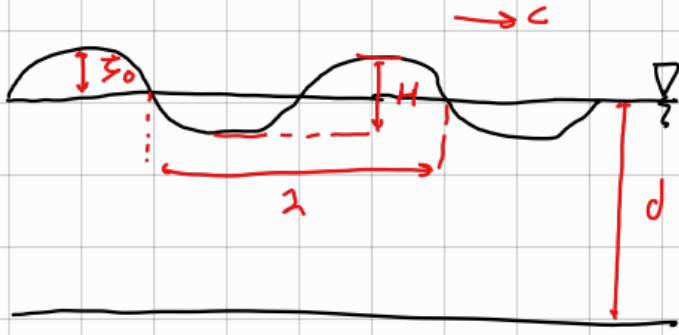


~ REGULAR WAVES ~



$\frac{H}{\lambda} \rightarrow$ wave steepness (dalganın dikliği)

dalganın sayısı

$$k = \frac{2\pi}{\lambda}$$

dalganın frekansı

$$\omega = \frac{2\pi}{T}$$

phase velocity

$$c = \frac{\lambda}{T} = \frac{\omega}{k} = \frac{g}{\omega} = \sqrt{\frac{g}{k}}$$

~ Hız Potansiyeli (\phi)

$$\phi_w(x, z, t) = P(z) \cdot \sin(kx - \omega t)$$

Teori $\rightarrow \left(\frac{H}{\lambda}\right)_{max} = \frac{1}{7} \text{ rad}$

- $\rightarrow$ inviscid, incompressible fluid
- $\rightarrow$ zemindeki partikül hızı 0
- $\rightarrow$ su yüzeyindeki basınç = atmosferik basınç

$$\phi_w = \dots$$

$$\omega^2 = \dots$$

$\frac{H}{\lambda} > \frac{1}{2} \rightarrow$ derin su dalgası

$$\phi_w = \frac{3g}{\omega} c^{\frac{1}{2}} \sin(kx - \omega t)$$

$$\omega^2 = gk$$

$$c = \frac{\lambda}{T} = \frac{\omega}{k} = \frac{g}{\omega} = \sqrt{\frac{g}{k}}$$

$$\lambda = \frac{2\pi g}{\omega^2}$$

$$\lambda = \frac{g T^2}{2\pi}$$

$$\omega = \sqrt{\frac{2\pi g}{\lambda}}$$

$$T = \sqrt{\frac{2\pi \lambda}{g}}$$

Derin su dalgaları formülleri

! WATER PARTICLE KINEMATICS OF DEEP WATER WAVES

$$u = \frac{\partial \phi_w}{\partial x} = \frac{dx}{dt} = \zeta_a \omega e^{kz} \cos(kx - \omega t)$$

→ water particle velocity

$$w = \frac{\partial \phi_w}{\partial z} = \frac{dz}{dt} = \zeta_a \omega e^{kz} \sin(kx - \omega t)$$

$$(x - x_1)^2 + (z - z_1)^2 = \zeta_a e^{kz_1}$$

→ trajectory (orbit) formula

radius

Derivatives give us:



$$x = \int_0^t u \cdot dt = -\zeta_a e^{kz} \sin(kx_1 - \omega t) + C_1$$

$$z = \int_0^t w \cdot dt = +\zeta_a e^{kz} \cos(kx_1 - \omega t) + C_2$$

→ displacements

$$\dot{u} = \frac{du}{dt} = +\zeta_a \omega^2 e^{kz} \sin(kx - \omega t)$$

→ accelerations

$$\dot{w} = \frac{dw}{dt} = -\zeta_a \omega^2 e^{kz} \cos(kx - \omega t)$$

$$\frac{kg}{m^2} \cdot \frac{kg}{s^2} \cdot m^3 \cdot \frac{k_s^2}{m^2 s^2}$$

$$P = -\rho g z + \rho g \zeta_a e^{kz} \cos(kx - \omega t) - \frac{1}{2} \rho \zeta_a^2 \omega^2 e^{2kz}$$

