan 20 knot, dimana peak terjadi pada 1,5 dengan frekuensi encouentering berkisar pada 1,81. Pada frekuensi encouentering 3 grafik mulai melandai.



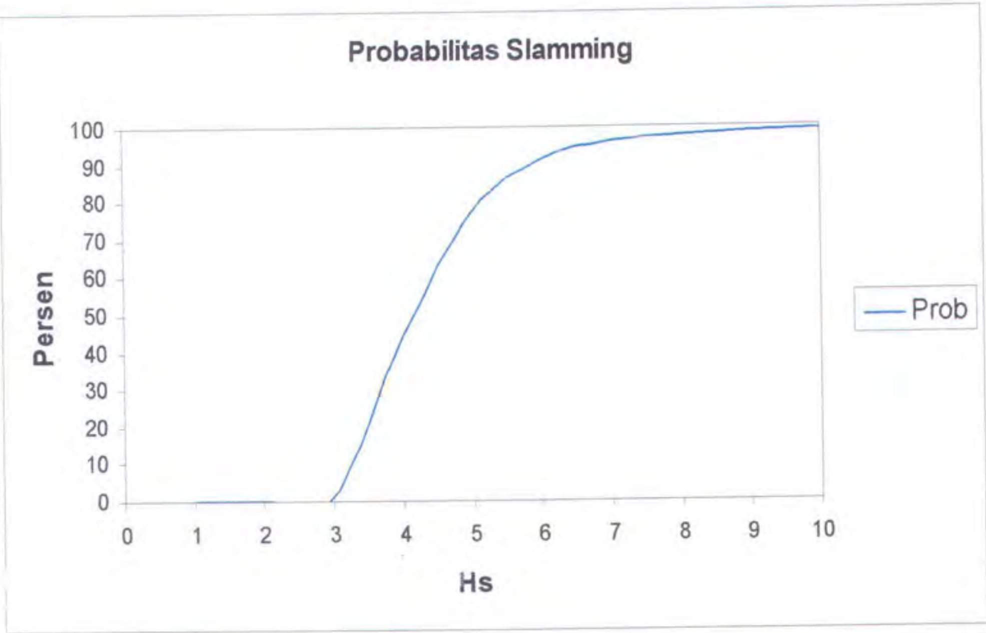
Gambar 4.7 Relatif Bow Motion Spectrum untuk Vs =30 knot

Untuk gambar 4.7 Relatif Bow Motion untuk kecepatan 30 knot, dimana peak terjadi pada 3,8 dengan frekuensi encouentering berkisar pada 1,81. Pada frekuensi encouentering 3 grafik mulai melandai.

Setelah mendapatkan grafik Relatif Bow Motion Spektrum, maka dapat dihitung probabilitas dari slamming untuk masing-masing varisai kecepatan .

Probabilitas slamming = $\exp\left\{-\frac{Z_{cx}^{\ 2}}{2E_d}\right\}$, dimana Zcx merupakan jarak antara permukaan air dengan wetdeck, pada catamaran ini jarak Zcx sejauh 0.5 meter dari permukaan air. Dapat pula probabilitas slamming dapat ditinjau pada Zcx yang berbeda pada catamaran, sedangkan $E_d = \int_0^\infty (Z_{drel}/\zeta_w)^2 S(\omega) d\omega$ adalah variance dari relatif displacement.

Sehingga didapatkan grafik probabilitas sebagai berikut:

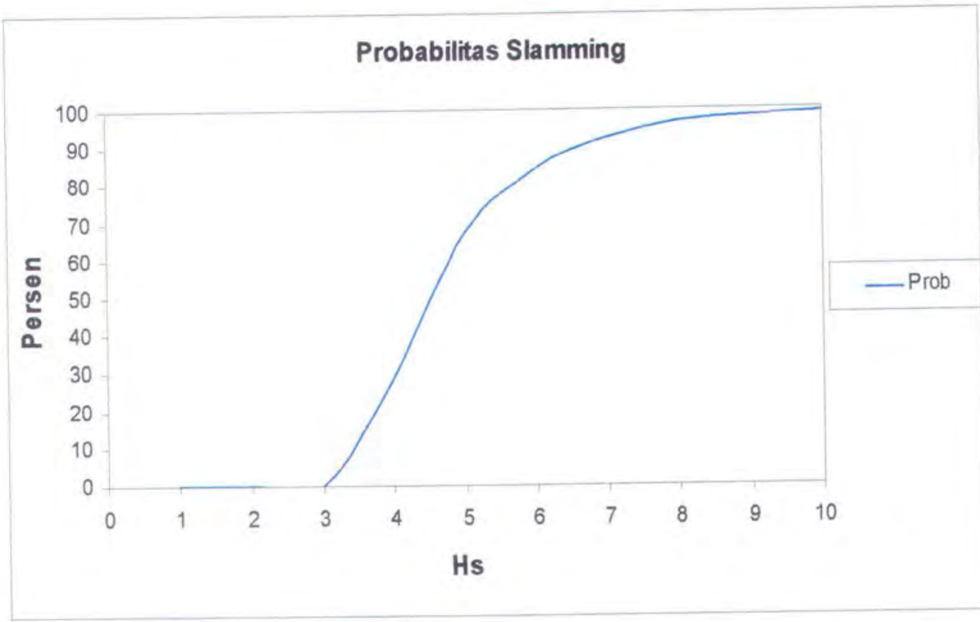


Gambar 4.8 Probabilitas Slamming untuk Vs =10 knot

Pada kecepatan 10 knot probabilitas slamming mulai terjadi pada Hs= 3 m dengan probabilitas 1,55%.Trend grafik terus naik sehingga pada Hs=10 m nilai probabilitas menjadi 99,154%. Untuk lebih jelasnya dapat dilihat pada table berikut.

Tabel 4.1 Probabilitas Slamming untuk Vs= 10 knot

H	Prob
1	0,000
2	0,000
3	1,555
4	44,428
5	77,547
6	91,034
7	95,890
8	97,794
9	98,676
10	99,150

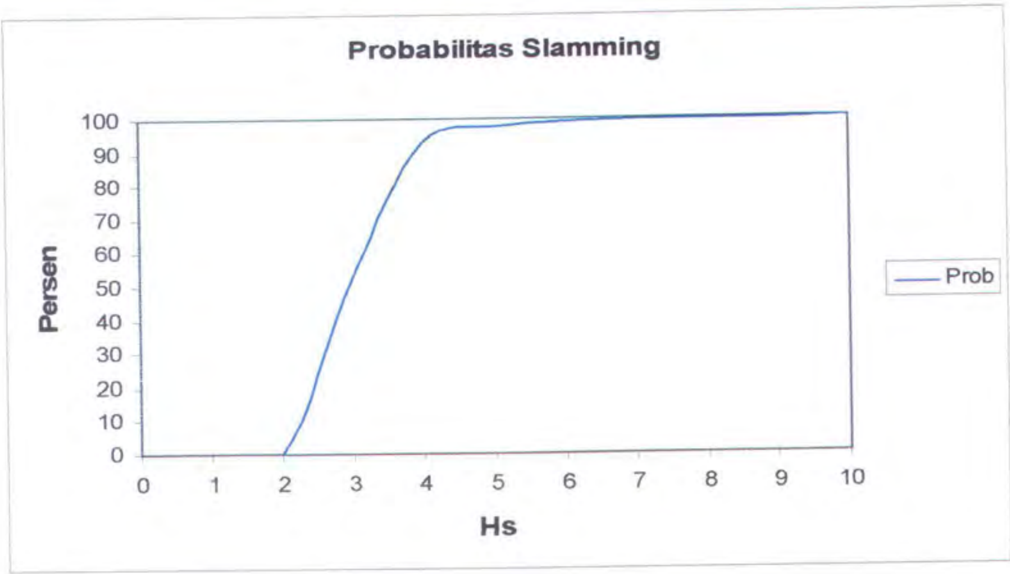


Gambar 4.9 Probabilitas Slamming untuk Vs =20 knot

Dengan ditambahnya kecepatan catamaran menjadi Vs= 20 knot, maka akan didapatkan probabiltas 0,05% pada Hs= 3 m, pada Hs dibawah nilai tersebut probabilitas slamming belum terjadi. Trend grafik akan terus naik hingga pada Hs= 10 m probabilitas slamming menjadi 99,092%. Atau bisa dilihat pada table dibawah ini.

Tabel 4.2 Probabilitas Slamming untuk Vs= 20 knot

H	Prob
1	0,000
2	0,000
3	0,050
4	28,711
5	67,218
6	84,265
7	92,687
8	96,604
9	98,316
10	99,092



Gambar 4.10 Probabilitas Slamming untuk Vs =30 knot

Dengan ditambahnya kecepatan catamaran hingga mencapai Vs= 30 knot, probabilitas slamming akan terus mengalami perubahan, pada Hs = 2 m slamming sudah mulai terjadi dengan probabilitas 0,215%. Trend grafik tersebut akan terus naik sejalan dengan bertambahnya Hs, hingga pada akhirnya probabilitas menjadi 99,882% pada Hs= 10 m. Grafik diatas dapat digambarkan pada table dibawah ini.

Tabel 4.3 Probabilitas Slamming untuk Vs= 30 knot

H	Prob
1	0,000
2	0,215
3	53,125
4	92,906
5	97,729
6	98,878
7	99,336
8	99,579
9	99,727
10	99,822

4.2. Analisa Data dan Pembahasan

Probabilitas slamming memiliki kecenderungan selalu naik sejalan dengan bertambahnya kecepatan catamaran dan tinggi gelombang. Pada kecepatan 20 knot probabilitas slamming mulai terjadi pada Hs 3 meter dengan persentase 0,05%, persentase ini cenderung turun jika dibandingkan pada kecepatan 10 knot, dimana pada Hs yang sama persentase slamming sebesar 1,555%, sedangkan pada kecepatan 30 knot pada Hs yang sama probabilitas cenderung naik secara significant jika dibandingkan dengan kecepatan 10 dan 20 knot yaitu mencapai persentase sebesar 53,125%. Untuk semua kecepatan, persentase slamming mulai menunjukkan nilai yang significant pada Hs 3 meter. Hal ini disebabkan karena struktur catamaran yang memiliki struktur lambung ganda dengan WSA yang kecil jika dibandingkan kapal-kapal konvensional pendahulunya dapat meminimalisir terjadinya slamming. WSA menentukan olah gerak dari suatu benda apung dan juga merupakan faktor terpenting dari slamming. Dengan WSA yang relatif kecil dan koefisien midship yang relatif ramping, maka suatu catamaran dengan lambung gandanya akan dapat dengan mudah membelah gelombang dengan tidak mengurangi kecepatannya.

BAB V
PENUTUP

BAB V

KESIMPULAN DAN SARAN

5.1 Kesimpulan

Dari hasil perhitungan prediksi slamming pada HYCAT serta analisa probabilitas pada kecepatan yang berbeda, dapatlah diambil beberapa kesimpulan berikut :

1. Relatif bow motion spektrum Vs = 10 knot mendapatkan peak spektrum pada ω_e = 1,1. Sedangkan pada Vs= 20 knot mendapatkan peak spektrum pada ω_e= 1,81. Pada Vs= 30 knot peak spektrum terjadi pada ω_e = 1,8.
2. Pada Vs = 10 knot slamming mulai terjadi pada Hs = 3m dengan probabilitas 1,55%. Untuk Vs = 20 knot slamming mulai terjadi pada Hs = 3 m dengan probabilitas 0,05%, sedangkan pada kecepatan 30 knot slamming mulai terjadi pada Hs = 2 m dengan probabilitas slamming 0,215%.
3. Setelah melihat dari hasil pembahasan dan analisa, dimana slamming pada catamaran mulai terjadi pada tinggi gelombang significant 3 meter. Maka dapat dikatakan bahwa catamaran tersebut relatif nyaman bila dioperasikan pada perairan Indonesia, dimana perairan Indonesia tinggi gelombang rata-rata tidak melebihi 3 meter.

5.2 Saran

Adapun saran yang bisa diberikan pada penulisan Tugas Akhir ini bisa digunakan sebagai kajian akan studi mengenai catamaran pada masa yang akan datang.

1. Prediksi slamming tidak hanya pada gelombang *head seas* melainkan dapat dipertimbangkan untuk arah gelombang *beam seas, following seas.*
2. Untuk menambah ketelitian dalam menghitung masa tambah catamaran dapat dilakukan dengan menggunakan metode lain. (*metode frank close fit*).
3. Penghitungan prediksi slamming seyogyanya dibarengi dengan adanya percobaan pada skala model di *Towing Tank.*

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LAMPIRAN

LAMPIRAN 1
LEMBAR ASISTENSI

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Prediksi Slamming Pada HYCAT Akibat Gerakan Kopel Heaving dan Pitching Pada Gelombang Acak

NO	TGL	MATERI KONSULTASI	TANDA TANGAN
	25/1 03	Pengambilan data di LHI	[signature]
	30/1 03	Perumusan Masalah	[signature]
	10/3 03	Asistensi Bab I	[signature]
	10/5 03	Asistensi Bab II	[signature]
	10/6 03	Metodologi penelitian.	[signature]
	5/8 03	Perhitungan relatif motion dan RAO	[signature]
	10/11 03	Asistensi Bab IV	[signature]
	30/11 03	Revisi.	[signature]
	8/1 03	kesimpulan.	[signature]

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NO	TGL	MATERI KONSULTASI	TANDA TANGAN
	25/1 03	Pengambilan data di LHI	[signature]
	30/1 03	Perumusan masalah	[signature]
	10/3 03	Asistensi Bab I	[signature]
	10/5 03	Asistensi Bab II	[signature]
	10/6 03	Metodologi Penelitian.	[signature]
	15/8 03	Perhitungan relatif motion	[signature]
	10/11 03	Asistensi Bab IV	[signature]
	30/11 03	Bab Kesimpulan	[signature]
	8/1 03	Keseluruhan.	[signature]

LAMPIRAN 2
PERHITUNGAN MASA TAMBAH

DATA KAPAL.

Type	= CATAMARAN		
Panjang (L_{pp})	= 24.6	m.	
Lebar (B)	= 9.1	m.	
Tinggi (H)	= 4.885	m.	
Sarat (T)	= 2.5	m.	
Koefisien Block (C_b)	= 0.71		
Kecepatan (V_s)	= 30 knot	MODEL	15.432 m/s
Sarat ($T_{free\ board}$)	= 3.920	m.	
LCG	= 0.983	m.	
Displacement (Δ)	= 407.285	ton.	
Gaya grafitasi (g)	= 9.81	m/sec^2.	3995.47 kN.
Berat jenis air laut (ρ)	= 1.025	ton/m^3.	

ω_w	ω_e	L_w	$h_w = L_w/20$	$\zeta_a = h_w/2$		
0.2	0.263	1540.951	77.048	38.524	1	0.983
0.3	0.442	684.867	34.243	17.122	2	
0.4	0.652	385.238	19.262	9.631	3	
0.5	0.893	246.552	12.328	6.164	4	
0.6	1.166	171.217	8.561	4.280	5	
0.7	1.471	125.792	6.290	3.145	6	
0.8	1.807	96.309	4.815	2.408	7	
0.9	2.174	76.096	3.805	1.902	8	
1	2.573	61.638	3.082	1.541	9	
1.1	3.003	50.941	2.547	1.274	10	
1.2	3.465	42.804	2.140	1.070	11	
1.3	3.959	36.472	1.824	0.912	12	
1.4	4.483	31.448	1.572	0.786	13	
1.5	5.039	27.395	1.370	0.685	14	
1.6	5.627	24.077	1.204	0.602	15	
1.7	6.246	21.328	1.066	0.533	16	
1.8	6.897	19.024	0.951	0.476	17	
1.9	7.579	17.074	0.854	0.427	18	
2	8.292	15.410	0.770	0.385	19	
2.1	9.037	13.977	0.699	0.349	20	
2.2	9.814	12.735	0.637	0.318	21	
2.3	10.622	11.652	0.583	0.291	22	
2.4	11.461	10.701	0.535	0.268	23	
2.5	12.332	9.862	0.493	0.247	24	
2.6	13.234	9.118	0.456	0.228	25	
2.7	14.168	8.455	0.423	0.211	26	
2.8	15.133	7.862	0.393	0.197	27	
2.9	16.130	7.329	0.366	0.183	28	
3	17.158	6.849	0.342	0.171	29	
3.1	18.217	6.414	0.321	0.160	30	
3.2	19.308	6.019	0.301	0.150	31	
3.3	20.431	5.660	0.283	0.142	32	
3.4	21.585	5.332	0.267	0.133	33	
3.5	22.770	5.032	0.252	0.126	34	
3.6	23.987	4.756	0.238	0.119	35	
3.7	25.236	4.502	0.225	0.113	36	
3.8	26.515	4.269	0.213	0.107	37	
3.9	27.827	4.052	0.203	0.101	38	
4	29.169	3.852	0.193	0.096	39	
4.1	30.544	3.667	0.183	0.092	40	
4.2	31.949	3.494	0.175	0.087	41	
4.3	33.386	3.334	0.167	0.083	42	
4.4	34.855	3.184	0.159	0.080	43	

ABLE 1 CALCULATIONS FOR a_z AND A_{yy}

Scale	=	1	9							
Vmodel	=	#VALUE!	Ww =	2.092	Amplitudo =	1.5	kyy =	0.68325		
Periode	=	3	We =	0.263	Disp =	407.285				
Lw	=	14.06	h =	3	s =	2.457				

St No. (1)	B_n [m] (2)	T_n [m] (3)	S_n [m²] (4)	ξ [m] (5)	$\frac{\omega_e^2 \times B_n}{2g}$ [-] (6)	$\frac{B_n}{T_n}$ [-] (2) / (3) (7)	$B_n \times T_n$ [m²] (2) x (3) (8)	β_n [-] (4) / (8) (9)	C [-] (10)	B_n^2 [-] (2) x (2) (11)	$\frac{\rho\pi}{8} \times B_n^2$ [kN-sec²/m²] (12)	a_n [kN-sec²/m²] (12) x (10) (13)	Simpson's Multiplier (14)	Product (13) x (14) (15)	ξ^2 [m²] (5) x (5) (16)	$a_n \times \xi^2$ [kN-sec²] (13) x (16) (17)	Simpson's Multiplier (18)	Pr (17
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	
2	8.397	2.500	19.076	7.290	0.030	3.359	20.993	0.909	1.315	70.510	28.381	37.321	4	149.286	53.144	1983.412	4	
4	8.397	2.500	19.076	4.860	0.030	3.359	20.993	0.909	1.315	70.510	28.381	37.321	2	74.643	23.620	881.516	2	
6	8.397	2.500	19.076	2.340	0.030	3.359	20.993	0.909	1.315	70.510	28.381	37.321	4	149.286	5.476	204.357	4	
8	8.397	2.500	19.041	-0.090	0.030	3.359	20.993	0.907	1.315	70.510	28.381	37.321	2	74.643	0.008	0.302	2	
10	8.397	2.500	18.797	-2.520	0.030	3.359	20.993	0.895	1.315	70.510	28.381	37.321	4	149.286	6.350	237.006	4	
12	8.397	2.500	18.304	-5.040	0.030	3.359	20.993	0.872	1.315	70.510	28.381	37.321	2	74.643	25.402	948.023	2	
14	7.920	2.500	17.639	-7.470	0.028	3.168	19.800	0.891	1.120	62.726	25.248	28.278	4	113.113	55.801	1577.950	4	
16	4.860	2.500	16.686	-9.900	0.017	1.944	12.150	1.373	1.025	23.620	9.507	9.745	2	19.490	98.010	955.104	2	
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	
													SUM_1	804.388			SUM_2	

dded mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.457 x 804.388

= **<u>658.79</u>** kN-sec²/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3$ x 2.457 x 21580.8

= **<u>17674.667</u>** kN-sec²-m.

<u>Keterangan :</u>

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

$S = L_{pp} / 10$

TABLE 2 CALCULATIONS FOR b AND B

Station No. (1)	$\frac{\omega_e^2 \times B_n}{2g}$ [-] (2)	$\frac{B_n}{T_n}$ [-] (3)	β_n [-] (4)	$\bar{A}$ [-] (5)	$\bar{A}^2$ [-] (5) x (5) (6)	b_n [kN-sec/m^2] (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)	ξ^2 [m^2] (10)	$b_n \times \xi^2$ [kN-sec] (7) x (10) (11)	Simpson's Multiplier (12)	Product (11) x (12) (13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000000	0.000	1	0.000	94.478	0.000	1	0.000
2	0.030	3.359	0.909	0.094	0.008836	509.709	4	2038.837	53.144	27088.038	4	108352.151
4	0.030	3.359	0.909	0.094	0.008836	509.709	2	1019.418	23.620	12039.128	2	24078.256
6	0.030	3.359	0.909	0.094	0.008836	509.709	4	2038.837	5.476	2790.964	4	11163.855
8	0.030	3.359	0.907	0.094	0.008836	509.709	2	1019.418	0.008	4.129	2	8.257
10	0.030	3.359	0.895	0.094	0.008836	509.709	4	2038.837	6.350	3236.857	4	12947.430
12	0.030	3.359	0.872	0.094	0.008836	509.709	2	1019.418	25.402	12947.430	2	25894.859
14	0.028	3.168	0.891	0.094	0.008836	509.709	4	2038.837	55.801	28442.233	4	113768.933
16	0.017	1.944	1.373	0.006	0.000036	32.535	2	65.069	98.010	3188.719	2	6377.438
18	0.000	0.000	#DIV/0!	0.000	0.000000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	0.000	0.000	0.000000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	11278.672			SUM_2	302591.18

Damping coefficient for heaving, b

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 11278.672$

$=$ **<u>9237.23</u>** kN-sec/m.

Damping coefficient for pitching, B

$B = \int b_n \xi^2 d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 302591.18$

$=$ **<u>247822.18</u>** m-kN-sec/rad.

<u>Keterangan :</u>

(4) = Sectional Area Coefficient, $\beta_n = S_n \, / \, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\bar{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \bar{A}$

S $= L_{pp} \, / \, 10$

TABLE 3 CALCULATIONS FOR *c* AND *C*

Station No. (1)	B_n [m] (2)	c_n [kN/m^2] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m^2] (6)	c_n x ξ^2 [kN] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, *c*

$c = \int c_n \, d\xi = (\rho g A_w)$

= 1/3 x S x SUM_1

= 1/3 x 2.457 x 1936.098

= **1585.66** kN/m.

Restoring moment coefficient for pitching, *C*

$C = \int c_n \xi^2 \, d\xi$

= 1/3 x S x SUM_2

= 1/3 x x2.457 57576.799

= **47155.4** m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S = L_{pp} / 10

TABLE 4 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No. (1)	ξ [m] (2)	a_n [ton/m] (3)	$a_n \times \xi$ [ton] (2) x (3) (4)	Simpson's Multiplier (5)	Product (4) x (5) (6)	b_n [kN-sec/m^2] (7)	$b_n \times \xi$ [kN-sec/m] (2) x (7) (8)	Simpson's Multiplier (9)	Product (8) x (9) (10)	c_n [kN/m^2] (11)	$c_n \times \xi$ [kN/m] (2) x (11) (12)	Simpson's Multiplier (13)	Product (12) x (13) (14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	37.321	272.073	4	1088.29	509.709	3715.780	4	14863.121	84.434	615.523	4	2462.094
4	4.860	37.321	181.382	2	362.76	509.709	2477.187	2	4954.374	84.434	410.349	2	820.698
6	2.340	37.321	87.332	4	349.33	509.709	1192.720	4	4770.878	84.434	197.575	4	790.302
8	-2.520	37.321	-94.050	2	-188.100	509.709	-1284.467	2	-2568.934	84.434	-212.774	2	-425.547
10	-5.040	37.321	-188.100	4	-752.399	509.709	-2568.934	4	-10275.738	84.434	-425.547	4	-1702.188
12	-7.470	37.321	-278.791	2	-557.582	509.709	-3807.528	2	-7615.056	84.434	-630.721	2	-1261.443
14	-9.900	28.278	-279.954	4	-1119.818	509.709	-5046.121	4	-20184.485	79.638	-788.412	4	-3153.648
16	-12.420	9.745	-121.032	2	-242.065	32.535	-404.080	2	-808.160	48.869	-606.947	2	-1213.894
18	-14.850	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	-1059.58			SUM_2	-16864.001			SUM_3	-3683.627

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$

= -1/3 x S x SUM_1

= -1/3 x 2.457 x -1059.579

= **867.795** kN-sec^2

$D = d$

= **867.795** kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$

= (-1/3 x S x SUM_2) + $V_s a_z$

=(-1/3 x 2.457 x -16864.001) + (15.432 × 658.7936426)

= **23978.1** kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$

= (-1/3 x S x SUM_2) − $V_s a_z$

=(-1/3 x 2.457 x -16864.001) - (15.432 x 658.7936426)

= **3645.1** kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$

= (-1/3 x S x SUM_3) + $V_s b$

= (-1/3 x 2.457 x -3683.627) + (15.432 × 9237.232426)

= **145565.9** kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$

= (-1/3 x S x SUM_3)

= (-1/3 x 2.457 x -3683.627)

= **3016.9** kN-sec^2/sec.

TABLE 5 CALCULATIONS FOR m AND I_{yy}

Station No.	Weight per Meter [N/m]	m_n [kN-sec²/m²]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m²]	$m_n \times \xi^2$ [kN-sec²] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
1	#REF!	#REF!	4	#REF!	54.373	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
3	#REF!	#REF!	4	#REF!	24.848	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
5	#REF!	#REF!	4	#REF!	6.704	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
7	#REF!	#REF!	4	#REF!	1.237	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
9	#REF!	#REF!	4	#REF!	7.579	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
11	#REF!	#REF!	4	#REF!	26.630	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
13	#REF!	#REF!	4	#REF!	57.029	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
15	#REF!	#REF!	4	#REF!	99.239	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
17	#REF!	#REF!	4	#REF!	155.485	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
19	#REF!	#REF!	4	#REF!	221.751	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, m

m = 1/3 x S x SUM_1
= 1/3 x 2.457 x #REF!
= [illegible] kN-sec²/m.

Ship mass moment of inertia. I_{yy}

I_{yy} = 1/3 x S x SUM_2
= 1/3 x 2.457 x #REF!
= [illegible] kN-sec²-m.

Keterangan :
(2) = Weight per Foot
(3) = Mass Distribution, Weight per Foot/g
S = L_{pp} / 20

Note :
If the distribution of weight along the length is not known, ship mass m and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, m
m = Δ/g
= 3995.466 / 9.81
= **407.29** kN-sec²/m.

Ship mass moment of inertia, I_{yy}
$I_{yy} = \Delta/g\,(k^2_{yy})$
where,
k_{yy}, the *radius of gyration*, is assumed to be between 0,24*L* and 0,26*L*.
k_{yy} = 0,26 *L*
= 0,26 x 24.600
= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²
= **16661.547** kN-sec²-m.

TABLE 6 CALCULATIONS FOR EXITING FORCES AND MOMENTS (F AND M)

[illegible] TABLE 4

Station No.	ξ [m]	$k\xi$	Sin $k\xi$	Cos $k\xi$	T_n [m]	$\frac{2\pi \cos\mu \times T_n}{L_w}$ [-]	$e^{-(2\pi\cos\mu/L_w)T_n}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ap	9.720	0.040	0.040	0.999	#DIV/0!	#DIV/0!	#DIV/0!
2	7.290	0.030	0.030	1.000	2.272	0.009	0.991
4	4.860	0.020	0.020	1.000	2.272	0.009	0.991
6	2.340	0.010	0.010	1.000	2.272	0.009	0.991
8	-2.520	-0.010	-0.010	1.000	2.268	0.009	0.991
10	-5.040	-0.021	-0.021	1.000	2.239	0.009	0.991
12	-7.470	-0.030	-0.030	1.000	2.180	0.008	0.992
14	-9.900	-0.040	-0.040	0.999	2.227	0.009	0.991
16	-12.420	-0.051	-0.051	0.999	3.433	0.012	0.987
18	-14.850	-0.061	-0.061	0.998	#DIV/0!	#DIV/0!	#DIV/0!
FP	0.000	0.000	0.000	1.000	0.000	0.000	1.000

Station No.	c_n [kN/m²]	$c_n \times \zeta_n$ [kN/m]	a_n [ton/m]	$a_n(-\zeta_n\omega_e^2)$ [ton/sec²]	(10) + (12)	$\frac{da_n}{d\xi}$ [kN-sec²/m²]	$V\zeta_n\omega_e\frac{da_n}{d\xi}$	$b_n\zeta_n\omega_e$ [ton/sec]	(16) - (15)
(1)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Ap	0.000	0.000	0.000	0.000	0.000	-7.679	-1200.334	0.000	1200.334
2	84.434	3252.714	37.321	-99.391	3153.324	-7.679	-1200.334	5162.747	6363.081
4	84.434	3252.714	37.321	-99.391	3153.324	0.000	0.000	5162.747	5162.747
6	84.434	3252.714	37.321	-99.391	3153.324	0.000	0.000	5162.747	5162.747
8	84.434	3252.714	37.321	-99.391	3153.324	0.000	0.000	5162.747	5162.747
10	84.434	3252.714	37.321	-99.391	3153.324	0.000	0.000	5162.747	5162.747
12	84.434	3252.714	37.321	-99.391	3153.324	1.861	290.847	5162.747	4871.900
14	79.638	3067.941	28.278	-75.308	2992.633	5.538	865.628	5162.747	4297.120
16	48.869	1882.600	9.745	-25.952	1856.648	5.682	888.199	329.537	-558.662
18	0.000	0.000	0.000	0.000	0.000	2.005	313.418	0.000	-313.418
FP	0.000	0.000	0.000	0.000	0.000	#DIV/0!	#DIV/0!	0.000	#DIV/0!