$$\rho = 1.025 \text{ t/m}^3 \text{ sea}$$

$$P \rightarrow kN/m^2$$

hydrostatic pressure

dynamic pressure due to wave form

pressure due to local wave energy

(radiation pressure)

$$F = \frac{1}{2} \rho g \zeta_a^2$$

! SHALLOW WATER WAVES

$$c = \sqrt{\frac{g}{k} \tanh(kh)}$$

→ simpl form

$$c = \sqrt{gh}$$

→ simpl form

Exercise → "Vizdu bentri fizika"

Consider a towing tank filled with fresh water with a length of 150 meters, a width of 5 meters and a wave maker in one end that generates long-crested regular waves. Assume in this tank a generated regular deep water wave with an amplitude $\zeta_a = 0.20$ meter and a wave period $T = 2.0$ seconds [2].

Determine:

1. The circular wave frequency, ω , the wave number, k , and the wave length, λ .
2. The maximum fluid particle velocity in the tank.
3. The path of a fluid particle in the surface of the wave.
4. The path of a fluid particle at 0.50 meter below the still water level.
5. The maximum pressure at 0.50 meter below the still water level.
6. The phase velocity, c , of these waves

Solutions:

1. $\omega = 3.14$ rad/s, $k = 1$, $\lambda = 6.25$ m.
2. $u_{max} = v_{max} = 0.63$ m/s.
3. Circular motion with a radius of 0.20 m.
4. Circular motion with a radius of 0.12 m.
5. $p_{max} = 0.62 \times 10^4$ N/m².
6. $c = 3.12$ m/s.

$$1) \quad \omega = \frac{2\pi}{T} = \frac{2 \cdot \pi}{2} = \boxed{3.14} \quad \lambda = \frac{2\pi g}{\omega^2} = \frac{2 \cdot \pi \cdot 9.81}{\pi^2} = \boxed{6.245} \quad k = \frac{2\pi}{\lambda} \approx \boxed{1}$$

$$2) \quad u = \zeta_a \omega e^{kz} \cos(kx - \omega t) \quad (e^{kz})_{z=0} = 1 (?) \rightarrow u_{max} = v_{max} = \zeta_a \cdot \omega = \boxed{0.628}$$

$$w = \zeta_a \omega e^{kz} \sin(kx - \omega t)$$

$$3, 4) \quad (x - x_0)^2 + (z - z_0)^2 = \zeta_a^2 e^{2kz} \quad \text{surface} \rightarrow e^{kz_1} = 1 \rightarrow \boxed{\text{radius} = 0.2 \text{ m}}$$

$$0.5 \text{ m below} \rightarrow e^{1 \cdot (-0.5)} = 0.607 \rightarrow \text{radius} = 0.2 \cdot 0.607 = \boxed{0.12 \text{ m}}$$

$$5) \quad p = -\rho g z + \rho g \zeta_a e^{kz} \cos(kx - \omega t) - \frac{1}{2} \rho \zeta_a^2 \omega^2 e^{2kz}$$

$$= -1.025 \cdot 9.81 \cdot (-0.5) + 1.025 \cdot 9.81 \cdot 0.2 \cdot e^{1 \cdot (-0.5)} \cdot 1 - \frac{1}{2} \cdot 1.025 \cdot (0.2)^2 \cdot (3.14)^2 \cdot e^{2 \cdot 1 \cdot (-0.5)}$$

$$= 6.274 - 0.0744 = \boxed{6.173 \text{ kN}}$$

$$6) \quad c = \sqrt{\frac{g'}{k}} = \sqrt{\frac{9.81}{1}} = \boxed{3.13 \text{ m/s}}$$

~ REGULAR WAVES ~

! WAVE HEIGHT STATISTICS

Table 1: Numerical example of wave height statistics [2]

Wave Height Intervals (m)	Wave Height Averages H_w (m)	Number of Waves, n	Frequency quotient, $f(x)=n/N$
0.25 - 0.75	0.5	15	15/150=0.100
0.75 - 1.25	1.0	30	30/150=0.200
1.25 - 1.75	1.5	55	55/150=0.367
1.75 - 2.25	2.0	21	21/150=0.140
2.25 - 2.75	2.5	14	14/150=0.093
2.75 - 3.25	3.0	9	9/150=0.060
3.25 - 3.75	3.5	5	5/150=0.033
3.75 - 4.25	4.0	1	1/150=0.007
Total		N=150	1.000

3.25'den büyük dalgaların olasılığı:

$$P\{H_w > 3.25\} = \frac{5+1}{150} = \boxed{0.04}$$

veya

$$P\{H_w > 3.25\} = 0.033 + 0.007 = \boxed{0.040}$$

! KARAKTERİSTİK DALGA YÜKSEKLİĞİ ($H_{1/3}$) → Average of the highest 1/3

Tabloda → en alt 1/3 → alt 50 tane

$$H_{1/3} = \frac{2.0 \times 21 + 2.5 \times 14 + 3.0 \times 9 + 3.5 \times 5 + 4.0 \times 1}{(150/3)} = \frac{125.5}{50} = \boxed{2.51 \text{ m}}$$

! WAVE HEIGHT AND PERIOD

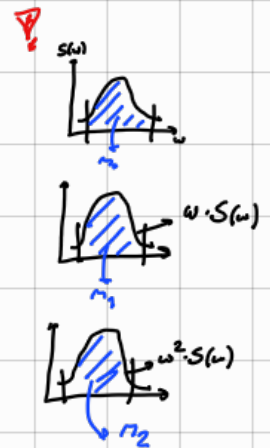
$$\sigma_z = \text{RMS} = \sqrt{m_0 z} \rightarrow \text{Root Mean Square of surface elevation}$$

$$z_{a1/3} = 2 \cdot \sqrt{m_0 z} \rightarrow \text{Significant (Karakteristik) wave Amplitude}$$

$$H_{1/3} = 4 \cdot \sqrt{m_0 z} \rightarrow \text{Significant (Karakteristik) wave Height}$$

$$T_1 = 2\pi \frac{m_0 z}{m_1 z} \rightarrow \text{Mean centroid wave period}$$

$$T_2 = 2\pi \sqrt{\frac{m_0 z}{m_2 z}} \rightarrow \text{Mean zero-crossing wave period}$$



m_0 : Area under curve

m_1 : First order mom. (static)

m_2 : Second order mom. (inertia)

Tabloda dalgaların Simpson ile hesaplanıyor.

! RAYLEIGH DISTRIBUTION

$$P\{z_a > a^2\} = e^{-\left(\frac{a^2}{2 \cdot m_0 z}\right)} \rightarrow \text{Gelişik } z_a \text{ 'nın } a^2 \text{ 'ya göre olasılığı}$$

$$N_{\text{hour}} = P\{z_a > a^2\} \cdot \frac{3600}{T_2} \rightarrow \text{Gelişik } a^2 \text{ 'ye göre kaç kez oluşur}$$

STANDARD WAVE SPECTRA → Standard wave spectra formulae

✓ **Britschneider:**
$$S_{\zeta}(\omega) = \frac{173 \cdot H_{1/3}^2}{T_1^4} \cdot \omega^{-5} \cdot \exp\left\{\frac{-692}{T_1^4} \cdot \omega^{-4}\right\}$$