Station No.	(15) x (4)	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)	Simpson's Multiplier	Product (24) x (25)	(23) x (8)
(1)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
Ap	0.000	1199.391	1199.391	0.000	47.560	-47.560	#DIV/0!	1	0.000	0.000
2	95.718	6360.270	6455.988	3151.931	189.113	2962.817	6397.457	4	25589.828	2956.866
4	62.484	5161.734	5224.217	3152.704	102.301	3050.404	5178.438	2	10356.915	3073.685
6	30.066	5162.512	5192.599	3153.180	49.258	3103.922	5147.116	4	20588.463	3076.734
8	-32.401	5162.475	5130.074	3153.157	-53.047	3206.205	5085.221	2	10170.442	3178.172
10	-64.798	5161.657	5096.859	3152.658	-106.089	3258.747	5052.865	4	20211.462	3230.619
12	-96.031	4869.640	4773.609	3151.861	-148.369	3300.230	4733.481	2	9466.962	3272.488
14	-130.771	4293.619	4172.848	2990.195	-173.415	3163.610	4137.013	4	16548.050	3136.441
16	-93.985	-557.945	-651.930	1854.268	28.280	1825.988	-643.319	2	-1286.639	1801.870
18	0.000	-312.844	-312.844	0.000	18.966	-18.966	#DIV/0!	4	0.000	0.000
FP	0.000	#DIV/0!	#DIV/0!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	1	0.000	0.000
								SUM_1	111645.486	

Station No.	Simpson's Multiplier	Product (27) x (28)	(24) x (2)	Simpson's Multiplier	Product (30) x (31)	(27) x (2)	Simpson's Multiplier	Product (33) x (34)
(1)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	1	0.000	#DIV/0!	1	#DIV/0!	0.000	1	0.000
2	4	11747.462	46637.462	4	186549.848	21409.750	4	85639.001
4	2	6047.369	25167.304	2	50334.609	14695.107	2	29390.214
6	4	12306.936	12044.251	4	48177.004	7199.557	4	28798.229
8	2	6356.345	-12814.757	2	-25629.515	-8008.994	2	-16017.989
10	4	12922.476	-25466.442	4	-101865.767	-16282.330	4	-65129.279
12	2	6544.975	-35359.106	2	-70718.211	-24445.480	2	-48890.961
14	4	12545.764	-40956.425	4	-163825.700	-31050.765	4	-124203.059
16	2	3603.740	7990.026	2	15980.051	-22379.228	2	-44758.457
18	4	0.000	0.000	4	0.000	0.000	4	0.000
FP	1	0.000	0.000	1	0.000	0.000	1	0.000
	SUM_2	73075.07		SUM_3	-60997.68		SUM_4	-155172

Keterangan :

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi \cos\mu / L_w) \times \xi$

(6) = Mean Draft, $T_n = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \omega g\, B_n$

(11) = Sectional Added Mass, a_n; $a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

S = L_{pp} / 10

TABLE 7

ζ	$= -38.524 \sin \omega_e t$	, Equation of wave motion
z	$= 53.459 \cos (\omega_e t + 81.727°)$	, Equation of heaving motion
θ	$= 1.097 \cos (\omega_e t + -83.326°)$	, Equation of pitching motion
F	$= 108836.22 \cos (\omega_e t + 32.845°)$	, Equation of exciting force
M	$= 136552.5273 \cos (\omega_e t + 68.540°)$	, Equation of exciting moment
z_{18}	$= z - \xi\theta$	, Equation of station 18 motion
ξ	$= -14.850$ m.	, Lever Arm from Longitudinal Centre of Buoyancy to station 18
$z_{18} - \zeta$		, Relative station 18 motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	z_{19} [m]	$z_{19} - \zeta$ [m]
0 π	0.000	0.000	7.692	0.127	91437.653	49957.1	9.585	9.585
0.25 π	2.987	-27.240	-31.97	0.860	22916.039	-54538.4	-19.191	8.049
0.5 π	5.974	-38.524	-52.90	1.089	-59029.480	-127086.1	-36.726	1.798
0.75 π	8.962	-27.240	-42.85	0.680	-106396.330	-125188.5	-32.747	-5.507
1 π	11.949	0.000	-7.692	-0.127	-91437.653	-49957.1	-9.585	-9.585
1.25 π	14.936	27.240	31.968	-0.860	-22916.039	54538.4	19.191	-8.049
1.5 π	17.923	38.524	52.903	-1.089	59029.480	127086.1	36.726	-1.798
1.75 π	20.910	27.240	42.847	-0.680	106396.330	125188.5	32.747	5.507
2 π	23.897	0.000	7.692	0.127	91437.653	49957.1	9.585	9.585

force component, F_1

F_1 = 1/3 x S x SUM_1

= 1/3 x 2.457 x 111645.486

= 91437.653 kN.

force component, F_2

F_2 = 1/3 x S x SUM_2

= 1/3 x 2.457 x 72075.067

= 59029.480 kN.

de of the exiting force, F_0

$F_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{91437.653^2 + 59029.480^2}$

= 108836.225 kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

= 32.845 °

F = 108836.225 cos ($\omega_e t$ + 32.845 °) kN.

$\overline{F} = F_1 + iF_2$

= 91437.653 + (59029.480) i

Exiting moment component, M_1

M_1 = 1/3 x S x SUM_3

= 1/3 x 2.457 x -60997.7

= -49957 kN-m.

Exiting moment component, M_2

M_2 = 1/3 x S x SUM_4

= 1/3 x 2.457 x -155172

= -127086 kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{-49957^2 + -127086^2}$

= 136552 kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

= 68.540 °

M = 136552.5 cos ($\omega_e t$ + 68.540 °) kN.

$\overline{M} = M_1 + iM_2$

= -49957 + (-127086) i

$P = -(m + a)\omega_e^2 + ib\omega_e + c$

= 1511.968 + 2428.686 i

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\omega_e + C$

= 47155.398 + 65158.28551 i

$Q = -d\omega_e^2 + ie\omega_e + h$

= 145505.872 + 6304.412 i

$R = D\omega_e^2 + iE\omega_e + H$

= 3076.880 + (958.386) i

PS = -86951573 + (213042872.804) i

QR = 441662095 + 158848719.387 i

QR = -528613668 + (54194153.42) i

$\overline{QR}$ = -528613668 + -54194153.42 i

$QR)\ (\overline{PS - QR})$ = 2.82369E+17

$\overline{F}S$ = 465519224 + 8741479325 i

$\overline{M}Q$ = -6467848158 + -18806726248.2 i

$\overline{M}Q$ = 6933367382 + (27548205574) i

$\overline{M}Q)\ (\overline{PS - QR})$ = -2.17212E+18 + (-1.49381E+19) i

$\overline{M}P$ = 233118739.3 + -313480204.6 i

$\overline{F}R$ = 224769686.2 + (269259216.7) i

$\overline{F}R$ = 8349053.106 + -582739421.2 i

$-\overline{F}R)\ (\overline{PS - QR})$ = -3.59945E+16 + (3.07592E+17) i

$$\overline{z} = \frac{(\overline{F}S - \overline{M}Q)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$$

= -7.69247999 + (-52.90270515) i

$z_1 = z$ (real) = -7.692

$z_2 = z$ (imaginer) = -52.903

$z_a = \sqrt{z_1^2 + z_2^2}$

= 53.459 m.

$\delta = \tan^{-1}(z_2/z_1)$

= 81.727 °

$z = z_a \cos(\omega_e t + \delta)$

53.459 cos ($\omega_e t$ + 81.727 °)

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since ξ = 0 at the CG of the ship

= -38.524 sin $\omega_e t$

$$\overline{\theta} = \frac{(\overline{M}P - \overline{F}R)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$$

= -0.127473059 + (1.089323189) i

$\theta_1 = \theta$ (real) = -0.127

$\theta_2 = \theta$ (imaginer) = 1.089

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

= 1.097 rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

= -83.326 °

$\theta = \theta_a \cos(\omega_e t + \theta)$

1.097 cos ($\omega_e t$ + -83.326 °)

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 1.02 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi \times B_n^2}{8}$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m²]	[m]	[-]	[-]	[m²]	[-]	[-]	[-]	[kN-sec²/m²]	[kN-sec²/m²]			[m²]	[kN-sec²]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	0.083	3.359	20.993	0.909	1.170	70.510	28.381	33.206	4	132.824	53.144	1764.708	4	7058.834
4	8.397	2.500	19.076	4.860	0.083	3.359	20.993	0.909	1.170	70.510	28.381	33.206	2	66.412	23.620	784.315	2	1568.630
6	8.397	2.500	19.076	2.340	0.083	3.359	20.993	0.909	1.170	70.510	28.381	33.206	4	132.824	5.476	181.823	4	727.293
8	8.397	2.500	19.041	-0.090	0.083	3.359	20.993	0.907	1.170	70.510	28.381	33.206	2	66.412	0.008	0.269	2	0.538
10	8.397	2.500	18.797	-2.520	0.083	3.359	20.993	0.895	1.170	70.510	28.381	33.206	4	132.824	6.350	210.872	4	843.488
12	8.397	2.500	18.304	-5.040	0.083	3.359	20.993	0.872	1.170	70.510	28.381	33.206	2	66.412	25.402	843.488	2	1686.976
14	7.920	2.500	17.639	-7.470	0.079	3.168	19.800	0.891	1.060	62.726	25.248	26.763	4	107.053	55.801	1493.417	4	5973.669
16	4.860	2.500	16.686	-9.900	0.048	1.944	12.150	1.373	1.025	23.620	9.507	9.745	2	19.490	98.010	955.104	2	1910.207
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM_1	724.253			SUM_2	19769.636

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 724.253$

$=$ [illegible] kN-sec²/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 19769.636$

$=$ [illegible] kN-sec²-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

S $= L_{pp} / 20$

TABLE 2.02 CALCULATIONS FOR b AND B

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	β_n	$\overline{A}$	$\overline{A}^2$	b_n	Simpson's Multiplier	Product	ξ^2	$b_n \times \xi^2$	Simpson's Multiplier	Product
	[-]	[-]	[-]	[-]	[-] (5) x (5)	[kN-sec/m^2]		(7) x (8)	[m^2]	[kN-sec] (7) x (10)		(11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	0.083	3.359	0.909	0.094	0.009	10.123	4	40.491	53.144	537.961	4	2151.842
4	0.083	3.359	0.909	0.094	0.009	10.123	2	20.245	23.620	239.094	2	478.187
6	0.083	3.359	0.909	0.094	0.009	10.123	4	40.491	5.476	55.428	4	221.711
8	0.083	3.359	0.907	0.094	0.009	10.123	2	20.245	0.008	0.082	2	0.164
10	0.083	3.359	0.895	0.094	0.009	10.123	4	40.491	6.350	64.283	4	257.132
12	0.083	3.359	0.872	0.094	0.009	10.123	2	20.245	25.402	257.132	2	514.264
14	0.079	3.168	0.891	0.094	0.009	10.123	4	40.491	55.801	564.854	4	2259.418
16	0.048	1.944	1.373	0.006	0.000	0.041	2	0.082	98.010	4.042	2	8.084
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	222.781			SUM_2	5890.803

Damping coefficient for heaving, b

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.457 $\times$ 222.781

= [illegible] kN-sec/m.

Damping coefficient for pitching, B

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.457 $\times$ 5890.803

= [illegible] m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \, / \, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\overline{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2 / \omega_e^3) \times \overline{A}$

S $= L_{pp} / 20$

TABLE 3.02 CALCULATIONS FOR *c* AND *C*

Station No.	B_n [m]	c_n [kN/m²]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m²]	$c_n \times \xi^2$ [kN] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, *c*

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

= [illegible]85.6644 kN/m.

Restoring moment coefficient for pitching, *C*

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

= 47[illegible].398 m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S $= L_{pp} / 20$

TABLE 4.02 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ	a_n	$a_n \times \xi$	Simpson's Multiplier	Product	b_n	$b_n \times \xi$	Simpson's Multiplier	Product	c_n	$c_n \times \xi$	Simpson's Multiplier	Product
	[m]	[ton/m]	[ton]			[kN-sec/m^2]	[kN-sec/m]			[kN/m^2]	[kN/m]		
			(2) x (3)		(4) x (5)		(2) x (7)		(8) x (9)		(2) x (11)		(12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	33.206	242.072	4	968.290	10.123	73.794	4	295.177	84.434	615.523	4	2462.094
4	4.860	33.206	161.382	2	322.763	10.123	49.196	2	98.392	84.434	410.349	2	820.698
6	2.340	33.206	77.702	4	310.809	10.123	23.687	4	94.748	84.434	197.575	4	790.302
8	-0.090	33.206	-2.989	2	-5.977	10.123	-0.911	2	-1.822	84.434	-7.599	2	-15.198
10	-2.520	33.206	-83.679	4	-334.718	10.123	-25.509	4	-102.037	84.434	-212.774	4	-851.094
12	-5.040	33.206	-167.359	2	-334.718	10.123	-51.018	2	-102.037	84.434	-425.547	2	-851.094
14	-7.470	26.763	-199.922	4	-799.688	10.123	-75.616	4	-302.466	79.638	-594.893	4	-2379.571
16	-9.900	9.745	-96.475	2	-192.950	0.041	-0.408	2	-0.817	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	-66.188			SUM_2	-20.859			SUM_3	-991.461

Keterangan :
Centre of Buoy
$a_n = C$ x (ρπ/
$b_n = (\rho g^2/\omega_e$
Coefficient, c_n

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM_1
= -1/3 x 2.46 x -66.188
= 54.27[illegible] kN-sec^2

$D = d$
= 54.27[illegible] kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM_2) + $V_s a_z$
= (-1/3 2.46 x -20.859) + (15.432 x593.8875159)
= 9181.977 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM_2) - $V_s a_z$
= (-1/3 2.46 x -20.859) + (15.432 x593.8875159)
= -9147.7[illegible] kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM_3) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 182.4579396)
= 3628.6[illegible] kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM_3)
= (-1/3 2.46 x -991.461)
= 812.998 kN-sec^2/sec.

TABLE 5.02 CALCULATIONS FOR m AND I_{yy}

Station No.	Weight per Meter [N/m]	m_n [kN-sec²/m²]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m²]	$m_n \times \xi^2$ [kN-sec²] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, m

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass m

Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, m

m = Δ/g

= 3995.466 / 9.81

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24L and 0,26L

k_{yy} = 0,26 L

= 0,26 x 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

TABLE 6.81 CALCULATIONS FOR EXITING FORCES AND MOMENTS (F AND M)

Station No.	ξ [m]	$k\xi$	Sin $k\xi$	Cos $k\xi$	T_m [m]	$\frac{2\pi}{L_w}\cos\mu \times T_m$ [-]	$e^{-[2\pi\cos\mu/L_w]T_m}$	c_n [kN/m²]	$c_n \times \zeta_a$ [kN/m]	a_n [ton/m]	$a_n(-\zeta_a\omega_e^2)$ [ton/sec²]	(10) + (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	9.720	0.089	0.089	0.996	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
2	7.290	0.067	0.067	0.998	2.272	-0.012	1.013	84.434	1445.651	33.206	-110.861	1334.790
4	4.860	0.045	0.045	0.999	2.272	-0.012	1.013	84.434	1445.651	33.206	-110.861	1334.790
6	2.340	0.021	0.021	1.000	2.272	-0.012	1.013	84.434	1445.651	33.206	-110.861	1334.790
8	-0.090	-0.001	-0.001	1.000	2.368	-0.012	1.013	84.434	1445.651	33.206	-110.861	1334.790
10	-2.520	-0.023	-0.023	1.000	2.239	-0.012	1.012	84.434	1445.651	33.206	-110.861	1334.790
12	-5.040	-0.046	-0.046	0.999	2.180	-0.012	1.012	84.434	1445.651	33.206	-110.861	1334.790
14	-7.470	-0.069	-0.068	0.998	2.227	-0.012	1.012	79.638	1363.529	26.763	-89.351	1274.178
16	-9.900	-0.091	-0.091	0.996	3.433	-0.019	1.019	48.869	836.711	9.745	-32.534	804.177
18	-12.420	-0.114	-0.114	0.994	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
FP	-14.850	-0.136	-0.136	0.991	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Station No.	$\frac{da_n}{d\xi}$ [kN-sec²/m³]	$V_e\zeta_a\omega_e\frac{da_n}{d\xi}$	$b_n\zeta_a\omega_e$ [ton/sec]	(16) - (15)	(13) x (4)	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)
(1)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Ap	-6.833	-797.182	0.000	797.182	0.000	794.015	794.015	0.000	70.994	-70.994	794.015
2	-6.833	-797.182	76.533	873.715	89.205	871.762	960.967	1331.806	58.391	1273.414	973.828
4	0.000	0.000	76.533	76.533	59.495	76.457	135.952	1333.463	3.411	1330.052	137.658
6	0.000	0.000	76.533	76.533	28.653	76.515	105.168	1334.482	1.643	1332.839	106.488
8	0.000	0.000	76.533	76.533	-1.102	76.533	75.431	1334.789	-0.063	1334.852	76.376
10	0.000	0.000	76.533	76.533	-30.857	76.513	45.656	1334.433	-1.769	1336.202	46.221
12	1.326	154.673	76.533	-78.140	-61.697	-78.056	-139.753	1333.363	3.612	1329.751	-141.435
14	4.827	563.234	76.533	-486.701	-87.254	-485.558	-572.812	1271.187	33.329	1237.858	-579.860
16	5.435	634.154	6.312	-633.843	-72.940	-631.230	-704.170	800.862	57.490	743.372	-717.560
18	1.934	225.993	0.000	-225.993	0.000	-224.130	-224.130	0.000	25.650	-25.650	-224.130
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No.	Simpson's Multiplier	Product (24) x (25)	(23) x (8)	Simpson's Multiplier	Product (27) x (28)	(24) x (2)	Simpson's Multiplier	Product (30) x (31)	(27) x (2)	Simpson's Multiplier	Product (33) x (34)
(1)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	1	794.015	-70.994	1	-70.994	7717.824	1	7717.824	-690.063	1	-690.062
2	4	3892.114	1289.397	4	5157.589	7090.377	4	28373.509	9399.705	4	37598.822
4	2	275.316	1346.746	2	2693.491	669.018	2	1338.037	6545.183	2	13090.367
6	4	425.953	1349.568	4	5398.272	249.183	4	996.731	3157.989	4	12631.956
8	2	152.752	1351.575	2	2703.151	-6.874	2	-13.748	-121.642	2	-243.284
10	4	184.882	1352.726	4	5410.905	-116.476	4	-465.904	-3408.870	4	-13635.481
12	2	-282.871	1345.762	2	2691.523	712.834	2	1425.668	-6782.639	2	-13565.278
14	4	-2319.438	1253.088	4	5012.351	4331.551	4	17326.205	-9360.566	4	-37442.263
16	2	-1435.139	757.518	2	1515.036	7103.938	2	14207.876	-7499.428	2	-14998.855
18	4	-896.520	-25.650	4	-102.598	2783.696	4	11134.783	318.568	4	1274.272
FP	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	SUM_1	791.064		SUM_2	30408.726		SUM_3	82040.981		SUM_4	-15979.5[illegible]

Keterangan :

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi\cos\mu/L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

(11) = Sectional Added Mass, a_n

$a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

$s = L_{pp} / 20$

force component, F_1

$F_1 = 1/3 \times S \times SUM_1$

$= 1/3 \times 2.46 \times 791.064$

$= 648.672$ kN.

force component, F_2

$F_2 = 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 30408.726$

$= 24935.155$ kN.

de of the exiting force, F_0

$F_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{648.672^2 + 24935.155^2}$

$= 24943.591$ kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

$= 88.510\ ^\circ$

$F = 24943.591 \cos(\omega_e t + 88.510^\circ)$ kN.

$\overline{F} = F_1 + iF_2$

$= 648.672 + (24935.155)\,i$

$P = -(m + a)\omega_e^2 + ib\,\omega_e + c$

$= 1390.445 + 80.569\,i$

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\,\omega_e + C$

$= 40745.524 + 2130.422787\,i$

$Q = -d\,\omega_e^2 + ie\,\omega_e + h$

$= 3618.106 + 4054.559\,i$

$R = D\,\omega_e^2 + iE\,\omega_e + H$

$= 823.581 + (-4039.453)\,i$

$PS = 56482748.907 + (6245077.739)\,i$

$QR = 19358000.731 + -11275910.170\,i$

$QR = 37124748.176 + (17520987.91)\,i$

$\overline{QR} = 37124748.176 + -17520987.91\,i$

$QR)\ (\overline{PS - QR}) = 1.68523E+15$

$FS = -26691921.97 + 1017377899.780\,i$

$MQ = 296531686.7 + 225355151.387\,i$

$MQ = -323223608.711 + (792022748.393)\,i$

$MQ)\ (\overline{PS - QR}) = 1.87743E+15 + (3.50668E+16)\,i$

$MP = 94595959.86 + -12799415.06\,i$

$FR = 101258612.1 + (17915832.16)\,i$

$FR = -6662652.252 + -30715247.22\,i$

$FR)\ (\overline{PS - QR}) = -7.85511E+14 + (-1.02356E+15)\,i$

$\overline{z} = \dfrac{(\overline{FS} - \overline{MQ})\,(\overline{PS - QR})}{(PS - QR)\,(\overline{PS - QR})}$

$= 1.114046008 + (20.80831789)\,i$

$z_1 = z\ \text{(real)} = 1.114$

$z_2 = z\ \text{(imaginer)} = 20.808$

$z_a = \sqrt{z_1^2 + z_2^2}$

$= 20.838$ m.

$\delta = \tan^{-1}(z_2/z_1)$

$= 86.935\ ^\circ$

$z = z_a \cos(\omega_e t + \delta)$

$20.838 \cos(\omega_e t + 86.935^\circ)$

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since $\xi = 0$ at the CG of the ship

$= -17.122 \sin \omega_e t$

Exiting moment component, M_1

$M_1 = 1/3 \times S \times SUM_3$

$= 1/3 \times 2.46 \times 82040.981$

$= 67273.604$ kN-m.

Exiting moment component, M_2

$M_2 = 1/3 \times S \times SUM_4$

$= 1/3 \times 2.46 \times -15979.806$

$= -13103.441$ kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{67273.604^2 + -13103.441^2}$

$= 68537.858$ kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

$= -11.022\ ^\circ$

$M = 68537.858 \cos(\omega_e t + -11.022^\circ)$ kN.

$\overline{M} = M_1 + iM_2$

$= 67273.604 + (-13103.441)\,i$

$\overline{\theta} = \dfrac{(\overline{MP} - \overline{FR})\,(\overline{PS - QR})}{(PS - QR)\,(\overline{PS - QR})}$

$= -0.466114332 + (-0.607370144)\,i$

$\theta_1 = \theta\ \text{(real)} = -0.466$

$\theta_2 = \theta\ \text{(imaginer)} = -0.607$

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

$= 0.766$ rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

$= 52.496\ ^\circ$

$\theta = \theta_a \cos(\omega_e t + \theta)$

$0.766 \cos(\omega_e t + 52.496^\circ)$

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.02

ζ = -17.122 $\sin \omega_e t$, Equation of wave motion

z = 20.838 $\cos(\omega_e t +$ 86.935 °) , Equation of heaving motion

θ = 0.766 $\cos(\omega_e t +$ 52.496 °) , Equation of pitching motion

F = 24943.59 $\cos(\omega_e t +$ 88.510 °) , Equation of exciting force

M = 68537.85809 $\cos(\omega_e t +$ -11.022 °) , Equation of exciting moment

ξ = -14.850m , Lever Arm from Longitudinal Centre of Buoyancy to bow

$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$z_b - \zeta$ [m]
0 π	0.00000	0.00000	1.1140460083	0.4661143	648.672	67273.604	8.036	8.036
0.25 π	1.77862	-12.10686	-13.9259532003	-0.0998829	-17173.136	56835.154	-15.409	-3.302
0.5 π	3.55723	-17.12168	-20.8083178932	-0.6073701	-24935.155	13103.441	-29.828	-12.706
0.75 π	5.33585	-12.10686	-15.5014521745	-0.7590682	-18090.498	-38304.090	-26.774	-14.667
1 π	7.11447	0.00000	-1.1140460083	-0.4661143	-648.672	-67273.604	-8.036	-8.036
1.25 π	8.89309	12.10686	13.9259532003	0.0998829	17173.136	-56835.154	15.409	3.302
1.5 π	10.67170	17.12168	20.8083178932	0.6073701	24935.155	-13103.441	29.828	12.706
1.75 π	12.45032	12.10686	15.5014521745	0.7590682	18090.498	38304.090	26.774	14.667
2 π	14.22894	0.00000	1.1140460083	0.4661143	648.672	67273.604	8.036	8.036

TABLE 1.03 CALCULATIONS FOR a_z AND $A_{\psi\psi}$

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi \times B_n^2}{8}$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m²]	[m]	[-]	[-]	[m²]	[-]	[-]	[-]	[kN-sec²/m²]	[kN-sec²/m²]			[m²]	[kN-sec²]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	0.182	3.359	20.993	0.909	0.920	70.510	28.381	26.111	4	104.443	53.144	1387.634	4	5550.536
4	8.397	2.500	19.076	4.860	0.182	3.359	20.993	0.909	0.920	70.510	28.381	26.111	2	52.222	23.620	616.726	2	1233.452
6	8.397	2.500	19.076	2.340	0.182	3.359	20.993	0.909	0.920	70.510	28.381	26.111	4	104.443	5.476	142.972	4	571.889
8	8.397	2.500	19.041	-0.090	0.182	3.359	20.993	0.907	0.920	70.510	28.381	26.111	2	52.222	0.008	0.211	2	0.423
10	8.397	2.500	18.797	-2.520	0.182	3.359	20.993	0.895	0.920	70.510	28.381	26.111	4	104.443	6.350	165.814	4	663.256
12	8.397	2.500	18.304	-5.040	0.182	3.359	20.993	0.872	0.920	70.510	28.381	26.111	2	52.222	25.402	663.256	2	1326.511
14	7.920	2.500	17.639	-7.470	0.171	3.168	19.800	0.891	0.785	62.726	25.248	19.820	4	79.280	55.801	1105.974	4	4423.897
16	4.860	2.500	16.686	-9.900	0.105	1.944	12.150	1.373	0.620	23.620	9.507	5.895	2	11.789	98.010	577.721	2	1155.443
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM₁	561.063			SUM₂	14925.406

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 561.063$

$=$ [illegible] kN-sec²/m.

Added mass moment of inertia for pitching, $A_{\psi\psi}$

$A_{\psi\psi} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 14925.406$

$=$ [illegible] kN-sec²-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

$S = L_{pp} / 20$

TABLE 2.03 CALCULATIONS FOR b AND B

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	β_n	$\bar{A}$	$\bar{A}^2$	b_n	Simpson's Multiplier	Product	ξ^2	$b_n \times \xi^2$	Simpson's Multiplier	Product
	[-]	[-]	[-]	[-]	[-]	[kN-sec/m^2]			[m^2]	[kN-sec]		
					(5) x (5)			(7) x (8)		(7) x (10)		(11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	0.182	3.359	0.909	0.094	0.009	3.149	4	12.596	53.144	167.356	4	669.424
4	0.182	3.359	0.909	0.094	0.009	3.149	2	6.298	23.620	74.380	2	148.761
6	0.182	3.359	0.909	0.094	0.009	3.149	4	12.596	5.476	17.243	4	68.973
8	0.182	3.359	0.907	0.094	0.009	3.149	2	6.298	0.008	0.026	2	0.051
10	0.182	3.359	0.895	0.094	0.009	3.149	4	12.596	6.350	19.998	4	79.992
12	0.182	3.359	0.872	0.094	0.009	3.149	2	6.298	25.402	79.992	2	159.984
14	0.171	3.168	0.891	0.094	0.009	3.149	4	12.596	55.801	175.722	4	702.890
16	0.105	1.944	1.373	0.006	0.000	0.013	2	0.026	98.010	1.257	2	2.515
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	69.306			SUM_2	1832.589

Damping coefficient for heaving, b

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 69.306$

$= 56.76$ kN-sec/m.

Damping coefficient for pitching, B

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 1832.589$

$= 1500.89$ m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\bar{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \bar{A}$

S $= L_{pp} / 20$

TABLE 3.03 CALCULATIONS FOR c AND C

Station No.	B_n [m]	c_n [kN/m^2]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m^2]	c_n x ξ^2 [kN] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, c

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

$=$ 1585.6644 kN/m.

Restoring moment coefficient for pitching, C

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

$=$ 47[illegible] m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S = L_{pp} / 20

TABLE 4.03 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ	a_n	$a_n \times \xi$	Simpson's Multiplier	Product	b_n	$b_n \times \xi$	Simpson's Multiplier	Product	c_n	$c_n \times \xi$	Simpson's Multiplier	Product
	[m]	[ton/m]	[ton]			[kN-sec/m^2]	[kN-sec/m]			[kN/m^2]	[kN/m]		
			(2) x (3)		(4) x (5)		(2) x (7)		(8) x (9)		(2) x (11)		(12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	26.111	190.348	4	761.390	3.149	22.957	4	91.828	84.434	615.523	4	2462.094
4	4.860	26.111	126.898	2	253.797	3.149	15.305	2	30.609	84.434	410.349	2	820.698
6	2.340	26.111	61.099	4	244.397	3.149	7.369	4	29.476	84.434	197.575	4	790.302
8	-0.090	26.111	-2.350	2	-4.700	3.149	-0.283	2	-0.567	84.434	-7.599	2	-15.198
10	-2.520	26.111	-65.799	4	-263.197	3.149	-7.936	4	-31.743	84.434	-212.774	4	-851.094
12	-5.040	26.111	-131.598	2	-263.197	3.149	-15.871	2	-31.743	84.434	-425.547	2	-851.094
14	-7.470	19.820	-148.055	4	-592.222	3.149	-23.524	4	-94.095	79.638	-594.893	4	-2379.571
16	-9.900	5.895	-58.356	2	-116.711	0.013	-0.127	2	-0.254	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM$_1$	19.558			SUM$_2$	-6.489			SUM$_3$	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM$_1$
= -1/3 x 2.46 x 19.558
= -16.037 kN-sec^2

$D = d$
= -16.037 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM$_2$) + $V_s a_z$
= (-1/3 2.46 x -6.489) + (15.432 x460.0717681)
= 7105.110 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM$_2$) − $V_s a_z$
= (-1/3 2.46 x -6.489) + (15.432 x460.0717681)
= [illegible] kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM$_3$) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 56.76)
= [illegible] kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM$_3$)
= (-1/3 2.46 x -991.461)
= [illegible] kN-sec^2/sec.

TABLE 5.03 CALCULATIONS FOR m AND I_{yy}

Station No.	Weight per Meter [N/m]	m_n [kN-sec²/m²]	Simpson's Multiplier	Product	ξ^2 [m²]	$m_n \times \xi^2$ [kN-sec²]	Simpson's Multiplier	Product
				(3) x (4)		(3) x (6)		(7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, m

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²/m

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass m

Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, m

m = Δ/g

= 3995.466 / 9.81

= 407.285 kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24L and 0,26L

k_{yy} = 0,26 L

= 0,26 x 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

TABLE 4.42 CALCULATIONS FOR EXITING FORCES AND MOMENTS (F AND M)

Station No.	ξ [m]	$k\xi$	Sin $k\xi$	Cos $k\xi$	T_m [m]	$\frac{2\pi}{L_w}\cos\mu \times T_m$ [-]	$e^{-(2\pi\cos\mu/L_w)T_m}$	c_n [kN/m^2]	$c_n \times \zeta_a$ [kN/m]	a_n [ton/m]	$a_n(-\zeta_a\omega_e^2)$ [ton/sec^2]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ap	9.720	0.089	0.089	0.996	0.000	0.000	1.000	0.000	0.000	0.000	0.000
2	7.290	0.067	0.067	0.998	2.272	-0.012	1.013	84.434	1445.651	33.206	-110.861
4	4.860	0.045	0.045	0.999	2.272	-0.012	1.013	84.434	1445.651	33.206	-110.861
6	2.340	0.021	0.021	1.000	2.272	-0.012	1.013	84.434	1445.651	33.206	-110.861
8	-0.090	-0.001	-0.001	1.000	2.268	-0.012	1.013	84.434	1445.651	33.206	-110.861
10	-2.520	-0.023	-0.023	1.000	2.239	-0.012	1.012	84.434	1445.651	33.206	-110.861
12	-5.040	-0.046	-0.046	0.999	2.180	-0.012	1.012	84.434	1445.651	33.206	-110.861
14	-7.470	-0.069	-0.068	0.998	2.227	-0.012	1.012	79.638	1363.529	26.763	-89.351
16	-9.900	-0.091	-0.091	0.996	3.433	-0.019	1.019	48.869	836.711	9.745	-32.534
18	-12.420	-0.114	-0.114	0.994	0.000	0.000	1.000	0.000	0.000	0.000	0.000
FP	-14.850	-0.136	-0.136	0.991	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Station No.	(10) + (12)	$\frac{da_n}{d\xi}$ [kN-sec^2/m^2]	$V\zeta_a\omega_e\frac{da_n}{d\xi}$	$b_n\zeta_a\omega_e$ [ton/sec]	(16) - (15)	(13) x (4)	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)
(1)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Ap	0.000	-6.833	-797.182	0.000	797.182	0.000	794.015	794.015	0.000	70.994	-70.994	794.015
2	1334.790	-6.833	-797.182	76.533	873.715	80.205	871.762	980.967	1231.806	58.391	1273.414	973.028
4	1334.790	0.000	0.000	76.533	76.533	59.495	76.457	135.952	1333.463	3.411	1330.052	137.658
6	1334.790	0.000	0.000	76.533	76.533	28.653	76.515	105.168	1334.482	1.643	1332.839	106.488
8	1334.790	0.000	0.000	76.533	76.533	-1.102	76.533	75.431	1334.789	-0.063	1334.852	76.576
10	1334.790	0.000	0.000	76.533	76.533	-30.857	76.513	45.656	1334.433	-1.769	1336.202	46.221
12	1334.790	1.326	154.673	76.533	-78.140	-61.697	-78.056	-139.753	1333.363	3.612	1329.751	-141.435
14	1274.178	4.827	563.234	76.533	-486.701	-87.254	-485.558	-572.812	1271.187	33.329	1237.858	-579.860
16	804.177	5.435	634.154	0.312	-633.843	-72.940	-631.230	-704.170	800.862	57.490	743.372	-717.569
18	0.000	1.954	225.993	0.000	-225.993	0.000	-224.130	-224.130	0.000	25.650	-25.650	-224.130
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No.	Simpson's Multiplier	Product (24) x (25)	(23) x (8)	Simpson's Multiplier	Product (27) x (28)	(24) x (2)	Simpson's Multiplier	Product (30) x (31)	(27) x (2)	Simpson's Multiplier	Product (33) x (34)
(1)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	1	794.015	-70.994	1	-70.994	7717.824	1	7717.824	-690.062	1	-690.062
2	4	3892.114	1289.397	4	5157.589	7093.377	4	28373.509	9399.705	4	37598.822
4	2	275.316	1346.746	2	2693.491	669.018	2	1338.037	6545.183	2	13090.367
6	4	425.953	1349.568	4	5398.272	249.183	4	996.731	3157.989	4	12631.956
8	2	152.752	1351.575	2	2703.151	-6.874	2	-13.748	-121.642	2	-243.284
10	4	184.882	1352.726	4	5410.905	-116.476	4	-465.904	-3408.870	4	-13635.481
12	2	-282.871	1345.762	2	2691.523	712.834	2	1425.668	-6782.639	2	-13565.278
14	4	-2319.438	1253.088	4	5012.351	4331.551	4	17326.205	-9360.566	4	-37442.263
16	2	-1435.139	757.518	2	1515.036	7103.938	2	14207.876	-7499.428	2	-14998.855
18	4	-896.520	-25.650	4	-102.598	2783.696	4	11134.783	318.568	4	1274.272
FP	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	SUM	791.064		SUM	30408.726		SUM	82040.981		SUM	-15979.551

Keterangan :

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi\cos\mu/L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

(11) = Sectional Added Mass, a_n, $a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

$S = L_{pp} / 20$

force component, F_1

F_1 = 1/3 x S x SUM$_1$

= 1/3 x 2.46 x 791.064

= 648.672 kN.

force component, F_2

F_2 = 1/3 x S x SUM$_2$

= 1/3 x 2.46 x 30408.726

= 24935.155 kN.

de of the exiting force, F_0

$F_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{648.672^2 + 24935.155^2}$

= 24943.591 kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

= 88.510 °

F = 24943.591 cos ($\omega_e t$ + 88.510 °) kN.

$\overline{F} = F_1 + iF_2$

= 648.672 + (24935.155) i

$P = -(m + a)\omega_e^2 + ib\omega_e + c$

= 1390.445 + 80.569 i

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\omega_e + C$

= 40745.524 + 2130.422787 i

$Q = -d\omega_e^2 + ie\omega_e + h$

= 3618.106 + 4054.559 i

$R = D\omega_e^2 + iE\omega_e + H$

= 823.581 + (-4039.453) i

PS = 56482748.907 + (6245077.739) i

QR = 19358000.731 + -11275910.170 i

QR = 37124748.176 + (17520987.91) i

$\overline{QR}$ = 37124748.176 + -17520987.91 i

$QR)\ (\overline{PS - QR})$ = 1.68523E+15

$\overline{F}S$ = -26691921.97 + 1017377899.780 i

$\overline{M}Q$ = 296531686.7 + 225355151.387 i

$\overline{M}Q$ = -323223608.711 + (792022748.393) i

$\overline{M}Q)\ (\overline{PS - QR})$ = 1.87743E+15 + (3.50668E+16) i

$\overline{M}P$ = 94595959.86 + -12799415.06 i

$\overline{F}R$ = 101258612.1 + (17915832.16) i

$\overline{F}R$ = -6662652.252 + -30715247.22 i

$-\overline{F}R)\ (\overline{PS - QR})$ = -7.85511E+14 + (-1.02356E+15) i

$$\overline{z} = \frac{(\overline{F}S - \overline{M}Q)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$$

= 1.114046008 + (20.80831789) i

$z_1 = z$ (real) = 1.114

$z_2 = z$ (imaginer) = 20.808

$z_a = \sqrt{z_1^2 + z_2^2}$

= 20.838 m.

$\delta = \tan^{-1}(z_2/z_1)$

= 86.935 °

$z = z_a \cos(\omega_e t + \delta)$

20.838 cos ($\omega_e t$ + 86.935 °)

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since ξ = 0 at the CG of the ship

= -17.122 sin $\omega_e t$

Exiting moment component, M_1

M_1 = 1/3 x S x SUM$_3$

= 1/3 x 2.46 x 82040.981

= 67273.604 kN-m.

Exiting moment component, M_2

M_2 = 1/3 x S x SUM$_4$

= 1/3 x 2.46 x -15979.806

= -13103.441 kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{67273.604^2 + (-13103.441)^2}$

= 68537.858 kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

= -11.022 °

M = 68537.858 cos ($\omega_e t$ + -11.022 °) kN.

$\overline{M} = M_1 + iM_2$

= 67273.604 + (-13103.441) i

$$\overline{\theta} = \frac{(\overline{M}P - \overline{F}R)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$$

= -0.466114332 + (-0.607370144) i

$\theta_1 = \theta$ (real) = -0.466

$\theta_2 = \theta$ (imaginer) = -0.607

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

= 0.766 rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

= 52.496 °

$\theta = \theta_a \cos(\omega_e t + \theta)$

0.766 cos ($\omega_e t$ + 52.496 °)

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.03

$\zeta = -9.631 \sin \omega_e t$, Equation of wave motion

$z = 13.804 \cos (\omega_e t + -81.740\,°)$, Equation of heaving motion

$\theta = 0.906 \cos (\omega_e t + 57.877\,°)$, Equation of pitching motion

$F = 13024.27 \cos (\omega_e t + -89.196\,°)$, Equation of exciting force

$M = 46047.67414 \cos (\omega_e t + -8.820\,°)$, Equation of exciting moment

$\xi = -14.850$m , Lever Arm from Longitudinal Centre of Buoyancy to bow

$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$zb - \zeta$ [m]
0 π	0.00000	0.00000	1.9831903497	0.4818787	182.729	45503.119	9.139	9.139
0.25 π	1.20516	-6.81011	11.0619333249	-0.2019721	9337.850	37168.282	8.063	14.873
0.5 π	2.41033	-9.63094	13.6607457844	-0.7675104	13022.984	7060.770	2.263	11.894
0.75 π	3.61549	-6.81011	8.2572786356	-0.8834515	9079.431	-27182.846	-4.862	1.948
1 π	4.82065	0.00000	-1.9831903497	-0.4818787	-182.729	-45503.119	-9.139	-9.139
1.25 π	6.02582	6.81011	-11.0619333249	0.2019721	-9337.850	-37168.282	-8.063	-14.873
1.5 π	7.23098	9.63094	-13.6607457844	0.7675104	-13022.984	-7060.770	-2.263	-11.894
1.75 π	8.43615	6.81011	-8.2572786356	0.8834515	-9079.431	27182.846	4.862	-1.948
2 π	9.64131	0.00000	1.9831903497	0.4818787	182.729	45503.119	9.139	9.139

TABLE 1.04 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi \times B_n^2}{8}$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m^2]	[m]	[-]	[-]	[m^2]	[-]	[-]	[-]	[kN-sec^2/m^2]	[kN-sec^2/m^2]			[m^2]	[kN-sec^2]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	0.342	3.359	20.993	0.909	0.815	70.510	28.381	23.131	4	92.523	53.144	1229.263	4	4917.051
4	8.397	2.500	19.076	4.860	0.342	3.359	20.993	0.909	0.815	70.510	28.381	23.131	2	46.261	23.620	546.339	2	1092.678
6	8.397	2.500	19.076	2.340	0.342	3.359	20.993	0.909	0.815	70.510	28.381	23.131	4	92.523	5.476	126.655	4	506.619
8	8.397	2.500	19.041	-0.090	0.342	3.359	20.993	0.907	0.815	70.510	28.381	23.131	2	46.261	0.008	0.187	2	0.375
10	8.397	2.500	18.797	-2.520	0.342	3.359	20.993	0.895	0.815	70.510	28.381	23.131	4	92.523	6.350	146.889	4	587.558
12	8.397	2.500	18.304	-5.040	0.342	3.359	20.993	0.872	0.815	70.510	28.381	23.131	2	46.261	25.402	587.558	2	1175.116
14	7.920	2.500	17.639	-7.470	0.322	3.168	19.800	0.891	0.635	62.726	25.248	16.033	4	64.131	55.801	894.642	4	3578.566
16	4.860	2.500	16.686	-9.900	0.198	1.944	12.150	1.373	0.555	23.620	9.507	5.277	2	10.553	98.010	517.154	2	1034.307
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM$_1$	491.038			SUM$_2$	12892.270

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 491.038$

$=$ [illegible] kN-sec^2/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 12892.270$

$=$ [illegible] kN-sec^2-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

$S = L_{pp} / 20$

TABLE 2.04 CALCULATIONS FOR *b* AND *B*

Station No. (1)	$\frac{\omega_e^2 \times B_n}{2g}$ [-] (2)	$\frac{B_n}{T_n}$ [-] (3)	β_n [-] (4)	$\bar{A}$ [-] (5)	$\bar{A}^2$ [-] (5) x (5) (6)	b_n [kN-sec/m^2] (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)	ξ^2 [m^2] (10)	$b_n \times \xi^2$ [kN-sec] (7) x (10) (11)	Simpson's Multiplier (12)	Product (11) x (12) (13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	0.342	3.359	0.909	0.094	0.009	1.223	4	4.891	53.144	64.986	4	259.945
4	0.342	3.359	0.909	0.094	0.009	1.223	2	2.446	23.620	28.883	2	57.766
6	0.342	3.359	0.909	0.094	0.009	1.223	4	4.891	5.476	6.696	4	26.783
8	0.342	3.359	0.907	0.094	0.009	1.223	2	2.446	0.008	0.010	2	0.020
10	0.342	3.359	0.895	0.094	0.009	1.223	4	4.891	6.350	7.765	4	31.062
12	0.342	3.359	0.372	0.094	0.009	1.223	2	2.446	25.402	31.062	2	62.124
14	0.322	3.168	0.891	0.094	0.009	1.223	4	4.891	55.801	68.235	4	272.940
16	0.198	1.944	1.373	0.006	0.000	0.005	2	0.010	98.010	0.488	2	0.977
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	26.912			SUM_2	711.615

Damping coefficient for heaving, *b*

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 26.912$

= [illegible] kN-sec/m.

Damping coefficient for pitching, *B*

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 711.615$

= 582.81 m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\bar{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \bar{A}^2$

S = L_{pp} / 20

TABLE 3.04 CALCULATIONS FOR c AND C

Station No.	B_n	c_n	Simpson's Multiplier	Product	ξ^2	$c_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[kN/m^2]			[m^2]	[kN]		
				(3) x (4)		(3) x (6)		(7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, c

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

= [illegible] kN/m.

Restoring moment coefficient for pitching, C

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

$= 47155.398$ m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S $= L_{pp} / 20$

TABLE 4.04 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ	a_n	$a_n \times \xi$	Simpson's Multiplier	Product	b_n	$b_n \times \xi$	Simpson's Multiplier	Product	c_n	$c_n \times \xi$	Simpson's Multiplier	Product
	[m]	[ton/m]	[ton]			[kN-sec/m^2]	[kN-sec/m]			[kN/m^2]	[kN/m]		
			(2) x (3)		(4) x (5)		(2) x (7)		(8) x (9)		(2) x (11)		(12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	23.131	168.623	4	674.493	1.223	8.914	4	35.658	84.434	615.523	4	2462.094
4	4.860	23.131	112.415	2	224.831	1.223	5.943	2	11.886	84.434	410.349	2	820.698
6	2.340	23.131	54.126	4	216.504	1.223	2.861	4	11.446	84.434	197.575	4	790.302
8	-0.090	23.131	-2.082	2	-4.164	1.223	-0.110	2	-0.220	84.434	-7.599	2	-15.198
10	-2.520	23.131	-58.289	4	-233.158	1.223	-3.082	4	-12.326	84.434	-212.774	4	-851.094
12	-5.040	23.131	-116.579	2	-233.158	1.223	-6.163	2	-12.326	84.434	-425.547	2	-851.094
14	-7.470	16.033	-119.765	4	-479.058	1.223	-9.135	4	-36.538	79.638	-594.893	4	-2379.571
16	-9.900	5.277	-52.238	2	-104.476	0.005	-0.049	2	-0.099	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	61.814			SUM_2	-2.520			SUM_3	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM_1
= -1/3 x 2.46 x 61.814
= -50.687 kN-sec^2

$D = d$
= -50.687 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM_2) + $V_s a_z$
= (-1/3 2.46 x -2.520) + (15.432 x402.6507563)
= 6215.773 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM_2) − $V_s a_z$
= (-1/3 2.46 x -2.520) + (15.432 x402.6507563)
= -6211.64 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM_3) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 22.04)
= 1153.136 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM_3)
= (-1/3 2.46 x -991.461)
= 812.998 kN-sec^2/sec.

TABLE 5.04 CALCULATIONS FOR m AND I_{yy}

Station No.	Weight per Meter [N/m]	m_n [kN-sec²/m²]	Simpson's Multiplier	Product	ξ^2 [m²]	$m_n \times \xi^2$ [kN-sec²]	Simpson's Multiplier	Product
				(3) x (4)		(3) x (6)		(7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, m

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass m

Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, m

m = Δ/g

= 3995.466 / 9.81

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24L and 0,26L

k_{yy} = 0,26 L

= 0,26 x 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

TABLE 4.84 CALCULATIONS FOR EXITING FORCES ...

Station No.	ξ [m]	$k\xi$	$\sin k\xi$	$\cos k\xi$	T_m [m]	$\frac{2\pi \cos\mu}{L_w} T_m$ [-]	$e^{-(2\pi \cos\mu/L_w) T_m}$	c_n [kN/m²]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	9.720	0.348	0.345	0.969	0.000	0.000	1.000	0.000
2	7.290	0.186	0.185	0.983	2.272	-0.035	1.035	84.434
4	4.860	0.124	0.124	0.992	2.272	-0.035	1.035	84.434
6	2.340	0.060	0.060	0.998	2.272	-0.035	1.035	84.434
8	-0.090	-0.002	-0.002	1.000	2.268	-0.035	1.035	84.434
10	-2.530	-0.064	-0.064	0.998	2.239	-0.034	1.035	84.434
12	-5.040	-0.128	-0.128	0.992	2.190	-0.073	1.034	84.434
14	-7.470	-0.190	-0.189	0.982	2.227	-0.034	1.035	79.638
16	-9.900	-0.252	-0.250	0.968	3.433	-0.052	1.054	48.869
18	-12.420	-0.317	-0.311	0.950	0.000	0.000	1.000	0.000
FP	-14.850	-0.378	-0.369	0.929	0.000	0.000	1.000	0.000

Station No.	$c_n \times \zeta_a$ [kN/m]	a_n [ton/m]	$a_n(-\zeta_a\omega_e^2)$ [ton/sec²]	(10) + (12)	$\frac{da_n}{d\xi}$ [kN-sec²/m²]	$V_r \zeta_a \omega_e \frac{da_n}{d\xi}$	$b_n \zeta_a \omega_e$ [ton/sec]	(16) - (15)
(1)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Ap	0.000	0.000	0.000	0.000	-4.759	-404.397	0.000	404.397
2	520.434	23.131	-113.764	406.670	-4.759	-404.397	6.733	411.130
4	520.434	23.131	-113.764	406.670	0.000	0.000	6.733	6.733
6	520.434	23.131	-113.764	406.670	0.000	0.000	6.733	6.733
8	520.434	23.131	-113.764	406.670	0.000	0.000	6.733	6.733
10	520.434	23.131	-113.764	406.670	0.000	0.000	6.733	6.733
12	520.434	23.131	-113.764	406.670	1.460	124.095	6.733	-117.362
14	490.870	16.033	-78.854	412.016	3.674	312.147	6.733	-305.414
16	301.216	5.277	-25.952	275.264	3.260	277.008	0.027	-276.980
18	0.000	0.000	0.000	0.000	1.047	88.956	0.000	-88.956
FP	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No.	(13) x (4)	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)	Simpson's Multiplier
(1)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
Ap	0.000	392.054	392.054	0.000	99.151	-99.151	392.054	1
2	75.117	404.056	479.173	399.672	75.941	323.731	496.066	4
4	50.239	6.681	56.920	405.555	0.832	402.723	58.927	2
6	24.237	6.721	30.957	405.947	0.401	405.546	32.049	4
8	-0.933	6.735	5.800	406.669	-0.015	406.684	6.004	2
10	-26.098	6.719	-19.380	405.832	-0.432	406.264	-20.053	4
12	-52.089	-116.396	-168.465	403.320	15.033	388.288	-174.180	2
14	-77.962	-299.897	-377.858	404.573	57.790	346.783	-390.913	4
16	-98.713	-268.212	-336.925	266.550	68.141	197.409	-355.837	2
18	0.000	-84.537	-84.537	0.000	27.688	-27.688	-84.537	4
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1
								SUM.

Station No.	Product (24) x (25)	(23) x (8)	Simpson's Multiplier	Product (27) x (28)	(26) x (2)	Simpson's Multiplier	Product (30) x (31)	(27) x (2)	Multiplier	(33) x (34)
(1)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	392.054	-99.151	1	-99.151	3810.765	1	3810.765	-963.743	1	-963.743
2	1984.264	335.144	4	1340.576	3616.320	4	14465.281	2443.200	4	9772.801
4	117.853	416.921	2	833.842	286.384	2	572.767	2026.236	2	4052.471
6	128.195	419.843	4	1679.373	74.994	4	299.977	982.433	4	3929.731
8	12.008	420.995	2	841.990	-0.540	2	-1.081	-37.890	2	-75.779
10	-80.210	420.373	4	1681.493	50.532	4	202.130	-1059.341	4	-4237.363
12	-348.361	401.413	2	802.826	877.869	2	1755.738	-2023.122	2	-4046.245
14	-1563.653	358.764	4	1435.058	2920.123	4	11680.491	-2679.971	4	-10719.882
16	-710.074	208.021	2	416.042	3514.886	2	7029.731	-2099.408	2	-4118.817
18	-338.148	-27.688	4	-110.752	1049.948	4	4199.794	343.884	4	1375.536
FP	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	-406.071		SUM.	8821.298		SUM.	44015.595		SUM.	-5031.29

Explanation:

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi \cos\mu / L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

(11) = Sectional Added Mass, a_n

$a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

$S = L_{pp} / 20$

rce component, F_1

$_1$ = 1/3 x S x SUM$_1$

= 1/3 x 2.46 x -406.071

= -332.978 kN.

rce component, F_2

$_2$ = 1/3 x S x SUM$_2$

= 1/3 x 2.46 x 8821.298

= 7233.464 kN.

e of the exiting force, F_0

$_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-332.978^2 + 7233.464^2}$

= 7241.124 kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

= -87.364 °

F = 7241.124 cos ($\omega_e t$ + -87.364 °) kN.

$\overline{F} = F_1 + iF_2$

= -332.978 + (7233.464) i

$P = -(m + a)\omega_e^2 + ib\,\omega_e + c$

= 939.388 + 19.689 i

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\,\omega_e + C$

= 25425.063 + 520.6106046 i

$Q = -d\,\omega_e^2 + ie\,\omega_e + h$

= 1193.582 + 5552.377 i

$R = D\,\omega_e^2 + iE\,\omega_e + H$

= 772.552 + (-5548.685) i

PS = 23873753.546 + (989642.286) i

QR = 31730496.195 + -2333306.263 i

QR = -7856742.649 + (3322948.55) i

$\overline{QR}$ = -7856742.649 + -3322948.549 i

$QR)\ (\overline{PS - QR})$ = 7.27704E+13

$\overline{F}S$ = -12231813.31 + 183737932.180 i

$\overline{M}Q$ = 65986887.01 + 195476451.241 i

$\overline{M}Q$ = -78218700.321 + (-11738519.061) i

$\overline{M}Q)\ (\overline{PS - QR})$ = 5.75538E+14 + (3.52143E+14) i

$\overline{M}P$ = 33986366.91 + -3164972.222 i

$\overline{F}R$ = 39878973.24 + (7435822.673) i

$\overline{F}R$ = -5892606.329 + -10600794.89 i

$-\overline{F}R)\ (\overline{PS - QR})$ = 1.10708E+13 + (1.02869E+14) i

$$\overline{z} = \frac{(\overline{F}S - \overline{M}Q)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$$

= 7.908954276 + (4.83910049) i

$z_1 = z$ (real) = 7.909

$z_2 = z$ (imaginer) = 4.839

$z_a = \sqrt{z_1^2 + z_2^2}$

= 9.272 m.

$\delta = \tan^{-1}(z_2/z_1)$

= 31.460 °

$z = z_a \cos(\omega_e t + \delta)$

9.272 cos ($\omega_e t$ + 31.460 °)

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since $\xi = 0$ at the CG of the ship

= -6.164 sin $\omega_e t$

Exiting moment component, M_1

M_1 = 1/3 x S x SUM$_3$

= 1/3 x 2.46 x 44015.595

= 36092.788 and kN-m.

Exiting moment component, M_2

M_2 = 1/3 x S x SUM$_4$

= 1/3 x 2.46 x -5031.288

= -4125.656 kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{36092.788^2 + -4125.656^2}$

= 36327.818 kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

= -6.521 °

M = 36327.818 cos ($\omega_e t$ + -6.521 °) kN.