→ Agik derizler egan

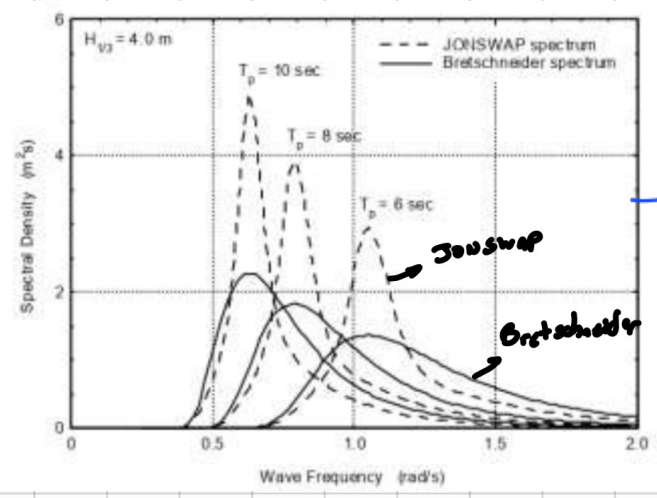
✓ **JONSWAP:**
$$S_{\zeta}(\omega) = \frac{320 \cdot H_{1/3}^2}{T_p^4} \cdot \omega^{-5} \cdot \exp\left\{\frac{-1950}{T_p^4} \cdot \omega^{-4}\right\} \cdot \gamma^A$$

with $\gamma = 3.3$ (peakedness factor)

$A = \exp\left\{-\left(\frac{\omega}{\omega_p} - 1\right)^2\right\}$
 $\omega_p = \frac{2\pi}{T_p}$ (circular frequency at spectral peak)
 $\sigma =$ a step function of ω : if $\omega < \omega_p$ then: $\sigma = 0.07$
 if $\omega > \omega_p$ then: $\sigma = 0.09$

Joint North Sea wave project

$T_p = 1.2 \cdot T_1$
 $T_p = 1.287 \cdot T_p$



Areas under the curves are the SSR.

LONG TERM WAVE DATA

Table 2: Sample Data [2]

Winter Data of Areas 5, 9, 15 and 16 of the North Atlantic (Global Wave Statistics)												
	T_2 (s)											
H_m (m)	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	Total
14.5	0	0	0	0	2	30	154	362	456	370	202	1556
13.5	0	0	0	0	3	33	145	293	322	219	101	1116
12.5	0	0	0	0	7	72	289	539	548	345	149	1949
11.5	0	0	0	0	17	160	555	996	931	543	217	2449
10.5	0	0	0	1	41	363	1200	1852	1579	843	310	6189
9.5	0	0	0	4	109	845	2455	3443	2648	1283	432	11249
8.5	0	0	0	12	295	1996	3157	4323	4333	1852	572	20570
7.5	0	0	0	41	818	4723	10337	11242	6735	2594	703	37413
6.5	0	0	1	138	2273	10967	20620	18718	9665	3222	767	66371
5.5	0	0	7	471	6187	24075	56940	27702	11969	3357	694	111432
4.5	0	0	31	1586	15757	47072	96347	25359	11710	2731	471	169244
3.5	0	0	145	5017	34720	74007	64509	28964	7804	1444	202	217115
2.5	0	4	681	13441	96847	77259	43013	13962	2725	351	41	210354
1.5	0	40	2699	22284	47539	34332	11354	2205	282	27	2	122457
0.5	5	310	3314	8131	5555	1595	216	15	1	0	0	10491
Total	5	524	6851	52126	170713	277122	565051	130161	81235	19271	4583	922993

data strategy

*T_2 series for 70%
No significant difference in g and in sea level*

BEAUFORT'S WIND FORCE SCALE

His scale measures winds by observing the effects on sailing ships and waves.

Exercise 1

The following histogram of wave heights has been derived from a time history of the surface elevation of an irregular wave system [2].

1. Give a definition of the conception "significant wave height, $H_{1/3}$ " and calculate this value.
2. What is the probability that the significant wave height, $H_{1/3}$, will be exceeded?

wave height $\bar{H}_w$ (m)	number n (-)
< 0.25	0
0.25 - 0.75	30
0.75 - 1.25	60
1.25 - 1.75	110
1.75 - 2.25	42
2.25 - 2.75	28
2.75 - 3.25	18
3.25 - 3.75	10
3.75 - 4.25	2
> 4.25	0

Solutions:

1. $H_{1/3} = 2.51$ m.