$\overline{M} = M_1 + iM_2$

= 36092.788 + (-4125.656) i

$$\overline{\theta} = \frac{(\overline{M}P - \overline{F}R)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$$

= 0.152133239 + (1.41360438) i

$\theta_1 = \theta$ (real) = 0.152

$\theta_2 = \theta$ (imaginer) = 1.414

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

= 1.422 rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

= 83.857 °

$\theta = \theta_a \cos(\omega_e t + \theta)$

1.422 cos ($\omega_e t$ + 83.857 °)

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.04

ζ	$= -6.164 \quad \sin \omega_e t$	, Equation of wave motion
z	$= 9.272 \quad \cos(\omega_e t + 31.460°)$	, Equation of heaving motion
θ	$= 1.422 \quad \cos(\omega_e t + 83.857°)$	, Equation of pitching motion
F	$= 7241.12 \quad \cos(\omega_e t + -87.364°)$	, Equation of exciting force
M	$= 36327.81827 \cos(\omega_e t + -6.521°)$	, Equation of exciting moment

ξ	$= -14.850$ m	, Lever Arm from Longitudinal Centre of Buoyancy to bow
$z - \zeta$		, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	z_b [m]	$z_b - \zeta$ [m]
0 π	0.00000	0.00000	7.9089542764	0.1521332	332.978	36092.788	10.168	10.168
0.25 π	0.87924	-4.35847	2.1707144298	-0.8919948	5350.283	28438.735	-11.075	-6.717
0.5 π	1.75847	-6.16380	-4.8391004896	-1.4136044	7233.464	4125.656	-25.831	-19.667
0.75 π	2.63771	-4.35847	-9.0142359720	-1.1071437	4879.380	-22604.175	-25.455	-21.097
1 π	3.51695	0.00000	-7.9089542764	-0.1521332	-332.978	-36092.788	-10.168	-10.168
1.25 π	4.39619	4.35847	-2.1707144298	0.8919948	-5350.283	-28438.735	11.075	6.717
1.5 π	5.27542	6.16380	4.8391004896	1.4136044	-7233.464	-4125.656	25.831	19.667
1.75 π	6.15466	4.35847	9.0142359720	1.1071437	-4879.380	22604.175	25.455	21.097
2 π	7.03390	0.00000	7.9089542764	0.1521332	332.978	36092.788	10.168	10.168

TABLE 1.05 CALCULATIONS FOR a_ξ AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi}{8} \times B_n^2$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m²]	[m]	[-]	[-]	[m²]	[-]	[-]	[-]	[kN-sec²/m²]	[kN-sec²/m²]			[m²]	[kN-sec²]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	0.582	3.359	20.993	0.909	0.460	70.510	28.381	13.055	4	52.222	53.144	693.817	4	2775.268
4	8.397	2.500	19.076	4.860	0.582	3.359	20.993	0.909	0.460	70.510	28.381	13.055	2	26.111	23.620	308.363	2	616.726
6	8.397	2.500	19.076	2.340	0.582	3.359	20.993	0.909	0.460	70.510	28.381	13.055	4	52.222	5.476	71.486	4	285.944
8	8.397	2.500	19.041	-0.090	0.582	3.359	20.993	0.907	0.460	70.510	28.381	13.055	2	26.111	0.008	0.106	2	0.211
10	8.397	2.500	18.797	-2.520	0.582	3.359	20.993	0.895	0.460	70.510	28.381	13.055	4	52.222	6.350	82.907	4	331.628
12	8.397	2.500	18.304	-5.040	0.582	3.359	20.993	0.872	0.460	70.510	28.381	13.055	2	26.111	25.402	331.628	2	663.256
14	7.920	2.500	17.639	-7.470	0.549	3.168	19.800	0.891	0.435	62.726	25.248	10.983	4	43.932	55.801	612.865	4	2451.459
16	4.860	2.500	16.686	-9.900	0.337	1.944	12.150	1.373	0.360	23.620	9.507	3.423	2	6.845	98.010	335.451	2	670.902
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM_1	285.775			SUM_2	7795.394

TABLE 2.05 CALCULATIONS FOR *b* AND *B*

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	β_n	$\overline{A}$	$\overline{A}^2$	b_n	Simpson's Multiplier	Product	ξ^2	$b_n \times \xi^2$	Simpson's Multiplier	Product
	[-]	[-]	[-]	[-]	[-] (5) x (5)	[kN-sec/m^2]		(7) x (8)	[m^2]	[kN-sec] (7) x (10)		(11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	0.582	3.359	0.909	0.094	0.009	0.549	4	2.198	53.144	29.196	4	116.785
4	0.582	3.359	0.909	0.094	0.009	0.549	2	1.099	23.620	12.976	2	25.952
6	0.582	3.359	0.909	0.094	0.009	0.549	4	2.198	5.476	3.008	4	12.033
8	0.582	3.359	0.907	0.094	0.009	0.549	2	1.099	0.008	0.004	2	0.009
10	0.582	3.359	0.895	0.094	0.009	0.549	4	2.198	6.350	3.489	4	13.955
12	0.582	3.359	0.872	0.094	0.009	0.549	2	1.099	25.402	13.955	2	27.910
14	0.549	3.168	0.891	0.094	0.009	0.549	4	2.198	55.801	30.656	4	122.624
16	0.337	1.944	1.373	0.006	0.000	0.002	2	0.004	98.010	0.219	2	0.439
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM$_1$	12.091			SUM$_2$	319.707

Damping coefficient for heaving, *b*

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.457 $\times$ 12.091

= 9.90 kN-sec/m.

Damping coefficient for pitching, *B*

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.457 $\times$ 319.707

= [illegible] m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\overline{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \overline{A}$

S $= L_{pp} / 20$

TABLE 3.05 CALCULATIONS FOR c AND C

Station No.	B_n [m]	c_n [kN/m²]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m²]	$c_n \times \xi^2$ [kN] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, c

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

$= 1585.6644$ kN/m.

Restoring moment coefficient for pitching, C

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

$= 47155.398$ m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S = $L_{pp} / 20$

TABLE 4.05 CALCULATIONS FOR *d*, *e*, *h*, *D*, *E* AND *H*

Station No. (1)	ξ [m] (2)	a_n [ton/m] (3)	$a_n \times \xi$ [ton] (2) x (3) (4)	Simpson's Multiplier (5)	Product (4) x (5) (6)	b_n [kN-sec/m^2] (7)	$b_n \times \xi$ [kN-sec/m] (2) x (7) (8)	Simpson's Multiplier (9)	Product (8) x (9) (10)	c_n [kN/m^2] (11)	$c_n \times \xi$ [kN/m] (2) x (11) (12)	Simpson's Multiplier (13)	Product (12) x (13) (14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	13.055	95.174	4	380.695	0.549	4.005	4	16.020	84.434	615.523	4	2462.094
4	4.860	13.055	63.449	2	126.898	0.549	2.670	2	5.340	84.434	410.349	2	820.698
6	2.340	13.055	30.550	4	122.198	0.549	1.286	4	5.142	84.434	197.575	4	790.302
8	-0.090	13.055	-1.175	2	-2.350	0.549	-0.049	2	-0.099	84.434	-7.599	2	-15.198
10	-2.520	13.055	-32.900	4	-131.598	0.549	-1.384	4	-5.538	84.434	-212.774	4	-851.094
12	-5.040	13.055	-65.799	2	-131.598	0.549	-2.769	2	-5.538	84.434	-425.547	2	-851.094
14	-7.470	10.983	-82.043	4	-328.174	0.549	-4.104	4	-16.415	79.638	-594.893	4	-2379.571
16	-9.900	3.423	-33.884	2	-67.768	0.002	-0.022	2	-0.044	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	-31.696			SUM_2	-1.132			SUM_3	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$

= -1/3 x S x SUM_1

= -1/3 x 2.46 x -31.696

= 25.991 kN-sec^2

$D = d$

= 25.991 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$

= (-1/3 x S x SUM_2) + $V_s a_z$

= (-1/3 2.46 x -1.132) + (15.432 x 234.33511)

= 3617.188 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$

= (-1/3 x S x SUM_2) − $V_s a_z$

= (-1/3 2.46 x -1.132) + (15.432 x 234.33511)

= -3615.331 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$

= (-1/3 x S x SUM_3) + $V_s b$

= (-1/3 2.46 x -991.461) + (15.432 x 9.90)

= 965.812 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$

= (-1/3 x S x SUM_3)

= (-1/3 2.46 x -991.461)

= 812.998 kN-sec^2/sec.

TABLE 5.05 CALCULATIONS FOR m AND I_{yy}

Station No. (1)	Weight per Meter [N/m] (2)	m_n [kN-sec²/m²] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m²] (6)	$m_n \times \xi^2$ [kN-sec²] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, m

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass m and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, m

m = Δ/g

= 3995.466 / 9.81

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24L and 0,26L.

k_{yy} = 0,26 L

= 0,26 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

TABLE 4.05 CALCULATIONS FOR EXITING FORCES AND MOMENTS (F AND M)

Station No. (1)	ξ [m] (2)	$k\xi$ (3)	Sin $k\xi$ (4)	Cos $k\xi$ (5)	T_m [m] (6)	$\frac{2\pi\cos\mu \times T_m}{L_w}$ (7)	$e^{-[2\pi\cos\mu/L_w]T_m}$ (8)	c_n [kN/m²] (9)	$c_n \times \zeta_a$ [kN/m] (10)	a_n [ton/m] (11)	$a_n(-\zeta_a\omega_e^2)$ [ton/sec²] (12)
Ap	9.720	0.357	0.349	0.937	0.000	0.000	1.000	0.000	0.000	0.000	0.000
2	7.290	0.268	0.264	0.964	2.272	-0.050	1.051	84.434	361.413	13.055	-76.016
4	4.860	0.178	0.177	0.984	2.272	-0.050	1.051	84.434	361.413	13.055	-76.016
6	2.340	0.086	0.086	0.996	2.272	-0.050	1.051	84.434	361.413	13.055	-76.016
8	-0.090	-0.003	-0.003	1.000	2.308	-0.050	1.051	84.434	361.413	13.055	-76.016
10	-2.520	-0.092	-0.092	0.996	2.239	-0.049	1.050	84.434	361.413	13.055	-76.016
12	-5.040	-0.185	-0.184	0.983	2.180	-0.048	1.049	84.434	361.413	13.055	-76.016
14	-7.470	-0.274	-0.271	0.963	2.227	-0.049	1.050	79.638	340.882	10.983	-63.950
16	-9.900	-0.363	-0.355	0.935	3.433	-0.075	1.078	48.949	309.178	3.423	-19.928
18	-12.430	-0.456	-0.440	0.898	0.000	0.000	1.000	0.000	0.000	0.000	0.000
FP	-14.850	-0.545	-0.518	0.855	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Station No. (1)	(10) + (12) (13)	$\frac{da_n}{d\xi}$ [kN-sec²/m²] (14)	$V_e\zeta_a\omega_e\frac{da_n}{d\xi}$ (15)	$b_n\zeta_a\omega_e$ [ton/sec] (16)	(16) - (15) (17)	(13) x (4) (18)	(17) x (5) (19)	(18) + (19) (20)	(13) x (5) (21)	(17) x (4) (22)	(21) - (22) (23)	(20) x (8) (24)
Ap	0.000	-2.686	-206.955	0.000	206.955	0.000	193.929	193.929	0.000	72.265	-72.265	195.929
2	285.397	-2.686	-206.955	2.743	209.698	75.443	202.239	277.682	275.245	55.432	219.812	291.887
4	285.397	0.000	0.000	2.743	2.743	50.431	2.699	53.130	280.870	0.487	280.383	56.058
6	285.397	0.000	0.000	2.743	2.743	24.477	2.733	27.210	284.345	0.235	284.110	28.602
8	285.397	0.000	0.000	2.743	2.743	-0.943	2.743	1.800	285.395	-0.009	285.404	1.892
10	285.397	0.000	0.000	2.743	2.743	-26.355	2.731	-23.624	284.177	-0.253	284.430	-24.815
12	285.397	0.426	32.851	2.743	-30.108	-52.485	-29.595	-82.079	280.529	5.537	274.992	-86.104
14	276.932	1.982	152.700	2.743	-149.957	-74.968	-144.358	-219.326	266.592	40.595	225.9[illegible]	-230.320
16	189.249	2.235	172.167	0.011	-172.156	-67.252	-160.919	-228.171	176.897	61.178	115.719	-246.041
18	0.000	0.679	52.318	0.000	-52.318	0.000	-46.977	-46.977	0.000	23.028	-23.028	-46.977
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No. (1)	Simpson's Multiplier (25)	(24) x (25) (26)	(23) x (8) (27)	Multiplier (28)	(27) x (28) (29)	(24) x (2) (30)	Multiplier (31)	(30) x (31) (32)	(27) x (2) (33)	Multiplier (34)	(33) x (34) (35)
Ap	1	193.929	-72.265	1	-72.265	1884.987	1	1884.987	-702.416	1	-702.416
2	4	1167.549	231.057	4	924.230	2127.857	4	8511.429	1684.409	4	6737.6[illegible]4
4	2	112.116	294.727	2	589.454	272.442	2	544.885	1432.372	2	2864.744
6	4	114.408	298.644	4	1194.577	66.928	4	267.714	698.827	4	2795.308
8	2	3.784	299.977	2	599.954	-0.170	2	-0.341	-26.998	2	-53.996
10	4	-99.258	298.763	4	1195.052	42.533	4	250.130	-752.883	4	-3011.532
12	2	-172.209	288.477	2	576.954	433.966	2	867.933	-1453.924	2	-2907.848
14	4	-92[illegible].280	237.327	4	949.306	1720.491	4	6891.965	-1772.829	4	-7091.316
16	2	-492.082	124.782	2	249.563	3035.806	2	4871.612	-1235.338	2	-2470.676
18	4	-187.909	-23.028	4	-92.114	583.459	4	2333.833	286.013	4	1144.054
FP	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	SUM:	-280.954		SUM:	6114.711		SUM:	26414.147		SUM:	-2696.[illegible]

Keterangan :

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi\cos\mu/L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g\, B_n$

(11) = Sectional Added Mass, a_n

$a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

$h = L_{pp}/20$

ce component, F_1

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.46 x -280.954

$=$ [illegible] kN.

ce component, F_2

$= 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.46 x 6114.711

$=$ [illegible] kN.

of the exiting force, F_0

$= \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-230.382^2 + 5014.063^2}$

$=$ [illegible] kN.

$= F_0 \cos(\omega_e t + \sigma)$

$= \tan^{-1}(F_2/F_1)$

$= -87.369$ °

$= 5019.353 \cos(\omega_e t + -87.369\,°)$ kN.

$\bar{F} = F_1 + iF_2$

$= -230.382 + (5014.063)i$

$= -(m+a)\omega_e^2 + ib\omega_e + c$

$= 712.879 + 11.549\,i$

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\omega_e + C$

$= 15795.734 + 305.3874499\,i$

$Q = -d\omega_e^2 + ie\omega_e + h$

$= 930.457 + 4218.769\,i$

$R = D\omega_e^2 + iE\omega_e + H$

$= 848.353 + (-4216.604)i$

$S = 11256922.547 + (400133.976)i$

$R = 18578233.749 + -344361.970\,i$

$R = -7321311.202 + (744495.95)i$

$\overline{R} = -7321311.202 + -744495.9465\,i$

$QR)\ \overline{(PS - QR)} = 5.41559E+13$

$\bar{F}S = -5170286.41 + 79130454.319\,i$

$Q = 29479984.94 + 89319845.031\,i$

$\bar{F}Q = -34650271.351 + (-10189390.711)i$

$MQ)\ \overline{(PS - QR)} = 2.46099E+14 + (1.00397E+14)i$

$MP = 15466210.34 + -1325847.979\,i$

$\bar{F}R = 20946872.5 + (5225125.079)i$

$\bar{F}R = -5480662.153 + -6550973.058\,i$

$\bar{F}R)\ \overline{(PS - QR)} = 3.52485E+13 + (5.2042E+13)i$

$\bar{z} = \dfrac{(\bar{F}S - \bar{M}Q)\ \overline{(PS - QR)}}{(PS - QR)\ \overline{(PS - QR)}}$

$= 4.544280259 + (1.853846746)i$

$z_1 = z$ (real) $= 4.544$

$z_2 = z$ (imaginer) $= 1.854$

$z_a = \sqrt{z_1^2 + z_2^2}$

$= 4.908$ m.

$\delta = \tan^{-1}(z_2/z_1)$

$= 22.193$ °

$z = z_a \cos(\omega_e t + \delta)$

$4.908 \cos(\omega_e t + 22.193\,°)$

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since $\xi = 0$ at the CG of the ship

$= -4.280 \sin \omega_e t$

Exiting moment component, M_1

$M_1 = 1/3 \times S \times SUM_3$

$= 1/3 \times$ 2.46 x 26414.147

$=$ [illegible] kN-m.

Exiting moment component, M_2

$M_2 = 1/3 \times S \times SUM_4$

$= 1/3 \times$ 2.46 x -2696.043

$=$ [illegible] kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{21659.601^2 + -2210.755^2}$

$=$ [illegible] kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

$= -5.828$ °

$M = 21772.132 \cos(\omega_e t + -5.828\,°)$ kN.

$\bar{M} = M_1 + iM_2$

$= 21659.601 + (-2210.755)i$

$\bar{\theta} = \dfrac{(\bar{M}P - \bar{F}R)\ \overline{(PS - QR)}}{(PS - QR)\ \overline{(PS - QR)}}$

$= 0.650870516 + (0.960967691)i$

$\theta_1 = \theta$ (real) $= 0.651$

$\theta_2 = \theta$ (imaginer) $= 0.961$

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

$= 1.161$ rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

$= 55.890$ °

$\theta = \theta_a \cos(\omega_e t + \theta)$

$1.161 \cos(\omega_e t + 55.890\,°)$

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.05

ζ	$= -4.280$	$\sin \omega_e t$	, Equation of wave motion
z	$= 4.908$	$\cos (\omega_e t + 22.193°)$	, Equation of heaving motion
θ	$= 1.161$	$\cos (\omega_e t + 55.890°)$	, Equation of pitching motion
F	$= 5019.35$	$\cos (\omega_e t + -87.369°)$	, Equation of exciting force
M	$= 21772.13232$	$\cos (\omega_e t + -5.828°)$	, Equation of exciting moment

$\xi = -14.850$m , Lever Arm from Longitudinal Centre of Buoyancy to bow

$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$z_b - \zeta$ [m]
0 π	0.00000	0.00000	4.5442802590	0.6508705	230.382	21659.601	14.210	14.210
0.25 π	0.67340	-3.02671	1.9024237817	-0.2192718	3708.383	16878.890	-1.354	1.673
0.5 π	1.34681	-4.28042	-1.8538467455	-0.9609677	5014.063	2210.755	-16.124	-11.844
0.75 π	2.02021	-3.02671	-4.5241589918	-1.1397417	3382.573	-13752.411	-21.449	-18.423
1 π	2.69361	0.00000	-4.5442802590	-0.6508705	-230.382	-21659.601	-14.210	-14.210
1.25 π	3.36702	3.02671	-1.9024237817	0.2192718	-3708.383	-16878.890	1.354	-1.673
1.5 π	4.04042	4.28042	1.8538467455	0.9609677	-5014.063	-2210.755	16.124	11.844
1.75 π	4.71382	3.02671	4.5241589918	1.1397417	-3382.573	13752.411	21.449	18.423
2 π	5.38723	0.00000	4.5442802590	0.6508705	230.382	21659.601	14.210	14.210

TABLE 1.06 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi \times B_n^2}{8}$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m^2]	[m]	[-]	[-]	[m^2]	[-]	[-]	[-]	[kN-sec^2/m^2]	[kN-sec^2/m^2]			[m^2]	[kN-sec^2]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	0.926	3.359	20.993	0.909	0.435	70.510	28.381	12.346	4	49.383	53.144	656.110	4	2624.438
4	8.397	2.500	19.076	4.860	0.926	3.359	20.993	0.909	0.435	70.510	28.381	12.346	2	24.692	23.620	291.604	2	583.209
6	8.397	2.500	19.076	2.340	0.926	3.359	20.993	0.909	0.435	70.510	28.381	12.346	4	49.383	5.476	67.601	4	270.404
8	8.397	2.500	19.041	-0.090	0.926	3.359	20.993	0.907	0.435	70.510	28.381	12.346	2	24.692	0.008	0.100	2	0.200
10	8.397	2.500	18.797	-2.520	0.926	3.359	20.993	0.895	0.435	70.510	28.381	12.346	4	49.383	6.350	78.401	4	313.605
12	8.397	2.500	18.304	-5.040	0.926	3.359	20.993	0.872	0.435	70.510	28.381	12.346	2	24.692	25.402	313.605	2	627.209
14	7.920	2.500	17.639	-7.470	0.873	3.168	19.800	0.891	0.315	62.726	25.248	7.953	4	31.813	55.801	443.799	4	1775.194
16	4.860	2.500	16.686	-9.900	0.536	1.944	12.150	1.373	0.285	23.620	9.507	2.710	2	5.419	98.010	265.565	2	531.131
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM$_1$	259.458			SUM$_2$	6725.389

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 259.458$

$=$ [illegible] kN-sec^2/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 6725.389$

$=$ [illegible] kN-sec^2-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

S $= L_{pp} / 20$

TABLE 2.06 CALCULATIONS FOR *b* AND *B*

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	β_n	$\overline{A}$	$\overline{A}^2$	b_n	Simpson's Multiplier	Product	ξ^2	$b_n \times \xi^2$	Simpson's Multiplier	Product
	[-]	[-]	[-]	[-]	[-] (5) x (5)	[kN-sec/m^2]		(7) x (8)	[m^2]	[kN-sec] (7) x (10)		(11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	0.926	3.359	0.909	0.094	0.009	0.274	4	1.096	53.144	14.558	4	58.232
4	0.926	3.359	0.909	0.094	0.009	0.274	2	0.548	23.620	6.470	2	12.940
6	0.926	3.359	0.909	0.094	0.009	0.274	4	1.096	5.476	1.500	4	6.000
8	0.926	3.359	0.907	0.094	0.009	0.274	2	0.548	0.008	0.002	2	0.004
10	0.926	3.359	0.895	0.094	0.009	0.274	4	1.096	6.350	1.740	4	6.958
12	0.926	3.359	0.872	0.094	0.009	0.274	2	0.548	25.402	6.958	2	13.917
14	0.873	3.168	0.891	0.094	0.009	0.274	4	1.096	55.801	15.286	4	61.143
16	0.536	1.944	1.373	0.006	0.000	0.001	2	0.002	98.010	0.109	2	0.219
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	6.029			SUM_2	159.413

Damping coefficient for heaving, *b*

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 6.029$

$= 4.94$ kN-sec/m.

Damping coefficient for pitching, *B*

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 159.413$

$= 130.56$ m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \; / \; (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\overline{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2 / \omega_e^3) \times \overline{A}$

S = L_{pp} / 20

TABLE 3.06 CALCULATIONS FOR c AND C

Station No. (1)	B_n [m] (2)	c_n [kN/m^2] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m^2] (6)	$c_n \times \xi^2$ [kN] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, c

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

= [illegible] kN/m.

Restoring moment coefficient for pitching, C

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

= [illegible] m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S $= L_{pp} / 20$

TABLE 4.06 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ [m]	a_n [ton/m]	$a_n \times \xi$ [ton] (2) x (3)	Simpson's Multiplier	Product (4) x (5)	b_n [kN-sec/m^2]	$b_n \times \xi$ [kN-sec/m] (2) x (7)	Simpson's Multiplier	Product (8) x (9)	c_n [kN/m^2]	$c_n \times \xi$ [kN/m] (2) x (11)	Simpson's Multiplier	Product (12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	12.346	90.001	4	360.005	0.274	1.997	4	7.988	84.434	615.523	4	2462.094
4	4.860	12.346	60.001	2	120.002	0.274	1.331	2	2.663	84.434	410.349	2	820.698
6	2.340	12.346	28.889	4	115.557	0.274	0.641	4	2.564	84.434	197.575	4	790.302
8	-0.090	12.346	-1.111	2	-2.222	0.274	-0.025	2	-0.049	84.434	-7.599	2	-15.198
10	-2.520	12.346	-31.112	4	-124.446	0.274	-0.690	4	-2.761	84.434	-212.774	4	-851.094
12	-5.040	12.346	-62.223	2	-124.446	0.274	-1.381	2	-2.761	84.434	-425.547	2	-851.094
14	-7.470	7.953	-59.411	4	-237.643	0.274	-2.046	4	-8.185	79.638	-594.893	4	-2379.571
16	-9.900	2.710	-26.825	2	-53.650	0.001	-0.011	2	-0.022	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM$_1$	53.157			SUM$_2$	-0.564			SUM$_3$	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM$_1$
= -1/3 x 2.46 x 53.157
= -43.589 kN-sec^2

$D = d$
= -43.589 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM$_2$) + $V_s a_z$
= (-1/3 2.46 x -0.564) + (15.432 x212.7552443)
= 3283.702 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM$_2$) − $V_s a_z$
= (-1/3 2.46 x -0.564) + (15.432 x212.7552443)
= -3282.776 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM$_3$) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 4.94)
= 889.154 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM$_3$)
= (-1/3 2.46 x -991.461)
= 812.998 kN-sec^2/sec.

TABLE 5.06 CALCULATIONS FOR *m* AND I_{yy}

Station No. (1)	Weight per Meter [N/m] (2)	m_n [kN-sec²/m²] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m²] (6)	$m_n \times \xi^2$ [kN-sec²] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM₁	#REF!			SUM₂	#REF!

Ship mass, *m*

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass *m* and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, *m*

m = Δ/g

= 3995.466 / 9.81

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24*L* and 0,26*L*.

k_{yy} = 0,26 *L*

= 0,26 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

TABLE 6.[illegible] CALCULATIONS FOR [illegible]

Station No. (1)	ξ [m] (2)	$k\xi$ (3)	Sin $k\xi$ (4)	Cos $k\xi$ (5)	T_m [m] (6)	$\frac{2\pi\cos\mu \times T_m}{L_w}$ [-] (7)	$e^{-(2\pi\cos\mu/L_w)T_m}$ (8)	c_n [kN/m²] (9)	$c_n \times \zeta_a$ [kN/m] (10)	a_n [ton/m] (11)	$a_n(-\zeta_a\omega_e^2)$ [ton/sec²] (12)
Ap	9.720	0.486	0.467	0.884	0.000	0.000	1.000	0.000	0.000	0.000	0.000
2	7.290	0.364	0.356	0.934	2.272	-0.068	1.070	84.434	265.528	12.346	-43.990
4	4.860	0.243	0.240	0.971	2.272	-0.068	1.070	84.434	265.528	12.346	-43.990
6	2.340	0.117	0.117	0.993	2.272	-0.068	1.070	84.434	265.528	12.346	-43.990
8	-0.090	-0.004	-0.004	1.000	2.268	-0.068	1.070	84.434	265.528	12.346	-43.990
10	-2.520	-0.126	-0.126	0.992	2.239	-0.067	1.069	84.434	265.528	12.346	-43.990
12	-5.040	-0.252	-0.249	0.968	2.190	-0.065	1.067	84.434	265.528	12.346	-43.990
14	-7.470	-0.373	-0.365	0.931	2.227	-0.067	1.069	70.638	250.444	7.953	-54.107
16	-9.900	-0.494	-0.475	0.880	1.433	-0.103	1.106	48.869	153.882	2.710	-18.434
18	-12.420	-0.620	-0.581	0.814	0.000	0.000	1.000	0.000	0.000	0.000	0.000
FP	-14.850	-0.742	-0.676	0.737	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Station No. (1)	(10) + (12) (13)	$\frac{da_n}{d\xi}$ [kN-sec²/m³] (14)	$V_v\zeta_a\omega_e\frac{da_n}{d\xi}$ (15)	$b_n\zeta_a\omega_e$ [ton/sec] (16)	(16) - (15) (17)	(13) x (4) (18)	(17) x (5) (19)	(18) + (19) (20)	(13) x (5) (21)	(17) x (4) (22)	(21) - (22) (23)	(20) x (8) (24)
Ap	0.000	-2.540	-181.325	0.000	181.325	0.000	160.371	160.371	0.000	84.616	-84.616	160.371
2	181.537	-2.540	-181.325	1.267	182.592	64.652	170.620	235.272	169.635	65.027	104.607	251.804
4	181.537	0.000	0.000	1.267	1.267	43.637	1.230	44.867	176.215	0.305	175.910	48.020
6	181.537	0.000	0.000	1.267	1.267	21.170	1.258	22.428	180.299	0.148	180.151	24.004
8	181.537	0.000	0.000	1.267	1.267	-0.816	1.267	0.451	181.536	-0.006	181.541	0.483
10	181.537	0.000	0.000	1.267	1.267	-22.790	1.257	-21.533	180.101	-0.159	180.260	-23.023
12	181.537	0.904	64.515	1.267	-63.248	-45.220	-61.254	-106.474	175.815	15.755	160.061	-113.643
14	196.337	1.983	141.529	1.267	-140.262	-71.549	-130.611	-202.181	182.828	51.129	131.700	-216.099
16	135.248	1.617	115.389	0.005	-115.384	-64.187	-101.562	-165.749	119.046	54.760	64.287	-183.663
18	0.000	0.538	38.375	0.000	-38.375	0.000	-31.224	-31.224	0.000	22.308	-22.308	-31.224
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No. (1)	Simpson's Multiplier (25)	Product (24) x (25) (26)	(23) x (8) (27)	Simpson's Multiplier (28)	Product (27) x (28) (29)	(24) x (2) (30)	Simpson's Multiplier (31)	Product (30) x (31) (32)	(27) x (2) (33)	Simpson's Multiplier (34)	Product (33) x (34) (35)
Ap	1	160.371	-84.616	1	-84.616	1558.806	1	1558.806	-822.469	1	-822.469
2	4	1007.216	111.958	4	447.831	1835.652	4	7342.608	816.173	4	3264.691
4	2	96.039	188.271	2	376.542	233.376	2	466.751	914.997	2	1829.995
6	4	96.017	192.810	4	771.239	56.170	4	224.681	451.175	4	1804.700
8	2	0.965	194.273	2	388.547	-0.043	2	-0.087	-17.485	2	-34.969
10	4	-92.093	192.795	4	770.941	58.019	4	232.075	-485.693	4	-1942.770
12	2	-227.285	170.838	2	341.675	572.759	2	1145.517	-851.022	2	-1722.044
14	4	-864.396	140.766	4	563.064	1614.239	4	6457.095	-1051.572	4	-4206.087
16	2	-367.327	71.235	2	142.470	1818.267	2	3636.535	-705.227	2	-1410.453
18	4	-124.896	-22.308	4	-89.234	387.802	4	1551.210	277.071	4	1108.282
FP	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.008
	SUM	-315.387		SUM	3628.459		SUM	22615.131		SUM	-2131.13

Explanation:

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi\cos\mu/L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

(11) = Sectional Added Mass, a_n

$a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

$s = L_{pp}/20$

force component, F_1

F_1 = 1/3 x S x SUM$_1$

= 1/3 x 2.46 x -315.387

= -258.618 kN.

force component, F_2

F_2 = 1/3 x S x SUM$_2$

= 1/3 x 2.46 x 3628.459

= 2975.337 kN.

de of the exiting force, F_0

$F_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-258.618^2 + 2975.337^2}$

= 2986.555 kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

= -85.032 °

F = 2986.555cos ($\omega_e t$ + -85.032 °) kN.

$\overline{F} = F_1 + iF_2$

= -258.618 + (2975.337) i

$P = -(m+a)\omega_e^2 + ib\,\omega_e + c$

= 244.336 + 4.938 i

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\,\omega_e + C$

= -818.563 + 192.0283854 i

$Q = -d\,\omega_e^2 + ie\,\omega_e + h$

= 983.489 + 4829.713 i

$R = D\,\omega_e^2 + iE\,\omega_e + H$

= 718.703 + (-4828.351) i

PS = -200952.660 + (42877.777) i

QR = 24026386.059 + -1277500.712 i

QR = -24227338.719 + (1320378.49) i

$\overline{QR}$ = -24227338.719 + -1320378.489 i

$-QR)\ \overline{(PS-QR)}$ = 5.88707E+14

$\overline{F}S$ = -359654.31 + -2485162.044 i

$\overline{M}Q$ = 26678253.45 + 87845491.143 i

$\overline{M}Q$ = -27037907.760 + (-90330653.187) i

$\overline{M}Q)\ \overline{(PS-QR)}$ = 5.35786E+14 + (2.22417E+15) i

$\overline{M}P$ = 4539697.744 + -335418.9706 i

$\overline{F}R$ = 14180101.09 + (3387080.255) i

$-\overline{F}R$ = -9640403.345 + -3722499.226 i

$-\overline{F}R)\ \overline{(PS-QR)}$ = 2.28646E+14 + (1.02915E+14) i

$$\overline{z} = \frac{(\overline{F}S - \overline{M}Q)\ \overline{(PS-QR)}}{(PS-QR)\ \overline{(PS-QR)}}$$

= 0.910105686 + (3.778059911) i

$z_1 = z$ (real) = 0.910

$z_2 = z$ (imaginer) = 3.778

$z_a = \sqrt{z_1^2 + z_2^2}$

= 3.886 m.

$\delta = \tan^{-1}(z_2/z_1)$

= 76.456 °

$z = z_a \cos(\omega_e t + \delta)$

3.886 cos ($\omega_e t$ + 76.456 °)

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since ξ = 0 at the CG of the ship

= -3.145 sin $\omega_e t$

Exiting moment component, M_1

M_1 = 1/3 x S x SUM$_3$

= 1/3 x 2.46 x 22615.131

= 18544.407 kN-m.

Exiting moment component, M_2

M_2 = 1/3 x S x SUM$_4$

= 1/3 x 2.46 x -2131.126

= -1747.523 kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{18544.407^2 + -1747.523^2}$

= 18626.564 kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

= -5.383 °

M = 18626.564 cos ($\omega_e t$ + -5.383 °) kN.

$\overline{M} = M_1 + iM_2$

= 18544.407 + (-1747.523) i

$$\overline{\theta} = \frac{(\overline{M}P - \overline{F}R)\ \overline{(PS-QR)}}{(PS-QR)\ \overline{(PS-QR)}}$$

= 0.388386883 + (0.174815606) i

$\theta_1 = \theta$ (real) = 0.388

$\theta_2 = \theta$ (imaginer) = 0.175

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

= 0.426 rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

= 24.233 °

$\theta = \theta_a \cos(\omega_e t + \theta)$

0.426 cos ($\omega_e t$ + 24.233 °)

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.06

ζ = -3.145 $\sin \omega_e t$, Equation of wave motion
z = 3.886 $\cos (\omega_e t +$ 76.456 °) , Equation of heaving motion
θ = 0.426 $\cos (\omega_e t +$ 24.233 °) , Equation of pitching motion
F = 2986.56 $\cos (\omega_e t +$ -85.032 °) , Equation of exciting force
M = 18626.56364 $\cos (\omega_e t +$ -5.383 °) , Equation of exciting moment

ξ = -14.850m , Lever Arm from Longitudinal Centre of Buoyancy to bow
$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$Zb - \zeta$ [m]
0 π	0.00000	0.00000	0.9101056860	0.3883869	258.618	18544.407	6.678	6.678
0.25 π	0.53399	-2.22371	-2.0279498805	0.1510177	2286.751	14348.561	0.215	2.438
0.5 π	1.06798	-3.14480	-3.7780599108	-0.1748156	2975.337	1747.523	-6.374	-3.229
0.75 π	1.60197	-2.22371	-3.3150336848	-0.3982443	1921.010	-11877.191	-9.229	-7.005
1 π	2.13596	0.00000	-0.9101056860	-0.3883869	-258.618	-18544.407	-6.678	-6.678
1.25 π	2.66994	2.22371	2.0279498805	-0.1510177	-2286.751	-14348.561	-0.215	-2.438
1.5 π	3.20393	3.14480	3.7780599108	0.1748156	-2975.337	-1747.523	6.374	3.229
1.75 π	3.73792	2.22371	3.3150336848	0.3982443	-1921.010	11877.191	9.229	7.005
2 π	4.27191	0.00000	0.9101056860	0.3883869	258.618	18544.407	6.678	6.678

TABLE 1.07 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi}{8} \times B_n^2$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m²]	[m]	[-]	[-]	[m²]	[-]	[-]	[-]	[kN-sec²/m²]	[kN-sec²/m²]			[m²]	[kN-sec²]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	1.397	3.359	20.993	0.909	0.510	70.510	28.381	14.474	4	57.898	53.144	769.232	4	3076.928
4	8.397	2.500	19.076	4.860	1.397	3.359	20.993	0.909	0.510	70.510	28.381	14.474	2	28.949	23.620	341.881	2	683.762
6	8.397	2.500	19.076	2.340	1.397	3.359	20.993	0.909	0.510	70.510	28.381	14.474	4	57.898	5.476	79.256	4	317.025
8	8.397	2.500	19.041	-0.090	1.397	3.359	20.993	0.907	0.510	70.510	28.381	14.474	2	28.949	0.008	0.117	2	0.234
10	8.397	2.500	18.797	-2.520	1.397	3.359	20.993	0.895	0.510	70.510	28.381	14.474	4	57.898	6.350	91.919	4	367.674
12	8.397	2.500	18.304	-5.040	1.397	3.359	20.993	0.872	0.510	70.510	28.381	14.474	2	28.949	25.402	367.674	2	735.349
14	7.920	2.500	17.639	-7.470	1.318	3.168	19.800	0.891	0.475	62.726	25.248	11.993	4	47.972	55.801	669.220	4	2676.880
16	4.860	2.500	16.686	-9.900	0.809	1.944	12.150	1.373	0.415	23.620	9.507	3.946	2	7.891	98.010	386.701	2	773.401
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM_1	316.403			SUM_2	8631.253

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times \quad 316.403$

= [illegible] kN-sec²/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times \quad 2.46 \times \quad 8631.253$

= [illegible] kN-sec²-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

S = L_{pp} / 20

TABLE 2.07 CALCULATIONS FOR b AND B

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	β_n	$\overline{A}$	$\overline{A}^2$	b_n	Simpson's Multiplier	Product	ξ^2	$b_n \times \xi^2$	Simpson's Multiplier	Product
	[-]	[-]	[-]	[-]	[-]	[kN-sec/m^2]			[m^2]	[kN-sec]		
					(5) x (5)			(7) x (8)		(7) x (10)		(11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	1.397	3.359	0.909	0.094	0.009	0.148	4	0.591	53.144	7.853	4	31.414
4	1.397	3.359	0.909	0.094	0.009	0.148	2	0.296	23.620	3.490	2	6.981
6	1.397	3.359	0.909	0.094	0.009	0.148	4	0.591	5.476	0.809	4	3.237
8	1.397	3.359	0.907	0.094	0.009	0.148	2	0.296	0.008	0.001	2	0.002
10	1.397	3.359	0.895	0.094	0.009	0.148	4	0.591	6.350	0.938	4	3.754
12	1.397	3.359	0.872	0.094	0.009	0.148	2	0.296	25.402	3.754	2	7.507
14	1.318	3.168	0.891	0.094	0.009	0.148	4	0.591	55.801	8.246	4	32.984
16	0.809	1.944	1.373	0.006	0.000	0.001	2	0.001	98.010	0.059	2	0.118
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM$_1$	3.252			SUM$_2$	85.997

Damping coefficient for heaving, b

$b = \int b_n \, d\xi$

= 1/3 x S x SUM$_1$

= 1/3 x 2.457 x 3.252

= 2.66 kN-sec/m.

Damping coefficient for pitching, B

$B = \int b_n \xi^2 \, d\xi$

= 1/3 x S x SUM$_2$

= 1/3 x 2.457 x 85.997

= 70.43 m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\overline{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \overline{A}$

S = L_{pp} / 20

TABLE 3.07 CALCULATIONS FOR c AND C

Station No. (1)	B_n [m] (2)	c_n [kN/m²] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m²] (6)	$c_n \times \xi^2$ [kN] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, c

$$c = \int c_n \, d\xi = (\rho g A_w)$$
$$= 1/3 \times S \times SUM_1$$
$$= 1/3 \times 2.457 \times 1936.098$$
$$= 1585.6644 \text{ kN/m.}$$

Restoring moment coefficient for pitching, C

$$C = \int c_n \xi^2 \, d\xi$$
$$= 1/3 \times S \times SUM_2$$
$$= 1/3 \times 2.457 \times 57576.799$$
$$= 47155.398 \text{ m-kN/rad.}$$

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S $= L_{pp} / 20$

TABLE 4.07 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ	a_n	$a_n \times \xi$	Simpson's Multiplier	Product	b_n	$b_n \times \xi$	Simpson's Multiplier	Product	c_n	$c_n \times \xi$	Simpson's Multiplier	Product
	[m]	[ton/m]	[ton] (2) x (3)		(4) x (5)	[kN-sec/m^2]	[kN-sec/m] (2) x (7)		(8) x (9)	[kN/m^2]	[kN/m] (2) x (11)		(12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	14.474	105.519	4	422.075	0.148	1.077	4	4.309	84.434	615.523	4	2462.094
4	4.860	14.474	70.346	2	140.692	0.148	0.718	2	1.436	84.434	410.349	2	820.698
6	2.340	14.474	33.870	4	135.481	0.148	0.346	4	1.383	84.434	197.575	4	790.302
8	-0.090	14.474	-1.303	2	-2.605	0.148	-0.013	2	-0.027	84.434	-7.599	2	-15.198
10	-2.520	14.474	-36.476	4	-145.903	0.148	-0.372	4	-1.490	84.434	-212.774	4	-851.094
12	-5.040	14.474	-72.951	2	-145.903	0.148	-0.745	2	-1.490	84.434	-425.547	2	-851.094
14	-7.470	11.993	-89.588	4	-358.351	0.148	-1.104	4	-4.416	79.638	-594.893	4	-2379.571
16	-9.900	3.946	-39.061	2	-78.121	0.001	-0.006	2	-0.012	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	-32.635			SUM_2	-0.305			SUM_3	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$

= -1/3 x S x SUM_1

= -1/3 x 2.46 x -32.635

= 26.761 kN-sec^2

$D = d$

= 26.761 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$

= (-1/3 x S x SUM_2) + $V_s a_z$

= (-1/3 2.46 x -0.305) + (15.432 ×259.4506472)

= 4004.092 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$

= (-1/3 x S x SUM_2) − $V_s a_z$

= (-1/3 2.46 x -0.305) + (15.432 x259.4506472)

= -4003.593 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$

= (-1/3 x S x SUM_3) + $V_s b$

= (-1/3 2.46 x -991.461) + (15.432 × 2.66)

= 854.103 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$

= (-1/3 x S x SUM_3)

= (-1/3 2.46 x -991.461)

= 812.998 kN-sec^2/sec.

TABLE 5.07 CALCULATIONS FOR *m* AND I_{yy}

Station No.	Weight per Meter [N/m]	m_n [kN-sec²/m²]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m²]	$m_n \times \xi^2$ [kN-sec²] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, *m*

m = 1/3 x S x SUM_1
= 1/3 x 2.46 x #REF!
= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2
= 1/3 x 2.46 x #REF!
= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot
(3) = Mass Distribution, Weight per Foot/g
S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass *m* and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, *m*

m = Δ/g
= 3995.466 / 9.81
= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24*L* and 0,26*L*.

k_{yy} = 0,26 *L*
= 0,26 24.600
= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²
= [illegible] kN-sec²-m.

Station No.	ξ [m]	$k\xi$	Sin $k\xi$	Cos $k\xi$	T_m [m]	$\frac{2\pi}{L_w} \cos\mu \times T_m$ [ ] - 1	$e^{-(2\pi\cos\mu/L_w)T_m}$	c_n [kN/m²]	$c_n \times \zeta_a$ [kN/m]	a_n [tonne/m]	$a_n \times (-\zeta_a \omega_e^2)$ [tonne/sec²]	(10) + (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	9.730	0.634	0.592	0.806	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
2	7.290	0.476	0.458	0.889	2.272	-0.089	1.093	84.434	203.295	14.474	-113.768	89.527
4	4.860	0.317	0.312	0.950	2.272	-0.089	1.093	84.434	203.295	14.474	-113.768	89.527
6	2.340	0.153	0.152	0.988	2.272	-0.089	1.093	84.434	203.295	14.474	-113.768	89.527
8	-0.090	-0.006	-0.006	1.000	2.268	-0.089	1.093	84.434	203.295	14.474	-113.768	89.527
10	-2.520	-0.164	-0.164	0.987	2.239	-0.087	1.091	84.434	203.295	14.474	-113.768	89.527
12	-5.040	-0.329	-0.323	0.946	2.180	-0.085	1.089	84.434	203.295	14.474	-113.768	89.527
14	-7.470	-0.487	-0.468	0.884	2.227	-0.087	1.091	79.638	191.746	11.993	-94.264	97.482
16	-9.900	-0.646	-0.602	0.799	3.433	-0.134	1.143	48.869	117.662	3.946	-31.011	86.651
18	-12.430	-0.810	-0.724	0.689	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
FP	-14.850	-0.969	-0.824	0.565	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Station No.	$\frac{da_n}{d\xi}$ [kN-sec²/m²]	$V \cdot \zeta_a \omega_e \frac{da_n}{d\xi}$	$b_n \zeta_a \omega_e$ [tonne/sec]	(16) - (15)	(13) x (4)	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)	Simpson's Multiplier
(1)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
Ap	-2.978	-199.941	0.000	199.941	0.000	161.070	161.070	0.000	118.460	-118.460	161.070	1
2	-2.978	-199.941	0.643	200.584	40.991	178.323	219.314	79.591	91.841	-12.250	239.656	4
4	0.000	0.000	0.643	0.643	27.812	0.611	28.523	85.064	0.200	84.864	31.169	2
6	0.000	0.000	0.643	0.643	13.614	0.635	14.250	88.485	0.098	88.388	15.571	4
8	0.000	0.000	0.643	0.643	-0.526	0.643	0.117	89.525	-0.004	89.529	0.128	2
10	0.000	0.000	0.643	0.643	-14.652	0.634	-14.018	88.319	-0.105	88.425	-15.298	4
12	0.511	34.277	0.643	-33.634	-28.909	-31.833	-60.742	84.731	10.861	73.869	-66.138	2
14	2.166	145.440	0.643	-144.797	-45.649	-127.940	-173.589	86.134	67.805	18.329	-189.359	4
16	2.439	163.717	0.003	-163.715	-52.155	-130.738	-182.893	69.197	98.539	-29.342	-209.129	2
18	0.783	52.554	0.000	-52.554	0.000	-36.226	-36.226	0.000	38.074	-38.074	-36.226	4
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.800	0.000	1
												SUM

Station No.	Product (24) x (25)	(23) x (8)	Simpson's Multiplier	Product (27) x (28)	(24) x (2)	Simpson's Multiplier	Product (30) x (31)	(27) x (2)	Simpson's Multiplier	(33) x (34)
(1)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	161.070	-118.460	1	-118.460	1565.601	1	1565.601	-1151.432	1	-1151.432
2	958.623	-13.386	4	-53.545	1747.090	4	6988.360	-97.586	4	-390.343
4	62.338	92.735	2	185.470	151.480	2	302.961	450.691	2	901.382
6	62.285	96.586	4	386.342	36.437	4	145.746	226.010	4	904.041
8	0.256	97.817	2	195.633	-0.012	2	-0.023	-8.804	2	-17.607
10	-61.194	96.501	4	386.007	38.552	4	154.208	-243.182	4	-972.728
12	-132.276	90.432	2	180.863	333.335	2	666.671	-405.375	2	-810.751
14	-757.436	19.994	4	79.974	1414.511	4	5658.045	-149.352	4	-597.409
16	-418.258	-33.550	2	-67.101	2070.376	2	4140.752	332.150	2	664.300
18	-144.903	-38.074	4	-152.298	449.924	4	1799.694	472.865	4	1891.540
FP	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	-209.495		SUM	1002.865		SUM	21422.014		SUM	420.539

Explanation:

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi \cos\mu / L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

(11) = Sectional Added Mass, a_n

$a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n / d\xi$

$s = L_w / 20$

orce component, F_1

$_1 = 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.46 $\times$ -269.495

$=$ -220.986 kN.

orce component, F_2

$_2 = 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.46 $\times$ 1002.882

$=$ 822.364 kN.

e of the exiting force, F_0

$_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-220.986^2 + 822.364^2}$

$=$ 851.538 kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

$= -74.959$ °

$F = 851.538 \cos(\omega_e t + -74.959°)$ kN.

$\overline{F} = F_1 + iF_2$

$= -220.986 + (822.364)i$

$= -(m+a)\omega_e^2 + ib\omega_e + c$

$= -590.856 + 4.813\,i$

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\omega_e + C$

$= -30339.767 + 127.2540544\,i$

$Q = -d\omega_e^2 + ie\omega_e + h$

$= 766.745 + 7234.501\,i$

$R = D\omega_e^2 + iE\omega_e + H$

$= 900.356 + (-7233.598)\,i$

$PS = 17925809.506 + (-221200.672)\,i$

$QR = 53021813.092 + 967303.164\,i$

$QR = -35096003.586 + (-1188503.84)\,i$

$\overline{QR} = -35096003.586 + 1188503.836\,i$

$-QR)\ (\overline{PS - QR}) = 1.23314E+15$

$\overline{F}S = 6600009.08 + -24978438.916\,i$

$\overline{M}Q = 10971215.28 + 127346309.706\,i$

$\overline{M}Q = -4371206.203 + (-152324748.622)\,i$

$\overline{M}Q)\ (\overline{PS - QR}) = 3.3445E+14 + (5.34079E+15)\,i$

$\overline{M}P = -10380662.36 + -119434.7573\,i$

$\overline{F}R = 5749681.379 + (2338942.459)\,i$

$\overline{F}R = -16130343.74 + -2458377.216\,i$

$-\overline{F}R)\ (\overline{PS - QR}) = 5.69032E+14 + (6.71082E+13)\,i$

$\overline{z} = \dfrac{(\overline{F}S - \overline{M}Q)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$

$= 0.271218087 + (4.33104597)\,i$

$z_1 = z$ (real) $= 0.271$

$z_2 = z$ (imaginer) $= 4.331$

$z_a = \sqrt{z_1^2 + z_2^2}$

$= 4.340$ m.

$\delta = \tan^{-1}(z_2/z_1)$

$= 86.417$ °

$z = z_a \cos(\omega_e t + \delta)$

$4.340 \cos(\omega_e t + 86.417°)$

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since $\xi = 0$ at the CG of the ship

$= -2.408 \sin \omega_e t$

Exiting moment component, M_1

$M_1 = 1/3 \times S \times SUM_3$

$= 1/3 \times$ 2.46 $\times$ 21422.016

$=$ 17566.053 kN-m.

Exiting moment component, M_2

$M_2 = 1/3 \times S \times SUM_4$

$= 1/3 \times$ 2.46 $\times$ 420.994

$=$ 345.215 kN-m.

Amplitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{17566.053^2 + 345.215^2}$

$=$ 17569.445 kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

$= 1.126$ °

$M = 17569.445 \cos(\omega_e t + 1.126°)$ kN.

$\overline{M} = M_1 + iM_2$

$= 17566.053 + (345.215)\,i$

$\overline{\theta} = \dfrac{(\overline{M}P - \overline{F}R)\ (\overline{PS - QR})}{(PS - QR)\ (\overline{PS - QR})}$

$= 0.461449199 + (0.054420529)\,i$

$\theta_1 = \theta$ (real) $= 0.461$

$\theta_2 = \theta$ (imaginer) $= 0.054$

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

$= 0.465$ rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

$= 6.726$ °

$\theta = \theta_a \cos(\omega_e t + \theta)$

$0.465 \cos(\omega_e t + 6.726°)$

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.07

ζ = -2.408 $\sin \omega_e t$, Equation of wave motion

z = 4.340 $\cos(\omega_e t +$ 86.417 °) , Equation of heaving motion

θ = 0.465 $\cos(\omega_e t +$ 6.726 °) , Equation of pitching motion

F = 851.54 $\cos(\omega_e t +$ -74.959 °) , Equation of exciting force

M = 17569.44455 $\cos(\omega_e t +$ 1.126 °) , Equation of exciting moment

ξ = -14.850 m , Lever Arm from Longitudinal Centre of Buoyancy to bow

$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$Zb - \zeta$ [m]
0 π	0.00000	0.00000	0.2712180869	0.4614492	220.986	17566.053	7.124	7.124
0.25 π	0.43470	-1.70253	-2.8707318264	0.2878127	737.759	12176.971	1.403	3.106
0.5 π	0.86939	-2.40774	-4.3310459698	-0.0544205	822.364	-345.215	-5.139	-2.731
0.75 π	1.30409	-1.70253	-3.2542921233	-0.3647750	425.238	-12665.179	-8.671	-6.969
1 π	1.73878	0.00000	-0.2712180869	-0.4614492	-220.986	-17566.053	-7.124	-7.124
1.25 π	2.17348	1.70253	2.8707318264	-0.2878127	-737.759	-12176.971	-1.403	-3.106
1.5 π	2.60817	2.40774	4.3310459698	0.0544205	-822.364	345.215	5.139	2.731
1.75 π	3.04287	1.70253	3.2542921233	0.3647750	-425.238	12665.179	8.671	6.969
2 π	3.47757	0.00000	0.2712180869	0.4614492	220.986	17566.053	7.124	7.124

TABLE 1.08 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi}{8} \times B_n^2$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m^2]	[m]	[-]	[-]	[m^2]	[-]	[-]	[-]	[$kN\text{-}sec^2/m^2$]	[$kN\text{-}sec^2/m^2$]			[m^2]	[$kN\text{-}sec^2$]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	2.023	3.359	20.993	0.909	0.665	70.510	28.381	18.874	4	75.494	53.144	1003.018	4	4012.072
4	8.397	2.500	19.076	4.860	2.023	3.359	20.993	0.909	0.665	70.510	28.381	18.874	2	37.747	23.620	445.786	2	891.572
6	8.397	2.500	19.076	2.340	2.023	3.359	20.993	0.909	0.665	70.510	28.381	18.874	4	75.494	5.476	103.344	4	413.376
8	8.397	2.500	19.041	-0.090	2.023	3.359	20.993	0.907	0.665	70.510	28.381	18.874	2	37.747	0.008	0.153	2	0.306
10	8.397	2.500	18.797	-2.520	2.023	3.359	20.993	0.895	0.665	70.510	28.381	18.874	4	75.494	6.350	119.855	4	479.418
12	8.397	2.500	18.304	-5.040	2.023	3.359	20.993	0.872	0.665	70.510	28.381	18.874	2	37.747	25.402	479.418	2	958.837
14	7.920	2.500	17.639	-7.470	1.908	3.168	19.800	0.891	0.560	62.726	25.248	14.139	4	56.556	55.801	788.975	4	3155.901
16	4.860	2.500	16.686	-9.900	1.171	1.944	12.150	1.373	0.465	23.620	9.507	4.421	2	8.842	98.010	433.291	2	866.582
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM_1	405.122			SUM_2	10778.064

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 405.122$

$=$ [illegible] $kN\text{-}sec^2/m$.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 10778.064$

$=$ [illegible] $kN\text{-}sec^2\text{-}m$.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

$S = L_{pp} / 20$

TABLE 2.08 CALCULATIONS FOR *b* AND *B*

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$ [-]	$\frac{B_n}{T_n}$ [-]	β_n [-]	$\bar{A}$ [-]	$\bar{A}^2$ [-] (5) x (5)	b_n [kN-sec/m^2]	Simpson's Multiplier	Product (7) x (8)	ξ^2 [m^2]	$b_n \times \xi^2$ [kN-sec] (7) x (10)	Simpson's Multiplier	Product (11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	2.023	3.359	0.909	0.094	0.009	0.085	4	0.339	53.144	4.507	4	18.027
4	2.023	3.359	0.909	0.094	0.009	0.085	2	0.170	23.620	2.003	2	4.006
6	2.023	3.359	0.909	0.094	0.009	0.085	4	0.339	5.476	0.464	4	1.857
8	2.023	3.359	0.907	0.094	0.009	0.085	2	0.170	0.008	0.001	2	0.001
10	2.023	3.359	0.895	0.094	0.009	0.085	4	0.339	6.350	0.539	4	2.154
12	2.023	3.359	0.872	0.094	0.009	0.085	2	0.170	25.402	2.154	2	4.308
14	1.908	3.168	0.891	0.094	0.009	0.085	4	0.339	55.801	4.732	4	18.929
16	1.171	1.944	1.373	0.006	0.000	0.000	2	0.001	98.010	0.034	2	0.068
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	1.866			SUM_2	49.351

Damping coefficient for heaving, *b*

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1.866$

= [illegible].53 kN-sec/m.

Damping coefficient for pitching, *B*

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 49.351$

= [illegible] m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \, / \, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\bar{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \bar{A}$

S = L_{pp} / 20

TABLE 3.08 CALCULATIONS FOR *c* AND *C*

Station No.	B_n [m]	c_n [kN/m²]	Simpson's Multiplier	Product (3) x (4)	ξ^2 [m²]	$c_n \times \xi^2$ [kN] (3) x (6)	Simpson's Multiplier	Product (7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, *c*

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

= [illegible]585.6644 kN/m.

Restoring moment coefficient for pitching, *C*

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

= 47[illegible].398 m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S $= L_{pp} / 20$

TABLE 4.08 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ	a_n	$a_n \times \xi$	Simpson's Multiplier	Product	b_n	$b_n \times \xi$	Simpson's Multiplier	Product	c_n	$c_n \times \xi$	Simpson's Multiplier	Product
	[m]	[ton/m]	[ton]			[kN-sec/m^2]	[kN-sec/m]			[kN/m^2]	[kN/m]		
			(2) x (3)		(4) x (5)		(2) x (7)		(8) x (9)		(2) x (11)		(12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	18.874	137.588	4	550.353	0.085	0.618	4	2.473	84.434	615.523	4	2462.094
4	4.860	18.874	91.725	2	183.451	0.085	0.412	2	0.824	84.434	410.349	2	820.698
6	2.340	18.874	44.164	4	176.656	0.085	0.198	4	0.794	84.434	197.575	4	790.302
8	-0.090	18.874	-1.699	2	-3.397	0.085	-0.008	2	-0.015	84.434	-7.599	2	-15.198
10	-2.520	18.874	-47.561	4	-190.245	0.085	-0.214	4	-0.855	84.434	-212.774	4	-851.094
12	-5.040	18.874	-95.123	2	-190.245	0.085	-0.427	2	-0.855	84.434	-425.547	2	-851.094
14	-7.470	14.139	-105.619	4	-422.477	0.085	-0.633	4	-2.534	79.638	-594.893	4	-2379.571
16	-9.900	4.421	-43.767	2	-87.534	0.000	-0.003	2	-0.007	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	16.562			SUM_2	-0.175			SUM_3	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM_1
= -1/3 x 2.46 x 16.562
= -13.581 kN-sec^2

$D = d$
= -13.581 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM_2) + $V_s a_z$
= (-1/3 2.46 x -0.175) + (15.432 x332.2002064)
= 5126.657 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM_2) − $V_s a_z$
= (-1/3 2.46 x -0.175) + (15.432 x332.2002064)
= -5126.370 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM_3) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 1.53)
= 836.587 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM_3)
= (-1/3 2.46 x -991.461)
= 812.998 kN-sec^2/sec.