2. $P \approx 0.146$

$$0.00667 + 0.0333 + 0.06 + \frac{0.093}{2} = 0.146$$

H (m)	n	$f = n/N$
0	0	0
0.5	30	0.1
1	60	0.2
1.5	110	0.3667
2	42	0.14
2.5	28	0.0933
3	18	0.06
3.5	10	0.0333
4	2	0.00667
	300	

$$H_{1/3} = \frac{2 \cdot 42 + 2.5 \cdot 28 + 3 \cdot 18 + 3.5 \cdot 10 + 4 \cdot 2}{300} = 2.51$$

$$N = 300$$

$$\frac{300}{3} = 100 \rightarrow \text{son 100 adet baskılır.}$$

Exercise 2 ✓

A simplified wave energy spectrum is given by [2]:

ω (1/s)	0.5	0.7	0.9	1.1	1.3	1.5
$S_{\zeta}(\omega)$ m ² s	0.00	0.75	0.95	0.43	0.12	0.00

1. Calculate (by using the trapezoid rule) the significant wave height, $H_{1/3}$, and the mean wave periods T_1 and T_2 . (Ans. $H_{1/3} = 2.7$ m, $T_1 = 7$ s, $T_2 = 6.9$ s.)
2. Determine the probability, P , of exceeding a wave height of 4.0 meter in this wave spectrum by using the Rayleigh probability density function. (Ans. $P = 1.2\%$)
3. Determine also the number of times per hour that this wave height will be exceeded. (Ans. 6.3 Times per hour. Use T_2 for this not T_1)

1

logische
Sens.

$$\begin{array}{ccccccc}
 0 & 0.75 & 0.55 & 0.43 & 0.12 & 0 & \\
 0.5 & 1 & 1 & 1 & 1 & 0.5 & \\
 0 & 0.75 & 0.55 & 0.43 & 0.12 & 0 & \rightarrow 2.25 \\
 & & & & m_0 = 0.45 & & \\
 & & & & 2.25 \cdot 0.2 & & \\
 & & & & \downarrow & & \\
 & & & & \text{amplitude} & &
 \end{array}$$

$$M_{1/2} = 4 \cdot \sqrt{m_0} = 2.7m$$

$$T_1 = 2\pi \cdot \frac{m_0 \xi}{m_1 \xi}$$

$$T_2 = 2\pi \sqrt{\frac{m_0 \xi^3}{m_2 \xi}}$$

① ω	0.5	0.7	0.9	1.1	1.3	1.5
② $S_\xi(\omega)$	0	0.25	0.95	0.43	0.12	0
③ ωS_ξ	0	0.525	0.855	0.477	0.156	0 $\rightarrow$ ③ = ① * ②
④	0.5	1	1	1	1	0.5
⑤	0	0.525	0.855	0.477	0.156	0 $\rightarrow$ ⑤ = ④ * ③

$$\xi_5 = 2.009$$

$$m_1 = 2.009 \cdot 0.2 = 0.402$$

① ω	0.5	0.7	0.9	1.1	1.3	1.5
② $S_\xi(\omega)$	0	0.25	0.95	0.43	0.12	0
③ $\omega^2 S_\xi(\omega)$	0	0.3675	0.7635	0.5207	0.2027	0
④	0.5	1	1	1	1	0.5
⑤	0	0.3675	0.7635	0.5207	0.2027	0

$$\xi = 1.8601$$

$$m_2 = 1.8601 \cdot 0.2 = 0.372$$

$$T_1 = 7.5$$

$$T_2 = 6.95$$

2

Rayleigh $\rightarrow$

$$P\{Z_a > a\} = e^{\left(-\frac{a^2}{2 \cdot m_0}\right)}$$

amplitude !!