TABLE 5.08 CALCULATIONS FOR *m* AND I_{yy}

Station No. (1)	Weight per Meter [N/m] (2)	m_n [kN-sec²/m²] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m²] (6)	$m_n \times \xi^2$ [kN-sec²] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, *m*

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= #REF! kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass *m* and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, *m*

m = Δ/g

= 3995.466 / 9.81

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24*L* and 0,26*L*.

k_{yy} = 0,26 *L*

= 0,26 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

TABLE 4.08 CALCULATIONS FOR EXITING FORCES AND MOMENTS (F AND M)

Station No. (1)	ξ [m] (2)	$k\xi$ (3)	Sin $k\xi$ (4)	Cos $k\xi$ (5)	T_m [m] (6)	$\frac{2\pi \cos\mu \times T_m}{L_w}$ [-] (7)	$e^{-[2\pi \cos\mu \times T_m / L_w]}$ (8)	c_s [kN/m²] (9)	$c_s \times \zeta_a$ [kN/m] (10)	a_s [ton/m] (11)	$a_s(-\zeta_a\omega_e^2)$ [ton/sec²] (12)
Ap	9.720	0.803	0.719	0.695	0.000	0.000	1.000	0.000	0.000	0.000	0.000
2	7.290	0.602	0.566	0.824	2.272	-0.112	1.119	84.434	160.628	18.874	-169.729
4	4.860	0.401	0.391	0.921	2.272	-0.112	1.119	84.434	160.628	18.874	-169.729
6	2.340	0.193	0.192	0.981	2.272	-0.112	1.119	84.434	160.628	18.874	-169.729
8	-0.090	-0.007	-0.007	1.000	2.268	-0.112	1.119	84.434	160.628	18.874	-169.729
10	-2.520	-0.208	-0.207	0.978	2.239	-0.111	1.117	84.434	160.628	18.874	-169.729
12	-5.040	-0.416	-0.404	0.915	2.190	-0.108	1.114	84.434	160.628	18.874	-169.729
14	-7.470	-0.617	-0.578	0.816	2.227	-0.110	1.116	79.638	151.503	14.139	-127.153
16	-9.900	-0.817	-0.729	0.684	3.435	-0.170	1.185	48.869	92.965	4.421	-39.757
18	-12.420	-1.026	-0.855	0.519	0.000	0.000	1.000	0.000	0.000	0.000	0.000
FP	-14.850	-1.226	-0.941	0.338	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Station No. (1)	(10) + (12) (13)	$\frac{da_s}{d\xi}$ [kN-sec²/m³] (14)	$F_s \zeta_a \omega_e \frac{da_s}{d\xi}$ (15)	$b_s \zeta_a \omega_e$ [ton/sec] (16)	(16) - (15) (17)	(13) x (4) (18)	(17) x (5) (19)	(18) + (19) (20)	(13) x (5) (21)	(17) x (4) (22)	(21) - (22) (23)	(20) x (8) (24)
Ap	0.000	-3.883	-247.881	0.000	247.881	0.000	172.343	172.343	0.000	178.362	-178.362	172.343
2	-9.102	-3.883	-247.881	0.351	248.232	-5.154	204.604	199.451	-7.502	140.557	-148.059	223.145
4	-9.102	0.000	0.000	0.351	0.351	-3.555	0.323	-3.232	-8.379	0.137	-8.516	-3.616
6	-9.102	0.000	0.000	0.351	0.351	-1.748	0.344	-1.403	-8.932	0.067	-9.000	-1.570
8	-9.102	0.000	0.000	0.351	0.351	0.068	0.351	0.418	-9.101	-0.003	-9.099	0.468
10	-9.102	0.000	0.000	0.351	0.351	1.880	0.343	2.223	-8.905	-0.072	-8.833	2.483
12	-9.102	0.974	62.181	0.351	-61.830	3.679	-56.553	-52.874	-8.325	24.994	-33.319	-58.887
14	24.350	2.974	189.818	0.351	-189.467	-14.085	-154.556	-168.641	19.864	109.591	-89.728	-188.260
16	53.211	2.877	183.626	0.001	-183.625	-38.812	-125.617	-164.429	36.401	133.934	-97.533	-194.831
18	0.000	0.877	55.989	0.000	-55.989	0.000	-29.040	-29.040	0.000	47.869	-47.869	-29.040
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No. (1)	Simpson's Multiplier (25)	Product (24) x (25) (26)	(23) x (8) (27)	Simpson's Multiplier (28)	Product (27) x (28) (29)	(24) x (2) (30)	Simpson's Multiplier (31)	Product (30) x (31) (32)	(27) x (2) (33)	Simpson's Multiplier (34)	Product (33) x (34) (35)
Ap	1	172.343	-178.262	1	-178.262	1674.303	1	1674.303	-1732.707	1	-1732.707
2	4	892.582	-165.648	4	-662.593	1626.730	4	6506.920	-1207.575	4	-4830.259
4	2	-7.232	-9.527	2	-19.055	-17.575	2	-35.149	-46.302	2	-92.605
6	4	-6.280	-10.069	4	-40.275	-3.674	4	-14.696	-23.561	4	-94.244
8	2	0.936	-10.178	2	-20.355	-0.042	2	-0.084	0.916	2	1.832
10	4	9.934	-9.866	4	-39.464	-6.258	4	-25.033	24.862	4	99.449
12	2	-117.775	-37.108	2	-74.217	296.793	2	593.585	187.026	2	374.053
14	4	-753.040	-100.166	4	-400.666	1406.302	4	5625.210	748.243	4	2992.974
16	2	-389.662	-115.566	2	-231.133	1928.828	2	3857.656	1144.106	2	2288.212
18	4	-116.159	-47.869	4	-191.478	360.674	4	1442.698	594.539	4	2378.155
FP	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	SUM	-314.455		SUM	-1857.496		SUM	19625.308		SUM	1384.512

Explanation :

(2) – Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) – $k\xi = (2\pi \cos\mu / L_w) \times \xi$

(6) – Mean Draft, $T_m = S_s / B_s$

(9) – Sectional Restoring Force Coefficient, $c_s = \rho g B_s$

(11) – Sectional Added Mass, a_s

$a_s = C \times (\rho\pi/8) \times B_s^2$

(14) – Slope of the added mass curve, $da_s/d\xi$

$\delta = L_w / 20$

rce component, F_1

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.46 x -314.455

$=$ 257.853 kN.

rce component, F_2

$_2 = 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.46 x -1857.496

$=$ 1523.147 kN.

e of the exiting force, F_0

$_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-257.853^2 + -1523.147^2}$

$=$ 1544.819 kN.

$F = F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

$= 80.392$ °

$F = 1544.819 \cos(\omega_e t + 80.392°)$ kN.

$\overline{F} = F_1 + iF_2$

$= -257.853 + (-1523.147)\,i$

$P = -(m+a)\omega_e^2 + ib\omega_e + c$

$= -1909.996 + 3.323\,i$

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\omega_e + C$

$= -73384.937 + 87.87814948\,i$

$Q = -d\omega_e^2 + ie\omega_e + h$

$= 900.785 + 11146.387\,i$

$R = D\omega_e^2 + iE\omega_e + H$

$= 748.799 + (-11145.764)\,i$

$PS = 140164627.262 + (-411735.890)\,i$

$QR = 124909500.500 + -1693534.848\,i$

$QR = 15255126.761 + (1281798.96)\,i$

$\overline{QR} = 15255126.761 + -1281798.958\,i$

$QR)\ (\overline{PS - QR}) =$ 2.34362E+14

$\overline{F}S = 19056373.08 + 111753386.686\,i$

$\overline{M}Q = 1838808.841 + 180398934.285\,i$

$\overline{M}Q = 17217564.241 + (-68645547.599)\,i$

$\overline{M}Q)\ (\overline{PS - QR}) =$ 1.74666E+14 + (-1.06927E+15) i

$\overline{M}P = -30740863.36 + -2115417.286\,i$

$\overline{F}R = -17169716.54 + (1733436.714)\,i$

$\overline{F}R = -13571146.82 + -3848854\,i$

$- \overline{F}R)\ (\overline{PS - QR}) =$ -2.11963E+14 + (-4.13193E+13) i

$$\overline{z} = \frac{(\overline{F}S - \overline{M}Q)\,(\overline{PS - QR})}{(PS - QR)\,(\overline{PS - QR})}$$

$= 0.745284677 + (-4.562456531)\,i$

$z_1 = z$ (real) $=$ 0.745

$z_2 = z$ (imaginer) $=$ -4.562

$z_a = \sqrt{z_1^2 + z_2^2}$

$= 4.623$ m.

$\delta = \tan^{-1}(z_2/z_1)$

$= -80.723$ °

$z = z_a \cos(\omega_e t + \delta)$

4.623 cos ($\omega_e t$ + -80.723 °)

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since $\xi = 0$ at the CG of the ship

$= -1.902 \sin \omega_e t$

Exiting moment component, M_1

$M_1 = 1/3 \times S \times SUM_3$

$= 1/3 \times$ 2.46 x 19625.308

$=$ 16092.753 kN-m.

Exiting moment component, M_2

$M_2 = 1/3 \times S \times SUM_4$

$= 1/3 \times$ 2.46 x 1384.820

$=$ 1135.552 kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{16092.753^2 + 1135.552^2}$

$=$ 16132.767 kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

$= 4.036$ °

$M = 16132.767 \cos(\omega_e t + 4.036°)$ kN.

$\overline{M} = M_1 + iM_2$

$= 16092.753 + (1135.552)\,i$

$$\overline{\theta} = \frac{(\overline{M}P - \overline{F}R)\,(\overline{PS - QR})}{(PS - QR)\,(\overline{PS - QR})}$$

$= -0.904426108 + (-0.176305422)\,i$

$\theta_1 = \theta$ (real) $=$ -0.904

$\theta_2 = \theta$ (imaginer) $=$ -0.176

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

$= 0.921$ rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

$= 11.031$ °

$\theta = \theta_a \cos(\omega_e t + \theta)$

0.921 cos ($\omega_e t$ + 11.031 °)

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.08

ζ = -1.902 sin $\omega_e t$, Equation of wave motion
z = 4.623 cos ($\omega_e t$ + -80.723c6) , Equation of heaving motion
θ = 0.921 cos ($\omega_e t$ + 11.031 °) , Equation of pitching motion
F = 1544.82 cos ($\omega_e t$ + 80.392 °) , Equation of exciting force
M = 16132.76684 cos ($\omega_e t$ + 4.036 °) , Equation of exciting moment

ξ = -14.850m , Lever Arm from Longitudinal Centre of Buoyancy to bow
$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$Zb - \zeta$ [m]
0 π	0.00000	0.00000	0.7452846767	0.9044261	257.853	16092.753	14.176	14.176
0.25 π	0.36124	-1.34521	3.7531398006	0.5148591	-894.698	10576.338	11.399	12.744
0.5 π	0.72247	-1.90241	4.5624565308	-0.1763054	-1523.147	-1135.552	1.944	3.847
0.75 π	1.08371	-1.34521	2.6991481030	-0.7641926	-1259.357	-12182.251	-8.649	-7.304
1 π	1.44494	0.00000	-0.7452846767	-0.9044261	-257.853	-16092.753	-14.176	-14.176
1.25 π	1.80618	1.34521	-3.7531398006	-0.5148591	894.698	-10576.338	-11.399	-12.744
1.5 π	2.16741	1.90241	-4.5624565308	0.1763054	1523.147	1135.552	-1.944	-3.847
1.75 π	2.52865	1.34521	-2.6991481030	0.7641926	1259.357	12182.251	8.649	7.304
2 π	2.88988	0.00000	0.7452846767	0.9044261	257.853	16092.753	14.176	14.176

TABLE 1.09 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi \times B_n^2}{8}$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m^2]	[m]	[-]	[-]	[m^2]	[-]	[-]	[-]	[kN-sec^2/m^2]	[kN-sec^2/m^2]			[m^2]	[kN-sec^2]		
						(2) / (3)	(2) x (3)	(4) / (8)		(2) x (2)		(12) x (10)		(13) x (14)	(5) x (5)	(13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	2.834	3.359	20.993	0.909	0.735	70.510	28.381	20.860	4	83.441	53.144	1108.599	4	4434.396
4	8.397	2.500	19.076	4.860	2.834	3.359	20.993	0.909	0.735	70.510	28.381	20.860	2	41.720	23.620	492.711	2	985.421
6	8.397	2.500	19.076	2.340	2.834	3.359	20.993	0.909	0.735	70.510	28.381	20.860	4	83.441	5.476	114.222	4	456.889
8	8.397	2.500	19.041	-0.090	2.834	3.359	20.993	0.907	0.735	70.510	28.381	20.860	2	41.720	0.008	0.169	2	0.338
10	8.397	2.500	18.797	-2.520	2.834	3.359	20.993	0.895	0.735	70.510	28.381	20.860	4	83.441	6.350	132.471	4	529.884
12	8.397	2.500	18.304	-5.040	2.834	3.359	20.993	0.872	0.735	70.510	28.381	20.860	2	41.720	25.402	529.884	2	1059.767
14	7.920	2.500	17.639	-7.470	2.673	3.168	19.800	0.891	0.635	62.726	25.248	16.033	4	64.131	55.801	894.642	4	3578.566
16	4.860	2.500	16.686	-9.900	1.640	1.944	12.150	1.373	0.565	23.620	9.507	5.372	2	10.743	98.010	526.472	2	1052.944
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM$_1$	450.359			SUM$_2$	12098.205

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 450.359$

$=$ [illegible] kN-sec^2/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 12098.205$

$=$ [illegible] kN-sec^2-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

S $= L_{pp} / 20$

TABLE 2.09 CALCULATIONS FOR b AND B

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	β_n	$\overline{A}$	$\overline{A}^2$	b_n	Simpson's Multiplier	Product	ξ^2	$b_n \times \xi^2$	Simpson's Multiplier	Product
	[-]	[-]	[-]	[-]	[-] (5) x (5)	[kN-sec/m^2]		(7) x (8)	[m^2]	[kN-sec] (7) x (10)		(11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	2.834	3.359	0.909	0.094	0.009	0.051	4	0.205	53.144	2.719	4	10.876
4	2.834	3.359	0.909	0.094	0.009	0.051	2	0.102	23.620	1.208	2	2.417
6	2.834	3.359	0.909	0.094	0.009	0.051	4	0.205	5.476	0.280	4	1.121
8	2.834	3.359	0.907	0.094	0.009	0.051	2	0.102	0.008	0.000	2	0.001
10	2.834	3.359	0.895	0.094	0.009	0.051	4	0.205	6.350	0.325	4	1.300
12	2.834	3.359	0.872	0.094	0.009	0.051	2	0.102	25.402	1.300	2	2.599
14	2.673	3.168	0.891	0.094	0.009	0.051	4	0.205	55.801	2.855	4	11.420
16	1.640	1.944	1.373	0.006	0.000	0.000	2	0.000	98.010	0.020	2	0.041
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	1.126			SUM_2	29.774

Damping coefficient for heaving, b

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1.126$

$= 0.92$ kN-sec/m.

Damping coefficient for pitching, B

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 29.774$

$= 24.38$ m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, A

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times A$

S $= L_{pp} / 20$

TABLE 3.09 CALCULATIONS FOR c AND C

Station No.	B_n	c_n	Simpson's Multiplier	Product	ξ^2	$c_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[kN/m^2]		(3) x (4)	[m^2]	[kN] (3) x (6)		(7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, c

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

= [illegible]585.6044 kN/m.

Restoring moment coefficient for pitching, C

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

= 47[illegible] m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S $= L_{pp} / 20$

TABLE 4.09 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ	a_n	$a_n \times \xi$	Simpson's Multiplier	Product	b_n	$b_n \times \xi$	Simpson's Multiplier	Product	c_n	$c_n \times \xi$	Simpson's Multiplier	Product
	[m]	[ton/m]	[ton] (2) x (3)		(4) x (5)	[kN-sec/m^2]	[kN-sec/m] (2) x (7)		(8) x (9)	[kN/m^2]	[kN/m] (2) x (11)		(12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	20.860	152.071	4	608.285	0.051	0.373	4	1.492	84.434	615.523	4	2462.094
4	4.860	20.860	101.381	2	202.762	0.051	0.249	2	0.497	84.434	410.349	2	820.698
6	2.340	20.860	48.813	4	195.252	0.051	0.120	4	0.479	84.434	197.575	4	790.302
8	-0.090	20.860	-1.877	2	-3.755	0.051	-0.005	2	-0.009	84.434	-7.599	2	-15.198
10	-2.520	20.860	-52.568	4	-210.271	0.051	-0.129	4	-0.516	84.434	-212.774	4	-851.094
12	-5.040	20.860	-105.136	2	-210.271	0.051	-0.258	2	-0.516	84.434	-425.547	2	-851.094
14	-7.470	16.033	-119.765	4	-479.058	0.051	-0.382	4	-1.529	79.638	-594.893	4	-2379.571
16	-9.900	5.372	-53.179	2	-106.358	0.000	-0.002	2	-0.004	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	-3.415			SUM_2	-0.105			SUM_3	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM_1
= -1/3 x 2.46 x -3.415
= 2.80 kN-sec^2

$D = d$
= 2.80 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM_2) + $V_s a_z$
= (-1/3 2.46 x -0.105) + (15.432 x369.2940542)
= 5699.032 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM_2) − $V_s a_z$
= (-1/3 2.46 x -0.105) + (15.432 x369.2940542)
= -5698.859 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM_3) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 0.92)
= 827.229 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM_3)
= (-1/3 2.46 x -991.461)
= 812.998 kN-sec^2/sec.

TABLE 5.09 CALCULATIONS FOR *m* AND I_{yy}

Station No. (1)	Weight per Meter [N/m] (2)	m_n [kN-sec²/m²] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m²] (6)	$m_n \times \xi^2$ [kN-sec²] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM₁	#REF!			SUM₂	#REF!

Ship mass, *m*

m = 1/3 x S x SUM_1
= 1/3 x 2.46 x #REF!
= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2
= 1/3 x 2.46 x #REF!
= [illegible] kN-sec²-m.

Keterangan :
(2) = Weight per Foot
(3) = Mass Distribution, Weight per Foot/g
S = L_{pp} / 20

Note :
If the distribution of weight along the length is not known, ship mass *m* and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, *m*

m = Δ/g
= 3995.466 / 9.81
= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,
k_{yy}, the *radius of gyration*, is assumed to be between 0,24*L* and 0,26*L*.

k_{yy} = 0,26 *L*
= 0,26 24.600
= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²
= [illegible] kN-sec²-m.

Station No.	ξ [m]	$k\xi$	Sin $k\xi$	Cos $k\xi$	T_x [m]	$-\frac{2\pi \cos\mu \times T_x}{L_w}$ [-]	$e^{-(2\pi\cos\mu/\lambda)T_x}$	c_x [kN/m²]	$c_x \times \zeta_x$ [kN/m]	a_x [ton/m]	$a_x(-\zeta_x\omega_e^2)$ [ton/sec²]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ap	9.720	0.991	0.836	0.548	0.000	0.000	1.000	0.000	0.000	0.000	0.000
2	7.290	0.743	0.677	0.736	2.272	-0.139	1.149	84.434	130.109	20.860	-212.823
4	4.860	0.495	0.475	0.880	2.272	-0.139	1.149	84.434	130.109	20.860	-212.823
6	2.340	0.239	0.236	0.972	2.272	-0.139	1.149	84.434	130.109	20.860	-212.823
8	-0.090	-0.009	-0.009	1.000	2.268	-0.138	1.148	84.434	130.109	20.860	-212.823
10	-2.520	-0.257	-0.254	0.967	2.239	-0.137	1.146	84.434	130.109	20.860	-212.823
12	-5.040	-0.514	-0.491	0.871	2.180	-0.133	1.142	84.434	130.109	20.860	-212.823
14	-7.470	-0.761	-0.690	0.724	2.227	-0.136	1.146	79.638	122.718	16.033	-163.571
16	-9.900	-1.009	-0.846	0.533	3.433	-0.209	1.223	48.869	75.304	5.372	-54.903
18	-12.420	-1.266	-0.954	0.300	0.000	0.000	1.000	0.000	0.000	0.000	0.000
FP	-14.850	-1.514	-0.998	0.057	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Station No.	(10) + (12)	$\frac{da_x}{d\xi}$ [kN-sec²/m²]	$V\zeta_a\omega_e \frac{da_x}{d\xi}$	[mm/sec]	(16) - (15)	(13) x (4)	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)
(1)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Ap	0.000	-4.292	-262.633	0.000	262.633	0.000	143.923	143.923	0.000	219.687	-219.687	143.923
2	-42.714	-4.292	-262.633	0.203	262.836	-55.963	193.542	137.579	-60.907	177.831	-238.739	158.080
4	-42.714	0.000	0.000	0.203	0.203	-39.322	0.178	-39.143	-72.770	0.096	-72.866	-44.962
6	-42.714	0.000	0.000	0.203	0.203	-19.543	0.197	-19.346	-80.372	0.048	-80.420	-22.232
8	-42.714	0.000	0.000	0.203	0.203	0.759	0.203	0.962	-82.711	-0.002	-82.709	1.104
10	-42.714	0.000	0.000	0.203	0.203	21.015	0.196	21.211	-80.000	-0.052	-79.948	24.315
12	-42.714	3.993	60.779	0.203	-60.576	40.650	-52.756	-12.105	-72.036	29.770	-101.806	-13.827
14	-40.853	3.187	195.004	0.203	-194.801	28.168	-141.001	-112.813	-29.571	134.410	-163.980	-129.231
16	20.501	3.299	199.429	0.001	-199.438	-17.352	-106.213	-123.565	10.918	168.803	-157.885	-152.355
18	0.000	1.066	65.214	0.000	-65.214	0.000	-19.567	-19.567	0.000	62.209	-62.209	-19.567
FP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No.	Multiplier	(24) x (25)	(23) x (8)	Multiplier	(27) x (28)	(24) x (2)	Multiplier	(30) x (31)	(27) x (2)		(33) x (34)
(1)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	1	143.923	-219.687	1	-219.687	1398.938	1	1398.928	-2135.355	1	-2135.355
2	4	632.121	-274.228	4	-1096.912	1152.040	4	4608.159	-1999.122	4	-7996.488
4	2	-89.924	-83.698	2	-167.395	-218.516	2	-437.032	-406.771	2	-813.541
6	4	-88.889	-92.375	4	-369.498	-52.000	4	-207.999	-216.157	4	-864.626
8	2	2.209	-94.979	2	-189.959	-0.099	2	-0.199	8.548	2	17.096
10	4	97.259	-91.647	4	-366.588	-61.273	4	-245.092	230.950	4	923.802
12	2	-27.654	-116.286	2	-232.572	69.688	2	139.377	586.081	2	1172.162
14	4	-516.924	-187.844	4	-751.377	965.355	4	3861.421	1403.196	4	5612.784
16	2	-304.711	-194.672	2	-389.344	1508.317	2	3016.634	1927.251	2	3854.503
18	4	-78.269	-62.209	4	-248.837	243.034	4	972.096	772.637	4	3090.549
FP	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
	SUM	-230.859		SUM	-4032.168		SUM	13106.295		SUM	2860.318

Explanation:

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi \cos\mu / L_w) \times \xi$

(6) = Mean Draft, $T_x = \Sigma_x / B_x$

(9) = Sectional Restoring Force Coefficient, $c_x = \rho g B_x$

(11) = Sectional Added Mass, a_x

$a_x = C \times (\rho\pi/8) \times B_x^2$

(14) = Slope of the added mass curve, $da_x/d\xi$

$s = L_w / 20$

rce component, F_1

= 1/3 x S x SUM$_1$

= 1/3 x 2.46 x -230.859

= [illegible] kN.

rce component, F_2

= 1/3 x S x SUM$_2$

= 1/3 x 2.46 x -4032.168

= [illegible] kN.

of the exiting force, F_0

$_0 = \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-189.305^2 + -3306.378^2}$

= [illegible] kN.

$= F_0 \cos(\omega_e t + \sigma)$

$\sigma = \tan^{-1}(F_2/F_1)$

= 86.723 °

F = 3311.793 cos ($\omega_e t$ + 86.723 °) kN.

$\overline{F} = F_1 + iF_2$

= -189.305 + (-3306.378) i

$P = -(m + a)\omega_e^2 + ib\omega_e + c$

= -3555.899 + 2.373 i

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\omega_e + C$

= -128838.815 + 62.74384207 i

$Q = -d\omega_e^2 + ie\omega_e + h$

= 808.686 + 14664.116 i

$R = D\omega_e^2 + iE\omega_e + H$

= 831.541 + (-14663.671) i

PS = 458137646.791 + (-528829.601) i

QR = 215702215.260 + 335499.752 i

QR = 242435431.531 + (-864329.35) i

$\overline{QR}$ = 242435431.531 + 864329.3529 i

$QR)\ (\overline{PS - QR})$ = 5.87757E+16

$\overline{F}S$ = 24597249.52 + 425977915.692 i

$\overline{M}Q$ = -25709841.08 + 159494743.656 i

$\overline{M}Q$ = 50307090.595 + (266483172.036) i

$\overline{M}Q)\ (\overline{PS - QR})$ = 1.19659E+16 + (6.46484E+16) i

$\overline{M}P$ = -38221387.85 + -8316372.134 i

$\overline{F}R$ = -48641048.91 + (26514.48424) i

$\overline{F}R$ = 10419661.06 + -8342886.618 i

$-\overline{F}R)\ (\overline{PS - QR})$ = 2.53331E+15 + (-2.01361E+15) i

$\overline{z} = \dfrac{(\overline{F}S - \overline{M}Q)\,(\overline{PS - QR})}{(PS - QR)\,(\overline{PS - QR})}$

= 0.203585749 + (1.099918174) i

z_1 = z (real) = 0.204

z_2 = z (imaginer) = 1.100

$z_a = \sqrt{z_1^2 + z_2^2}$

= 1.119 m.

$\delta = \tan^{-1}(z_2/z_1)$

= 79.514 °

$z = z_a \cos(\omega_e t + \delta)$

1.119 cos ($\omega_e t$ + 79.514 °)

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since ξ = 0 at the CG of the ship

= -1.541 sin $\omega_e t$

Exiting moment component, M_1

M_1 = 1/3 x S x SUM$_3$

= 1/3 x 2.46 x 13106.295

= [illegible] kN-m.

Exiting moment component, M_2

M_2 = 1/3 x S x SUM$_4$

= 1/3 x 2.46 x 2860.885

= [illegible] kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{10747.162^2 + 2345.926^2}$

= [illegible] kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

= 12.314 °

M = 11000.221 cos ($\omega_e t$ + 12.314 °) kN.