$$a = \frac{4}{2} \rightarrow \text{gültig beim Verschr. !}$$

$$P = e^{\left(-\frac{2^2}{2 \cdot 0.35}\right)} = 0.012 \neq 1.2$$

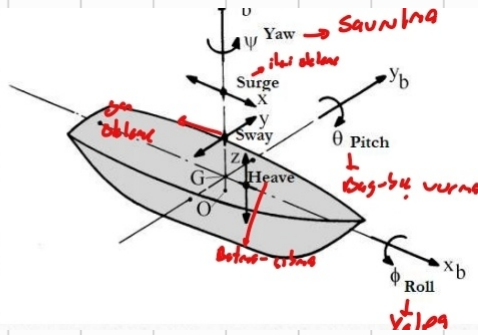
3

$$N = P(Z > a) \cdot \frac{3600}{T_2} = 0.012 \cdot \frac{3600}{6.5} = 6.3 \text{ def/s}$$

HEAVING MOTION IN REGULAR SEAS

BEHAVIOR IN REGULAR WAVES

6 serbestlik derecesi:
3 dönme
3 doğrusal



KARŞILAŞMA FREKANSI (WEL)

$$\omega_e = \omega - \frac{\omega^2}{g} \cdot V \cdot \cos \chi$$

Genel Dedektör:

Genel Dedektör:

$$(M+a)\ddot{z} + b\dot{z} + cz = F_0 \cos(\omega_e t)$$

ELEMENTS OF FORCED, DAMPED HEAVING IN REGULAR SEAS

1) Inertial Force: $(M+a)\ddot{z}$
→ ship mass
→ added mass

3) Restoring Force: cz
→ disp. of center of buoyancy
→ restoring const.

2) Damping Force: $b\dot{z}$
→ velocity
→ damping constant

4) Exciting Force: $F = F_0 \cos(\omega_e t)$
→ amplitude of encounter force

INERTIAL FORCE

$$(M+a_z) \frac{d^2 z}{dt^2}$$

Added mass of a section (a_z) → $a_z = C \cdot \frac{\rho \pi B_s^2}{8}$
→ slight
→ Lewis tan. coef. → Grafikte bulunur

Exercise 1 → Virmen 3. Sayfa

Given:
Length of the model : $L=5.85m$
Maximum beam : $B=0.90m$
Draught : $T=0.375m$
Model Speed : $V=1.5m/s$
Direction of Ship Travel : $\chi=180^\circ$
Ship Length-Wave Length : $\lambda=5.85m$
Displacement : $\Delta=1250 kg=1.25ton$
Water Density : $\rho=1025 kg/m^3$
Longitudinal Center of Gravity (LCG)=+0.15m forward from midship.
Longitudinal Center of Buoyancy (LCB)=+0.15m forward from midship.

Station No	B_s (m)	T_s (m)	S_s Sectional Area (m ²)
0	0	0.375	0
5	0.900	0.375	0.27
10	0.900	0.375	0.27
15	0.900	0.375	0.236
20	0	0.375	0

Find the added mass for heaving, in terms of the model mass.

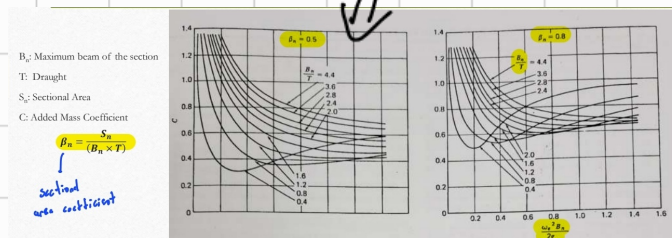


Fig. 5a: Added Mass Coefficients for two dimensional floating bodies in heaving motion [2]