$\overline{M} = M_1 + iM_2$

= 10747.162 + (2345.926) i

$\overline{\theta} = \dfrac{(\overline{M}P - \overline{F}R)\,(\overline{PS - QR})}{(PS - QR)\,(\overline{PS - QR})}$

= 0.043101259 + (-0.034259155) i

θ_1 = θ (real) = 0.043

θ_2 = θ (imaginer) = -0.034

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

= 0.055 rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

= -38.480 °

$\theta = \theta_a \cos(\omega_e t + \theta)$

0.055 cos ($\omega_e t$ + -38.480 °)

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

TABLE 7.09

ζ = -1.541 sin $\omega_e t$, Equation of wave motion
z = 1.119 cos ($\omega_e t$ + 79.514cθ) , Equation of heaving motion
θ = 0.055 cos ($\omega_e t$ + -38.480 °) , Equation of pitching motion
F = 3311.79 cos ($\omega_e t$ + 86.723 °) , Equation of exciting force
M = 11000.22087 cos ($\omega_e t$ + 12.314 °) , Equation of exciting moment

ξ = -14.850m , Lever Arm from Longitudinal Centre of Buoyancy to bow
$z - \zeta$, Relative bow motion

$\omega_e t$ [rad]	t [sec]	ζ [m]	z [m]	θ [rad]	F [kN]	M [kN-m]	Zb [m]	$Zb - \zeta$ [m]
0 π	0.00000	0.00000	0.2035857495	0.0431013	189.305	10747.162	0.844	0.844
0.25 π	0.30524	-1.08962	-0.6338027356	0.0547021	-2204.103	5940.571	0.179	1.268
0.5 π	0.61047	-1.54095	-1.0999181741	0.0342592	-3306.378	-2345.926	-0.591	0.950
0.75 π	0.91571	-1.08962	-0.9217164636	-0.0062523	-2471.821	-9258.211	-1.015	0.075
1 π	1.22094	0.00000	-0.2035857495	-0.0431013	-189.305	-10747.162	-0.844	-0.844
1.25 π	1.52618	1.08962	0.6338027356	-0.0547021	2204.103	-5940.571	-0.179	-1.268
1.5 π	1.83141	1.54095	1.0999181741	-0.0342592	3306.378	2345.926	0.591	-0.950
1.75 π	2.13665	1.08962	0.9217164636	0.0062523	2471.821	9258.211	1.015	-0.075
2 π	2.44188	0.00000	0.2035857495	0.0431013	189.305	10747.162	0.844	0.844

TABLE 1.10 CALCULATIONS FOR a_z AND A_{yy}

St No.	B_n	T_n	S_n	ξ	$\frac{\omega_e^2 \times B_n}{2g}$	$\frac{B_n}{T_n}$	$B_n \times T_n$	β_n	C	B_n^2	$\frac{\rho\pi \times B_n^2}{8}$	a_n	Simpson's Multiplier	Product	ξ^2	$a_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[m]	[m²]	[m]	[-]	[-] (2) / (3)	[m²] (2) x (3)	[-] (4) / (8)	[-]	[-] (2) x (2)	[kN-sec²/m²]	[kN-sec²/m²] (12) x (10)		(13) x (14)	[m²] (5) x (5)	[kN-sec²] (13) x (16)		(17) x (18)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Ap	0.000	2.500	0.000	9.720	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	2.500	19.076	7.290	3.861	3.359	20.993	0.909	0.780	70.510	28.381	22.137	4	88.550	53.144	1176.472	4	4705.889
4	8.397	2.500	19.076	4.860	3.861	3.359	20.993	0.909	0.780	70.510	28.381	22.137	2	44.275	23.620	522.877	2	1045.753
6	8.397	2.500	19.076	2.340	3.861	3.359	20.993	0.909	0.780	70.510	28.381	22.137	4	88.550	5.476	121.216	4	484.862
8	8.397	2.500	19.041	-0.090	3.861	3.359	20.993	0.907	0.780	70.510	28.381	22.137	2	44.275	0.008	0.179	2	0.359
10	8.397	2.500	18.797	-2.520	3.861	3.359	20.993	0.895	0.780	70.510	28.381	22.137	4	88.550	6.350	140.581	4	562.325
12	8.397	2.500	18.304	-5.040	3.861	3.359	20.993	0.872	0.780	70.510	28.381	22.137	2	44.275	25.402	562.325	2	1124.651
14	7.920	2.500	17.639	-7.470	3.641	3.168	19.800	0.891	0.655	62.726	25.248	16.538	4	66.151	55.801	922.819	4	3691.277
16	4.860	2.500	16.686	-9.900	2.234	1.944	12.150	1.373	0.560	23.620	9.507	5.324	2	10.648	98.010	521.813	2	1043.626
18	0.000	2.500	8.875	-12.420	0.000	0.000	0.000	#DIV/0!	0.000	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	2.500	0.000	-14.850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
													SUM_1	475.272			SUM_2	12658.742

Added mass for heaving, a_z

$a_z = \int a_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \quad 2.46 \times 475.272$

= [illegible] kN-sec²/m.

Added mass moment of inertia for pitching, A_{yy}

$A_{yy} = \int a_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.46 \times 12658.742$

= [illegible] kN-sec²-m.

Keterangan :

(2) = Beam of Station, B_n

(3) = Draft at Station, T_n

(4) = Sectional Area at Station, S_n

(5) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(9) = Sectional Area Coefficient, $\beta_n = S_n / (B_n \times T_n)$

(10) = Added Mass Coefficient, C

(13) = Sectional Added Mass, $a_n = C \times (\rho\pi/8) \times B_n^2$

S = L_{pp} / 20

TABLE 2.10 CALCULATIONS FOR b AND B

Station No.	$\frac{\omega_e^2 \times B_n}{2g}$ [-]	$\frac{B_n}{T_n}$ [-]	β_n [-]	$\overline{A}$ [-]	$\overline{A}^2$ [-] (5) x (5)	b_n [kN-sec/m²]	Simpson's Multiplier	Product (7) x (8)	ξ^2 [m²]	$b_n \times \xi^2$ [kN-sec] (7) x (10)	Simpson's Multiplier	Product (11) x (12)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ap	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	3.861	3.359	0.909	0.094	0.009	0.032	4	0.129	53.144	1.710	4	6.839
4	3.861	3.359	0.909	0.094	0.009	0.032	2	0.064	23.620	0.760	2	1.520
6	3.861	3.359	0.909	0.094	0.009	0.032	4	0.129	5.476	0.176	4	0.705
8	3.861	3.359	0.907	0.094	0.009	0.032	2	0.064	0.008	0.000	2	0.001
10	3.861	3.359	0.895	0.094	0.009	0.032	4	0.129	6.350	0.204	4	0.817
12	3.861	3.359	0.872	0.094	0.009	0.032	2	0.064	25.402	0.817	2	1.634
14	3.641	3.168	0.891	0.094	0.009	0.032	4	0.129	55.801	1.795	4	7.181
16	2.234	1.944	1.373	0.006	0.000	0.000	2	0.000	98.010	0.013	2	0.026
18	0.000	0.000	#DIV/0!	0.000	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	#DIV/0!	0.000	0.000	0.000	1	0.000	220.523	0.000	1	0.000
							SUM_1	0.708			SUM_2	18.722

Damping coefficient for heaving, b

$b = \int b_n \, d\xi$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.457 $\times$ 0.708

= 0.58 kN-sec/m.

Damping coefficient for pitching, B

$B = \int b_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.457 $\times$ 18.722

= [illegible] m-kN-sec/rad.

Keterangan :

(4) = Sectional Area Coefficient, $\beta_n = S_n \,/\, (B_n \times T_n)$

(5) = Amplitude Ratio for Two-Dimensional Body in Heaving Motion, $\overline{A}$

(7) = Sectional Damping Coefficient, $b_n = (\rho g^2/\omega_e^3) \times \overline{A}$

S $= L_{pp} / 20$

TABLE 3.10 CALCULATIONS FOR *c* AND *C*

Station No.	B_n	c_n	Simpson's Multiplier	Product	ξ^2	$c_n \times \xi^2$	Simpson's Multiplier	Product
	[m]	[kN/m²]		(3) x (4)	[m²]	[kN] (3) x (6)		(7) x (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ap	0.000	0.000	1	0.000	94.478	0.000	1	0.000
2	8.397	84.434	4	337.736	53.144	4487.165	4	17948.662
4	8.397	84.434	2	168.868	23.620	1994.296	2	3988.592
6	8.397	84.434	4	337.736	5.476	462.326	4	1849.306
8	8.397	84.434	2	168.868	0.008	0.684	2	1.368
10	8.397	84.434	4	337.736	6.350	536.189	4	2144.757
12	8.397	84.434	2	168.868	25.402	2144.757	2	4289.514
14	7.920	79.638	4	318.550	55.801	4443.849	4	17775.395
16	4.860	48.869	2	97.737	98.010	4789.603	2	9579.206
18	0.000	0.000	4	0.000	154.256	0.000	4	0.000
FP	0.000	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	1936.098			SUM_2	57576.799

Restoring force coefficient for heaving, *c*

$c = \int c_n \, d\xi = (\rho g A_w)$

$= 1/3 \times S \times SUM_1$

$= 1/3 \times 2.457 \times 1936.098$

$= 1585.6644$ kN/m.

Restoring moment coefficient for pitching, *C*

$C = \int c_n \xi^2 \, d\xi$

$= 1/3 \times S \times SUM_2$

$= 1/3 \times 2.457 \times 57576.799$

= [illegible] m-kN/rad.

Keterangan :

(2) = Beam of Station, B_n

(3) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

S = $L_{pp} / 20$

TABLE 4.10 CALCULATIONS FOR *d, e, h, D, E* AND *H*

Station No.	ξ [m]	a_n [ton/m]	$a_n \times \xi$ [ton] (2) x (3)	Simpson's Multiplier	Product (4) x (5)	b_n [kN-sec/m^2]	$b_n \times \xi$ [kN-sec/m] (2) x (7)	Simpson's Multiplier	Product (8) x (9)	c_n [kN/m^2]	$c_n \times \xi$ [kN/m] (2) x (11)	Simpson's Multiplier	Product (12) x (13)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ap	9.720	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
2	7.290	22.137	161.382	4	645.527	0.032	0.235	4	0.938	84.434	615.523	4	2462.094
4	4.860	22.137	107.588	2	215.176	0.032	0.156	2	0.313	84.434	410.349	2	820.698
6	2.340	22.137	51.802	4	207.206	0.032	0.075	4	0.301	84.434	197.575	4	790.302
8	-0.090	22.137	-1.992	2	-3.985	0.032	-0.003	2	-0.006	84.434	-7.599	2	-15.198
10	-2.520	22.137	-55.786	4	-223.145	0.032	-0.081	4	-0.324	84.434	-212.774	4	-851.094
12	-5.040	22.137	-111.573	2	-223.145	0.032	-0.162	2	-0.324	84.434	-425.547	2	-851.094
14	-7.470	16.538	-123.537	4	-494.147	0.032	-0.240	4	-0.961	79.638	-594.893	4	-2379.571
16	-9.900	5.324	-52.708	2	-105.417	0.000	-0.001	2	-0.003	48.869	-483.798	2	-967.597
18	-12.420	0.000	0.000	4	0.000	0.000	0.000	4	0.000	0.000	0.000	4	0.000
FP	-14.850	0.000	0.000	1	0.000	0.000	0.000	1	0.000	0.000	0.000	1	0.000
				SUM_1	18.070			SUM_2	-0.066			SUM_3	-991.461

Coupling terms, d, D, e, E, h, H

$d = -\int a_n \xi \, d\xi$
= -1/3 x S x SUM_1
= -1/3 x 2.46 x 18.070
= -14.817 kN-sec^2

$D = d$
= -14.817 kN-sec^2

$e = -\int b_n \xi \, d\xi + V_s a_z$
= (-1/3 x S x SUM_2) + $V_s a_z$
= (-1/3 2.46 x -0.066) + (15.432 x389.7232401)
= 6014.263 kN-sec^2/sec.

$E = -\int b_n \xi \, d\xi - V_s a_z$
= (-1/3 x S x SUM_2) − $V_s a_z$
= (-1/3 2.46 x -0.066) + (15.432 x389.7232401)
= -6014.155 kN-sec^2/sec.

$h = -\int c_n \xi \, d\xi + V_s b$
= (-1/3 x S x SUM_3) + $V_s b$
= (-1/3 2.46 x -991.461) + (15.432 x 0.58)
= 821.946 kN-sec^2/sec.

$H = -\int c_n \xi \, d\xi$
= (-1/3 x S x SUM_3)
= (-1/3 2.46 x -991.461)
= 812.998 kN-sec^2/sec.

TABLE 5.10 CALCULATIONS FOR m AND I_{yy}

Station No. (1)	Weight per Meter [N/m] (2)	m_n [kN-sec²/m²] (3)	Simpson's Multiplier (4)	Product (3) x (4) (5)	ξ^2 [m²] (6)	$m_n \times \xi^2$ [kN-sec²] (3) x (6) (7)	Simpson's Multiplier (8)	Product (7) x (8) (9)
Ap	0	0.000	1	0.000	94.478	0.000	1	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
2	0	0.000	2	0.000	53.144	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
4	0	0.000	2	0.000	23.620	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
6	0	0.000	2	0.000	5.476	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
8	0	0.000	2	0.000	0.008	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
10	0	0.000	2	0.000	6.350	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
12	0	0.000	2	0.000	25.402	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
14	0	0.000	2	0.000	55.801	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
16	0	0.000	2	0.000	98.010	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
18	0	0.000	2	0.000	154.256	0.000	2	0.000
#REF!	#REF!	#REF!	4	#REF!	#REF!	#REF!	4	#REF!
FP	0	0.000	1	0.000	220.523	0.000	1	0.000
			SUM_1	#REF!			SUM_2	#REF!

Ship mass, m

m = 1/3 x S x SUM_1

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

I_{yy} = 1/3 x S x SUM_2

= 1/3 x 2.46 x #REF!

= [illegible] kN-sec²-m.

Keterangan :

(2) = Weight per Foot

(3) = Mass Distribution, Weight per Foot/g

S = L_{pp} / 20

Note :

If the distribution of weight along the length is not known, ship mass m and Ship mass moment of inertia I_{yy} are obtained as :

Ship mass, m

m = Δ/g

= 3995.466 / 9.81

= [illegible] kN-sec²/m.

Ship mass moment of inertia, I_{yy}

$I_{yy} = \Delta/g\,(k^2_{yy})$

where,

k_{yy}, the *radius of gyration*, is assumed to be between 0,24L and 0,26L.

k_{yy} = 0,26 L

= 0,26 24.600

= 6.396 m.

I_{yy} =(3995.466 / 9.81) x 6.396)²

= [illegible] kN-sec²-m.

Station No.	ξ	kξ	Sin kξ	Cos kξ	T_m	$\frac{2\pi \cos\mu \times T_m}{L_w}$	$e^{-(\ldots)}$	c_n	$c_n \times \zeta_a$	a_n	$a_n(-\zeta_a \omega_e^2)$		$\frac{da_n}{d\xi}$	$V \zeta_a \omega_e \frac{da_n}{d\xi}$	$b_n \zeta_a \omega_e$		
	[m]				[m]	[-]		[kN/m²]	[kN/m]	[ton/m]	[ton/sec²]	(10) + (12)	[kN-sec²/m²]		[ton/sec]	(16) - (15)	(13) x (4)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Ap	9.720	1.199	0.932	0.363	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	-4.555	-268.865	0.000	268.865	0.000
2	7.290	0.899	0.783	0.622	2.272	-0.168	1.183	84.434	107.528	22.137	-254.312	-146.785	-4.555	-268.865	0.123	268.988	-114.905
4	4.860	0.599	0.564	0.826	2.272	-0.168	1.183	84.434	107.528	22.137	-254.312	-146.785	0.000	0.000	0.123	0.123	-82.814
6	2.340	0.289	0.285	0.959	2.272	-0.168	1.183	84.434	107.528	22.137	-254.312	-146.785	0.000	0.000	0.123	0.123	-41.780
8	-0.090	-0.011	-0.011	1.000	2.268	-0.167	1.182	84.434	107.528	22.137	-254.312	-146.785	0.000	0.000	0.123	0.123	1.629
10	-2.520	-0.311	-0.306	0.952	2.239	-0.165	1.180	84.434	107.528	22.137	-254.312	-146.785	0.000	0.000	0.123	0.123	44.893
12	-5.040	-0.622	-0.582	0.813	2.180	-0.161	1.175	84.434	107.528	22.137	-254.312	-146.785	1.152	68.010	0.123	-67.887	85.484
14	-7.470	-0.921	-0.796	0.605	2.227	-0.164	1.179	79.638	101.420	16.538	-189.984	-88.564	3.460	204.203	0.123	-204.080	70.535
16	-9.900	-1.221	-0.939	0.343	3.433	-0.253	1.288	48.869	62.235	5.324	-61.162	1.072	3.364	198.546	0.005	-198.545	-1.007
18	-12.430	-1.532	-0.999	0.039	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	1.056	62.333	0.000	-62.333	0.000
FP	-14.850	-1.832	-0.966	-0.258	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Station No.							Simpson's Multiplier	Product		Simpson's Multiplier	Product		Simpson's Multiplier	Product		Multiplier	
	(17) x (5)	(18) + (19)	(13) x (5)	(17) x (4)	(21) - (22)	(20) x (8)		(24) x (25)	(23) x (8)		(27) x (28)	(24) x (2)		(30) x (31)	(27) x (2)		(33) x (34)
(1)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)
Ap	97.701	97.701	0.000	250.486	-250.486	97.701	1	97.701	-250.486	1	-250.486	949.656	1	949.656	-2434.719	1	-2434.719
2	167.380	52.475	-91.338	210.568	-301.905	62.055	4	248.221	-357.025	4	-1428.101	452.384	4	1809.534	-2602.713	4	-10410.854
4	0.102	-82.712	-121.192	0.069	-121.262	-97.814	2	-195.627	-143.401	2	-286.801	-475.374	2	-950.748	-696.927	2	-1393.854
6	0.118	-41.662	-140.713	0.035	-140.748	-49.268	4	-197.073	-166.445	4	-665.779	-115.287	4	-461.150	-389.481	4	-1557.924
8	0.123	1.752	-146.775	-0.001	-146.774	2.072	2	4.144	-173.518	2	-347.036	-0.186	2	-0.373	15.617	2	31.233
10	0.117	45.010	-139.751	-0.038	-139.713	53.098	4	212.391	-164.816	4	-659.265	-133.806	4	-535.226	415.337	4	1661.349
12	-55.186	30.298	-119.324	39.536	-158.860	35.587	2	71.174	-186.593	2	-373.185	-179.358	2	-358.716	940.426	2	1880.853
14	-123.412	-52.877	-53.557	162.536	-216.093	-62.325	4	-249.299	-254.706	4	-1018.822	465.567	4	1862.266	1902.651	4	7610.604
16	-68.024	-69.031	0.367	186.529	-186.162	-88.943	2	-177.886	-239.859	2	-479.718	880.536	2	1761.072	2374.602	2	4749.205
18	-2.423	-2.423	0.000	62.306	-62.306	-2.423	4	-9.692	-62.306	4	-249.224	30.094	4	120.377	773.841	4	3095.362
FP	0.000	0.000	0.000	0.000	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000	0.000	1	0.000
							SUM$_1$	-195.946		SUM$_2$	-5738.417		SUM$_3$	4196.093		SUM$_4$	3231.25

Keterangan :

(2) = Lever Arm from Longitudinal Centre of Buoyancy, ξ

(3) = $k\xi = (2\pi \cos\mu / L_w) \times \xi$

(6) = Mean Draft, $T_m = S_n / B_n$

(9) = Sectional Restoring Force Coefficient, $c_n = \rho g B_n$

(11) = Sectional Added Mass, a_n

$a_n = C \times (\rho\pi/8) \times B_n^2$

(14) = Slope of the added mass curve, $da_n/d\xi$

h $= L_w / 20$

rce component, F_1

$= 1/3 \times S \times SUM_1$

$= 1/3 \times$ 2.46 x -195.946

$= -160.676$ kN.

rce component, F_2

$= 1/3 \times S \times SUM_2$

$= 1/3 \times$ 2.46 x -5758.417

$= -4721.902$ kN.

of the exiting force, F_0

$= \sqrt{F_1^2 + F_2^2}$

$= \sqrt{-160.676^2 + -4721.902^2}$

$= 4724.635$ kN.

$= F_0 \cos(\omega_e t + \sigma)$

$= \tan^{-1}(F_2/F_1)$

$= 88.051$ °

$= 4724.635 \cos(\omega_e t + 88.051°)$ kN.

$\bar{F} = F_1 + iF_2$

$= -160.676 + (-4721.902)\,i$

$= -(m+a)\omega_e^2 + ib\,\omega_e + c$

$= -5603.857 + 1.742\,i$

$S = -(I_{yy} + A_{yy})\omega_e^2 + iB\,\omega_e + C$

$= -196778.066 + 46.05146772\,i$

$Q = -d\,\omega_e^2 + ie\,\omega_e + h$

$= 955.609 + 18063.463\,i$

$R = D\,\omega_e^2 + iE\,\omega_e + H$

$= 679.336 + (-18063.137)\,i$

$S = 1102715974.229 + (-600774.055)\,i$

$R = 326931979.094 + -4990135.294\,i$

$R = 775783995.135 + (4389361.24)\,i$

$\overline{R} = 775783995.135 + -4389361.239\,i$

$QR)\ (\overline{PS - QR}) = 6.0186E+17$

$\bar{F}S = 31834934.48 + 929159343.654\,i$

$\bar{Q} = -44572946.78 + 64693585.835\,i$

$\bar{Q} = 76407881.258 + (864465757.820)\,i$

$\bar{M}Q)\ (\overline{PS - QR}) = 6.30705E+16 + (6.70303E+17)\,i$

$\bar{M}P = -19289098.66 + -14842146.08\,i$

$\bar{F}R = -85401513.5 + (-305445.9827)\,i$

$\bar{F}R = 66112414.83 + -14536700.1\,i$

$\bar{F}R)\ (\overline{PS - QR}) = 5.12251E+16 + (-1.15675E+16)\,i$

$$\bar{z} = \frac{(\bar{F}S - \bar{M}Q)\,\overline{(PS - QR)}}{(PS - QR)\,\overline{(PS - QR)}}$$

$= 0.10479257 + (1.113719529)\,i$

$z_1 = z$ (real) $= 0.105$

$z_2 = z$ (imaginer) $= 1.114$

$z_a = \sqrt{z_1^2 + z_2^2}$

$= 1.119$ m.

$\delta = \tan^{-1}(z_2/z_1)$

$= 84.625$ °

$z = z_a \cos(\omega_e t + \delta)$

$1.119 \cos(\omega_e t + 84.625°)$

$\zeta = \zeta_a \sin(k\xi - \omega_e t)$, since $\xi = 0$ at the CG of the ship

$= -1.274 \sin \omega_e t$

Exiting moment component, M_1

$M_1 = 1/3 \times S \times SUM_3$

$= 1/3 \times$ 2.46 x 4196.693

$= 3441.288$ kN-m.

Exiting moment component, M_2

$M_2 = 1/3 \times S \times SUM_4$

$= 1/3 \times$ 2.46 x 3231.255

$= 2649.629$ kN-m.

Ampitude of the exiting moment, M_0

$M_0 = \sqrt{M_1^2 + M_2^2}$

$= \sqrt{3441.288^2 + 2649.629^2}$

$= 4343.155$ kN-m.

$M = M_0 \cos(\omega_e t + \tau)$

$\tau = \tan^{-1}(M_2/M_1)$

$= 37.595$ °

$M = 4343.155 \cos(\omega_e t + 37.595°)$ kN.

$\bar{M} = M_1 + iM_2$

$= 3441.288 + (2649.629)\,i$

$$\bar{\theta} = \frac{(\bar{M}P - \bar{F}R)\,\overline{(PS - QR)}}{(PS - QR)\,\overline{(PS - QR)}}$$

$= 0.085111388 + (-0.019219634)\,i$

$\theta_1 = \theta$ (real) $= 0.085$

$\theta_2 = \theta$ (imaginer) $= -0.019$

$\theta_a = \sqrt{\theta_1^2 + \theta_2^2}$

$= 0.087$ rad.

$\varepsilon = \tan^{-1}(\theta_2/\theta_1)$

$= -12.725$ °

$\theta = \theta_a \cos(\omega_e t + \theta)$

$0.087 \cos(\omega_e t + -12.725°)$

Keterangan :

z_a = amplitude of heaving motion

θ_a = amplitude of pitching motion

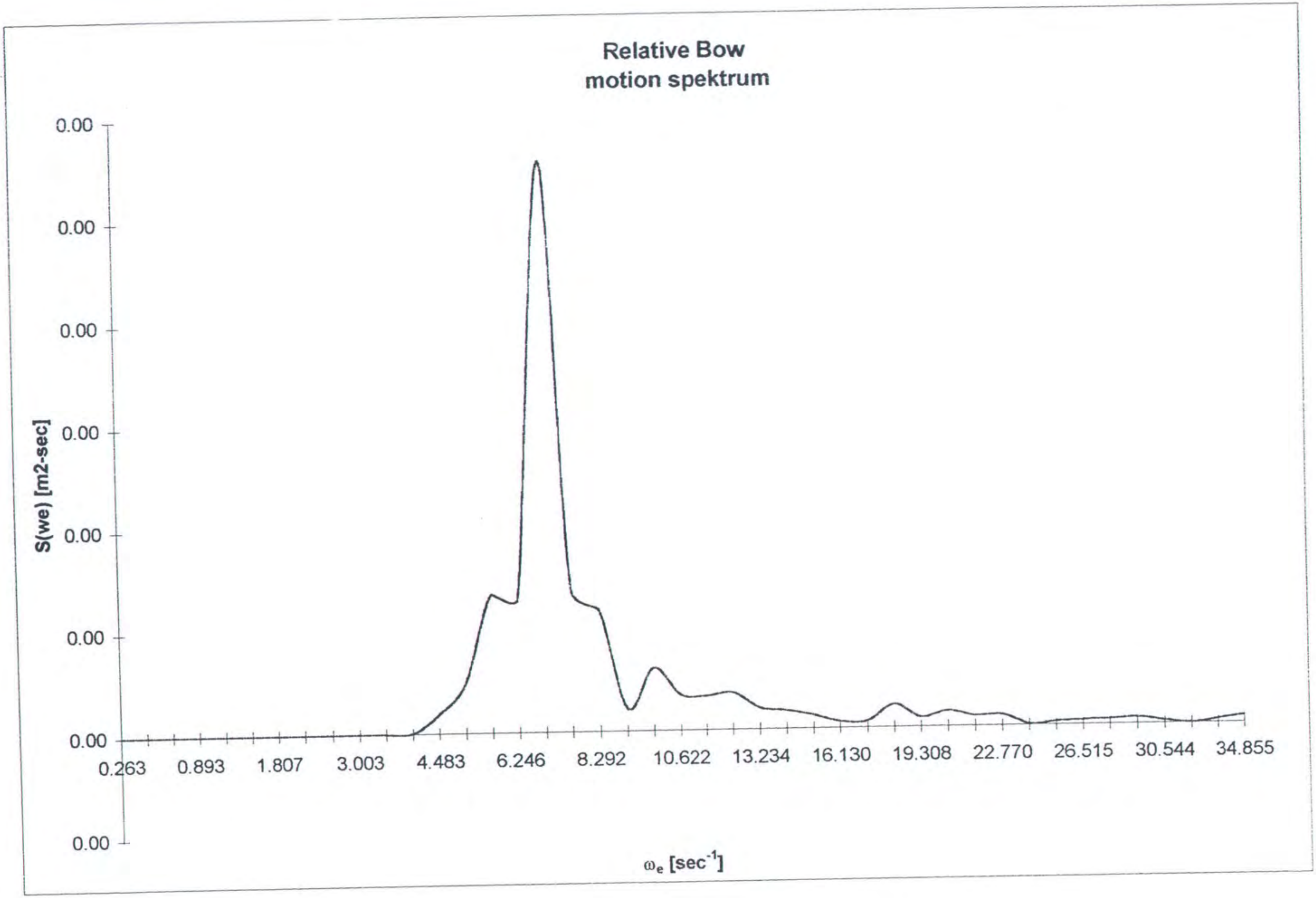
δ = phase of heaving motion after wave node at CG

ε = phase of pitching motion after wave node at CG

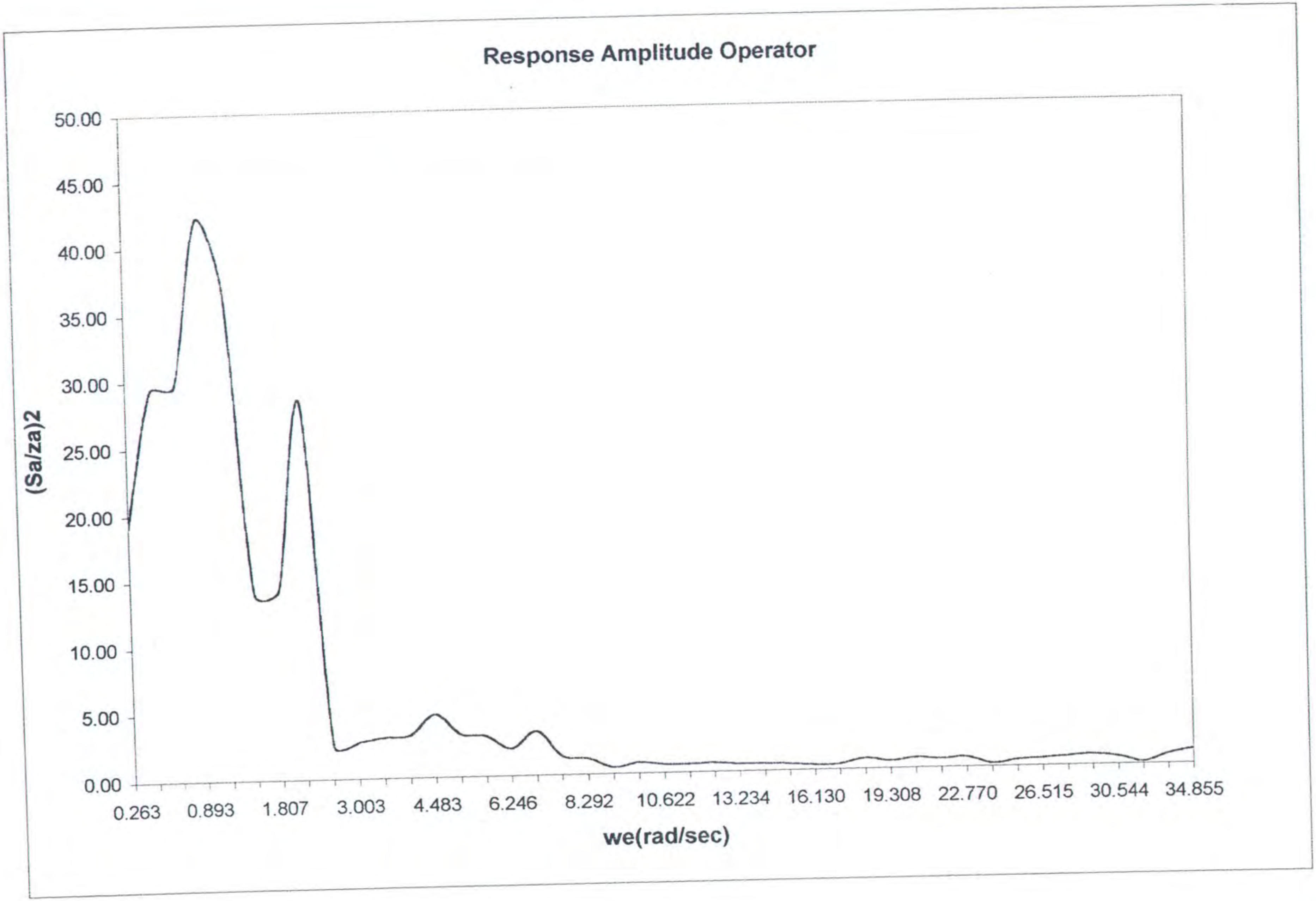
LAMPIRAN 3
RELATIF MOTION DAN RAO

Membuat Relative motion spectrum dan Response Amplitudo Operator (RAO)

	ω_w	ω_e	Sa [m]	ζa [m]	Sa/ζa	$(Sa/\zeta a)^2$ RAO	Sζ (ω_e)	S (ω_e)
1	0.2	0.263	9.585	0.500	19.171	367.524	0.000000	0.000000
2	0.3	0.442	14.667	0.500	29.334	860.455	0.000000	0.000000
3	0.4	0.652	14.873	0.500	29.746	884.795	0.000000	0.000000
4	0.5	0.893	21.097	0.500	42.194	1780.309	0.000000	0.000000
5	0.6	1.166	18.423	0.500	36.845	1357.570	0.000000	0.000000
6	0.7	1.471	7.005	0.500	14.011	196.294	0.000000	0.000000
7	0.8	1.807	7.124	0.500	14.247	202.991	0.000000	0.000000
8	0.9	2.174	14.176	0.500	28.352	803.837	0.000000	0.000000
9	1	2.573	1.268	0.500	2.536	6.433	0.000000	0.000000
10	1.1	3.003	1.369	0.500	2.737	7.493	0.000000	0.000000
11	1.2	3.465	1.536	0.500	3.071	9.433	0.000000	0.000000
12	1.3	3.959	1.598	0.500	3.197	10.220	0.000000	0.000003
13	1.4	4.483	2.358	0.500	4.715	22.235	0.000004	0.000096
14	1.5	5.039	1.600	0.500	3.200	10.239	0.000024	0.000242
15	1.6	5.627	1.513	0.500	3.026	9.155	0.000073	0.000672
16	1.7	6.246	1.025	0.500	2.049	4.200	0.000155	0.000652
17	1.8	6.897	1.659	0.500	3.317	11.005	0.000253	0.002780
18	1.9	7.579	0.710	0.500	1.420	2.018	0.000343	0.000692
19	2	8.292	0.601	0.500	1.203	1.446	0.000409	0.000592
20	2.1	9.037	0.246	0.500	0.492	0.242	0.000446	0.000108
21	2.2	9.814	0.410	0.500	0.820	0.672	0.000455	0.000305
22	2.3	10.622	0.312	0.500	0.624	0.390	0.000442	0.000172
23	2.4	11.461	0.315	0.500	0.630	0.397	0.000416	0.000165
24	2.5	12.332	0.345	0.500	0.690	0.476	0.000381	0.000181
25	2.6	13.234	0.274	0.500	0.548	0.300	0.000342	0.000103
26	2.7	14.168	0.268	0.500	0.537	0.288	0.000304	0.000088
27	2.8	15.133	0.245	0.500	0.490	0.241	0.000267	0.000064
28	2.9	16.130	0.184	0.500	0.368	0.135	0.000233	0.000031
29	3	17.158	0.194	0.500	0.387	0.150	0.000203	0.000030
30	3.1	18.217	0.394	0.500	0.788	0.621	0.000176	0.000109
31	3.2	19.308	0.276	0.500	0.552	0.305	0.000152	0.000046
32	3.3	20.431	0.377	0.500	0.754	0.568	0.000132	0.000075
33	3.4	21.585	0.327	0.500	0.653	0.427	0.000114	0.000049
34	3.5	22.770	0.367	0.500	0.734	0.538	0.000099	0.000053
35	3.6	23.987	0.117	0.500	0.233	0.054	0.000085	0.000005
36	3.7	25.236	0.235	0.500	0.471	0.222	0.000074	0.000016
37	3.8	26.515	0.286	0.500	0.571	0.326	0.000065	0.000021
38	3.9	27.827	0.338	0.500	0.675	0.456	0.000056	0.000026
39	4	29.169	0.398	0.500	0.795	0.632	0.000049	0.000031
40	4.1	30.544	0.296	0.500	0.591	0.350	0.000043	0.000015
41	4.2	31.949	0.079	0.500	0.158	0.025	0.000038	0.000001
42	4.3	33.386	0.362	0.500	0.724	0.524	0.000033	0.000017
43	4.4	34.855	0.552	0.500	1.103	1.217	0.000029	0.000035



Relative Bow
motion spektrum
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
S(we) [m2-sec]
0.263
0.893
1.807
3.003
4.483
6.246
8.292
10.622
13.234
16.130
19.308
22.770
26.515
30.544
34.855
ωe [sec-1]


Response Amplitude Operator
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
(Sa/za)2
0.263
0.893
1.807
3.003
4.483
6.246
8.292
10.622
13.234
16.130
19.308
22.770
26.515
30.544
34.855
we(rad/sec)

$$\Pr\{slam\ .impact\} = \exp\left\{-\frac{Z^2 cx}{2Ed}\right\}$$

$$Ed = \int_0^{\infty} (Z_{drel} / \zeta_w)^2 S(\omega) d\omega$$

Zcx = 0.5

Membuat Relative motion spectrum dan Response Amplitudo Operator (RAO)

H = 1

	ω_W	ω_e	Sa [m]	ζa [m]	Sa/ζa	$(Sa/\zeta a)^2$ RAO	$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
1	0.20	0.263	9.585	0.500	19.171	367.524	0.000	0.000	1	0.000
2	0.30	0.442	14.667	0.500	29.334	860.455	0.000	0.000	4	0.000
3	0.40	0.652	14.873	0.500	29.746	884.795	0.000	0.000	2	0.000
4	0.50	0.893	21.097	0.500	42.194	1780.309	0.000	0.000	4	0.000
5	0.60	1.166	18.423	0.500	36.845	1357.570	0.000	0.000	2	0.000
6	0.70	1.471	7.005	0.500	14.011	196.294	0.000	0.000	4	0.000
7	0.80	1.807	7.124	0.500	14.247	202.991	0.000	0.000	2	0.000
8	0.90	2.174	14.176	0.500	28.352	803.837	0.000	0.000	4	0.000
9	1.00	2.573	1.268	0.500	2.536	6.433	0.000	0.000	2	0.000
10	1.10	3.003	1.369	0.500	2.737	7.493	0.000	0.000	4	0.000
11	1.20	3.465	1.536	0.500	3.071	9.433	0.000	0.000	2	0.000
12	1.30	3.959	1.598	0.500	3.197	10.220	0.000	0.000	4	0.000
13	1.40	4.483	2.358	0.500	4.715	22.235	0.000	0.000	2	0.000
14	1.50	5.039	1.600	0.500	3.200	10.239	0.000	0.000	4	0.001
15	1.60	5.627	1.513	0.500	3.026	9.155	0.000	0.001	2	0.001
16	1.70	6.246	1.025	0.500	2.049	4.200	0.000	0.001	4	0.003
17	1.80	6.897	1.659	0.500	3.317	11.005	0.000	0.003	2	0.006
18	1.90	7.579	0.710	0.500	1.420	2.018	0.000	0.001	4	0.003
19	2.00	8.292	0.601	0.500	1.203	1.446	0.000	0.001	2	0.001
20	2.10	9.037	0.246	0.500	0.492	0.242	0.000	0.000	4	0.000
21	2.20	9.814	0.410	0.500	0.820	0.672	0.000	0.000	2	0.001
22	2.30	10.622	0.312	0.500	0.624	0.390	0.000	0.000	4	0.001
23	2.40	11.461	0.315	0.500	0.630	0.397	0.000	0.000	2	0.000
24	2.50	12.332	0.345	0.500	0.690	0.476	0.000	0.000	4	0.001
25	2.60	13.234	0.274	0.500	0.548	0.300	0.000	0.000	2	0.000
26	2.70	14.168	0.268	0.500	0.537	0.288	0.000	0.000	4	0.000
27	2.80	15.133	0.245	0.500	0.490	0.241	0.000	0.000	2	0.000
28	2.90	16.130	0.184	0.500	0.368	0.135	0.000	0.000	4	0.000
29	3.00	17.158	0.194	0.500	0.387	0.150	0.000	0.000	2	0.000
30	3.10	18.217	0.394	0.500	0.788	0.621	0.000	0.000	4	0.000
31	3.20	19.308	0.276	0.500	0.552	0.305	0.000	0.000	2	0.000
32	3.30	20.431	0.377	0.500	0.754	0.568	0.000	0.000	4	0.000
33	3.40	21.585	0.327	0.500	0.653	0.427	0.000	0.000	2	0.000
34	3.50	22.770	0.367	0.500	0.734	0.538	0.000	0.000	4	0.000
35	3.60	23.987	0.117	0.500	0.233	0.054	0.000	0.000	2	0.000
36	3.70	25.236	0.235	0.500	0.471	0.222	0.000	0.000	4	0.000
37	3.80	26.515	0.286	0.500	0.571	0.326	0.000	0.000	1	0.000
									SUM0	0.020

Ed = 0.000650956

$$\Pr\{slam\ .impact\} = \exp\left\{-\frac{Z^2 cx}{2Ed}\right\}$$

= 0.00000

4.022E-82

H = 2

Sζ (ω_e)	S_{18} (ω_e)	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.001	4	0.003
0.000	0.000	2	0.001
0.000	0.003	4	0.011
0.001	0.011	2	0.022
0.002	0.022	4	0.089
0.003	0.067	2	0.134
0.003	0.035	4	0.140
0.003	0.031	2	0.063
0.003	0.013	4	0.053
0.003	0.031	2	0.061
0.002	0.005	4	0.019
0.002	0.003	2	0.006
0.002	0.000	4	0.002
0.001	0.001	2	0.002
0.001	0.000	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.001
0.001	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	0.611

Ed = 0.02035

Pr = 0.00215

0.21

H = 3

$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.015	2	0.030
0.001	0.940	4	3.761
0.005	0.029	2	0.058
0.008	0.064	4	0.254
0.011	0.102	2	0.205
0.011	0.114	4	0.456
0.010	0.225	2	0.451
0.009	0.088	4	0.351
0.007	0.064	2	0.127
0.006	0.023	4	0.093
0.004	0.048	2	0.095
0.003	0.007	4	0.027
0.003	0.004	2	0.008
0.002	0.001	4	0.002
0.002	0.001	2	0.002
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	5.929

Ed = 0.197622

Pr = 0.531251
53.13

H = 4

$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.001
0.000	0.046	4	0.182
0.004	0.818	2	1.636
0.014	11.301	4	45.203
0.023	0.148	2	0.296
0.026	0.194	4	0.775
0.024	0.225	2	0.449
0.020	0.202	4	0.807
0.016	0.345	2	0.689
0.012	0.121	4	0.485
0.009	0.082	2	0.163
0.007	0.028	4	0.113
0.005	0.056	2	0.111
0.004	0.008	4	0.031
0.003	0.004	2	0.008
0.002	0.001	4	0.002
0.002	0.001	2	0.002
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	50.964

Ed = 1.698803

Pr = 0.929061
92.91

H = 5

$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.149	2	0.299
0.005	1.059	4	4.235
0.025	5.170	2	10.339
0.044	35.722	4	142.889
0.049	0.315	2	0.631
0.043	0.324	4	1.297
0.034	0.323	2	0.646
0.026	0.263	4	1.052
0.019	0.420	2	0.839
0.014	0.141	4	0.563
0.010	0.092	2	0.183
0.007	0.031	4	0.123
0.005	0.060	2	0.120
0.004	0.008	4	0.033
0.003	0.004	2	0.009
0.002	0.001	4	0.002
0.002	0.001	2	0.002
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	163.270

Ed = 5.442336

Pr = 0.977294
97.73

H = 6

$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.006	4	0.023
0.003	3.536	2	7.071
0.030	5.844	4	23.374
0.069	14.073	2	28.145
0.083	66.750	4	266.998
0.074	0.475	2	0.950
0.057	0.429	4	1.717
0.042	0.394	2	0.788
0.030	0.304	4	1.214
0.021	0.467	2	0.934
0.015	0.153	4	0.610
0.011	0.098	2	0.195
0.008	0.032	4	0.130
0.006	0.062	2	0.124
0.004	0.008	4	0.034
0.003	0.005	2	0.009
0.002	0.001	4	0.002
0.002	0.001	2	0.002
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	332.330

Ed = 11.07768

Pr = 0.988779
98.88

H = 7

$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.300	4	1.200
0.018	23.838	2	47.676
0.083	16.370	4	65.479
0.127	25.740	2	51.480
0.121	97.311	4	389.243
0.095	0.608	2	1.217
0.068	0.508	4	2.033
0.047	0.444	2	0.888
0.032	0.331	4	1.324
0.022	0.498	2	0.996
0.016	0.160	4	0.641
0.011	0.101	2	0.203
0.008	0.033	4	0.134
0.006	0.064	2	0.127
0.004	0.009	4	0.034
0.003	0.005	2	0.009
0.002	0.001	4	0.002
0.002	0.001	2	0.002
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	562.696

Ed = 18.75652

Pr = 0.993358
99.34

H =8

$S\zeta(\omega_e)$	$S_{18}(\omega_e)$	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.002	3.912	4	15.648
0.061	82.260	2	164.520
0.163	31.945	4	127.778
0.188	38.090	2	76.180
0.155	124.284	4	497.137
0.111	0.714	2	1.429
0.076	0.567	4	2.269
0.051	0.480	2	0.959
0.034	0.350	4	1.401
0.023	0.519	2	1.038
0.016	0.165	4	0.661
0.011	0.104	2	0.208
0.008	0.034	4	0.136
0.006	0.065	2	0.129
0.004	0.009	4	0.035
0.003	0.005	2	0.009
0.002	0.001	4	0.002
0.002	0.001	2	0.003
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUM0	889.550

Ed = 29.6516707

Pr = 0.99579326
99.58

H = 9

SL (m_s)	S_{ig} (m_s)	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.003	2	0.006
0.013	22.750	4	91.031
0.142	192.303	2	384.606
0.267	50.570	4	202.280
0.245	49.831	2	99.662
0.183	146.882	4	587.528
0.124	0.798	2	1.595
0.082	0.611	4	2.446
0.054	0.506	2	1.011
0.030	0.364	4	1.456
0.024	0.534	2	1.068
0.017	0.169	4	0.676
0.012	0.106	2	0.211
0.008	0.034	4	0.136
0.006	0.066	2	0.131
0.004	0.009	4	0.035
0.003	0.005	2	0.009
0.002	0.001	4	0.002
0.002	0.001	2	0.003
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUMA	1374.101

Ed = 45.8033691

Fi = 0.99727466
99.73

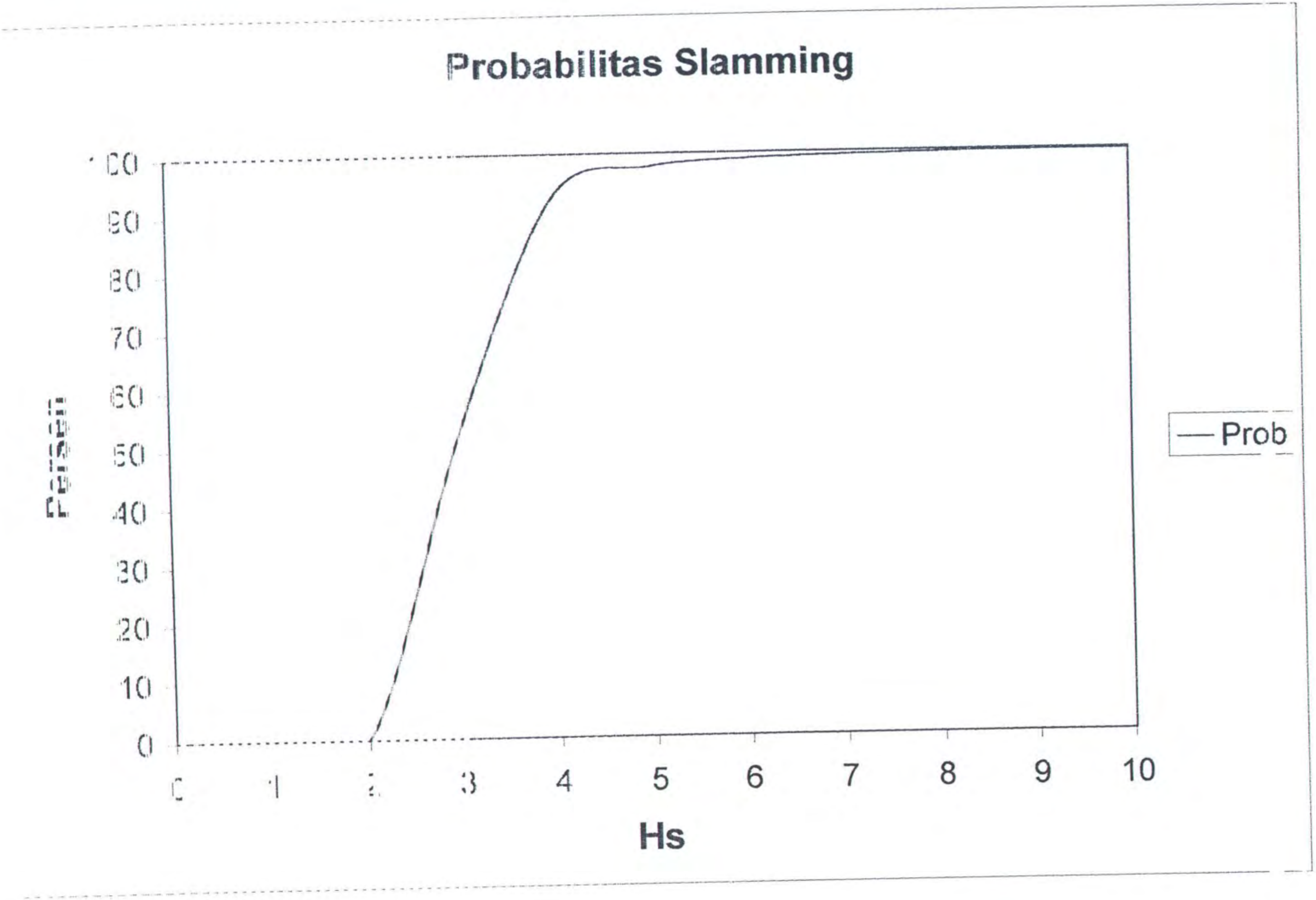
H = 10

SL (m_s)	S_{ig} (m_s)	FM	
0.000	0.000	1	0.000
0.000	0.000	4	0.000
0.000	0.060	2	0.121
0.045	80.194	4	320.775
0.200	353.006	2	706.012
0.307	70.122	4	280.488
0.238	60.350	2	120.700
0.206	165.719	4	662.876
0.104	0.860	2	1.720
0.086	0.645	4	2.581
0.056	0.525	2	1.051
0.037	0.374	4	1.496
0.025	0.546	2	1.091
0.017	0.172	4	0.687
0.012	0.107	2	0.214
0.008	0.035	4	0.139
0.006	0.066	2	0.132
0.004	0.009	4	0.035
0.003	0.005	2	0.009
0.002	0.001	4	0.002
0.002	0.001	2	0.003
0.001	0.001	4	0.002
0.001	0.000	2	0.001
0.001	0.000	4	0.002
0.001	0.000	2	0.000
0.001	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.001
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	2	0.000
0.000	0.000	4	0.000
0.000	0.000	1	0.000
		SUMA	2100.224

Ed = 70.00746

Fi = 0.9982161
99.82

LAMPIRAN 4
PROBABILITAS SLAMMING


Probabilitas Slamming
Persen
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Hs
Prob

spektrum dari ITTC

n angin sebesar 20 knot, dari buku Dynamics of Marine Vehicles halaman 118 grafik 5.15

significant wave height sebesar

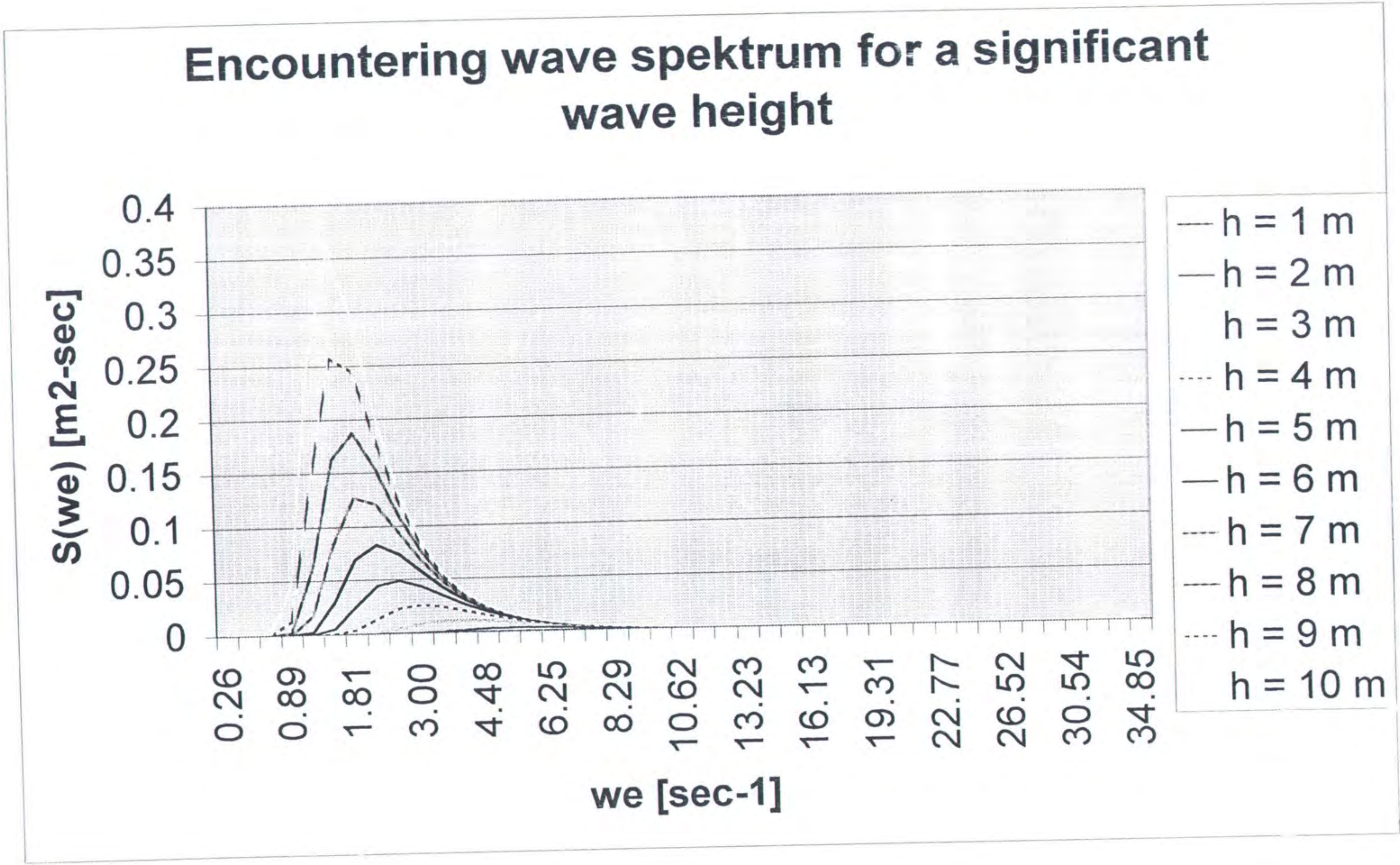
1 m.

0.778

33,56 / (H)ω^4

33.000

S (ω)	Simpson	product	ω^2	$\omega^2 S$	Simpson	product	ω^4	$\omega^4 S$	Simpson	product
[m² sec]										
0.000	1	0.000	0.040	0.000	1	0.000	0.002	0.000	1	0.000
0.000	4	0.000	0.090	0.000	4	0.000	0.008	0.000	4	0.000
0.000	2	0.000	0.160	0.000	2	0.000	0.026	0.000	2	0.000
0.000	4	0.000	0.250	0.000	4	0.000	0.063	0.000	4	0.000
0.000	2	0.000	0.360	0.000	2	0.000	0.130	0.000	2	0.000
0.000	4	0.000	0.490	0.000	4	0.000	0.240	0.000	4	0.000
0.000	2	0.000	0.640	0.000	2	0.000	0.410	0.000	2	0.000
0.000	4	0.000	0.810	0.000	4	0.000	0.656	0.000	4	0.000
0.000	2	0.000	1.000	0.000	2	0.000	1.000	0.000	2	0.000
0.000	4	0.000	1.210	0.000	4	0.000	1.464	0.000	4	0.000
0.000	2	0.000	1.440	0.000	2	0.000	2.074	0.000	2	0.000
0.000	4	0.000	1.690	0.000	4	0.000	2.856	0.000	4	0.000
0.000	2	0.000	1.960	0.000	2	0.000	3.842	0.000	2	0.000
0.000	4	0.001	2.250	0.000	4	0.001	5.063	0.001	4	0.003
0.000	2	0.001	2.560	0.001	2	0.001	6.554	0.003	2	0.006
0.001	4	0.004	2.890	0.002	4	0.007	8.352	0.008	4	0.033
0.002	2	0.003	3.240	0.003	2	0.006	10.498	0.018	2	0.035
0.002	4	0.010	3.610	0.005	4	0.018	13.032	0.031	4	0.125
0.003	2	0.006	4.000	0.006	2	0.012	16.000	0.048	2	0.096
0.003	4	0.014	4.410	0.007	4	0.028	19.448	0.066	4	0.264
0.004	2	0.007	4.840	0.008	2	0.016	23.426	0.084	2	0.169
0.004	4	0.015	5.290	0.008	4	0.034	27.984	0.102	4	0.408
0.004	2	0.007	5.760	0.009	2	0.017	33.178	0.118	2	0.236
0.003	4	0.013	6.250	0.008	4	0.034	39.063	0.132	4	0.527
0.003	2	0.006	6.760	0.009	2	0.018	45.698	0.144	2	0.287
0.003	4	0.012	7.290	0.008	4	0.031	53.144	0.153	4	0.613
0.003	2	0.005	7.840	0.007	2	0.015	61.466	0.161	2	0.322
0.002	4	0.009	8.410	0.007	4	0.027	70.728	0.167	4	0.668
0.002	2	0.004	9.000	0.006	2	0.013	81.000	0.171	2	0.343
0.002	4	0.006	9.610	0.006	4	0.023	92.352	0.174	4	0.696
0.001	4	0.006	10.890	0.005	4	0.020	118.592	0.178	4	0.711
0.001	2	0.003	11.560	0.005	2	0.009	133.634	0.178	2	0.356
0.001	4	0.005	12.250	0.004	4	0.017	150.063	0.178	4	0.711
0.001	2	0.002	12.960	0.004	2	0.008	167.962	0.177	2	0.354
0.001	4	0.004	13.690	0.003	4	0.014	187.416	0.176	4	0.703
0.001	2	0.002	14.440	0.003	2	0.006	208.514	0.174	2	0.348
0.001	4	0.003	15.210	0.003	4	0.012	231.344	0.172	4	0.690
0.001	2	0.001	16.000	0.003	2	0.005	256.000	0.171	2	0.341
0.001	4	0.002	16.810	0.002	4	0.010	282.576	0.169	4	0.674
0.001	2	0.001	17.640	0.002	2	0.004	311.170	0.166	2	0.333
0.000	4	0.002	18.490	0.002	4	0.008	341.880	0.164	4	0.658
0.000	1	0.000	19.360	0.002	1	0.002	374.810	0.162	1	0.162
	SUM_0	0.158			SUM_2	0.425			SUM_4	11.222


Encountering wave spektrum for a significant wave height
S(we) [m2-sec]
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.26
0.89
1.81
3.00
4.48
6.25
8.29
10.62
13.23
16.13
19.31
22.77
26.52
30.54
34.85
we [sec-1]
h = 1 m
h = 2 m
h = 3 m
h = 4 m
h = 5 m
h = 6 m
h = 7 m
h = 8 m
h = 9 m
h = 10 m