Exercise 1

$$\omega = \frac{2\pi g}{\lambda} = \frac{2\pi \cdot 9.81}{5.85} = 3.246 \text{ rad/s}$$

$$\omega_e = \omega - \frac{\omega^2}{g} V \cos \chi = 3.246 - \frac{3.246^2}{9.81} \times 1.5 \times \cos(180^\circ) = 4.857 \text{ rad/s}$$

Station Number	B_s (m)	T_s (m)	S_s (m ²)	$a_z/(B_s \times T_s)$	B_s/T_s	$B_s \times T_s$	$S_s/(B_s \times T_s)$	C_a	a_z	SM	Product
0	0.000	0.375	0.000	0	0	0.000	0	0.000	1	0.000	
5	0.900	0.375	0.270	1.34	2.40	0.3375	0.80	0.65	211.925	4	847.700
10	0.900	0.375	0.270	1.34	2.40	0.3375	0.80	0.65	211.925	2	423.850
15	0.900	0.375	0.236	1.34	2.40	0.3375	0.70	0.66	195.625	4	782.492
20	0.000	0.375	0.000	0	0	0.000	0	0.000	1	0.000	
										Σ	2054.042

Therefore the added mass for heaving is 80% of the mass of the ship.

Simpson's rule: $\frac{L}{3} \sum$

! Damping Force → Soin kuvut

Always acts in the opposite direction of motion

$$F_b = -b \frac{dz}{dt} \rightarrow \text{velocity}$$

coefficient for damping

$$b_n = \frac{g \theta^2 \bar{A}^2}{\omega_0^3}$$

$$\bar{A} = \frac{z_a}{z_a}$$

Amplitude of radiated waves
Amplitude of heaving motion
graphites oblique

B_n : Maximum beam of the section
T: Draught
 S_n : Sectional Area
 $\bar{A}$: Amplitude Ratio
$$\beta_n = \frac{S_n}{(B_n \times T)}$$

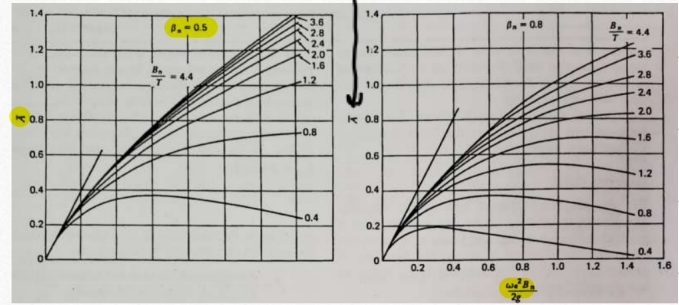


Fig. 6a: Amplitude Ratios for two dimensional floating bodies in heaving motion [2]

! RESTORING FORCE

$$Cz = gg A_{up} z \rightarrow C = gg C_{up} L B$$

($A_{up} = C_{up} \cdot L \cdot B$) restoring force coefficient

! EXCITING FORCE

$$F = F_0 \cdot \cos(\omega_0 t)$$

amplitude of total excitation force → non dimensional form → $f_0 = \frac{F_0}{gg z_a L B}$

g-value

! FREE, UNDAMPED HEAVING MOTION ($b, F_0 = 0$)

$$\left. \begin{matrix} b=0 \\ F_0=0 \end{matrix} \right\} \rightarrow (M+g)\ddot{z} + Cz = 0 \rightarrow \text{solution: } z = A \cdot \sin(\omega_z t) + B \cdot \cos(\omega_z t)$$

natural freq. of heaving (undamped)

$$\omega_z = \frac{2\pi}{T} = \sqrt{\frac{C}{(M+g)}}$$

Exercise 2 1

Given:
Length of the Ship: 1512m
Maximum beam: 30.75m
Draught: 7.1m
Block Coefficient C_{bp} : Water Plane Area Coefficient C_{wp} : 0.75 of ship mass
Added mass: 10% of ship mass
Water Density: 1025 kg/m³
Assuming that there is no damping.

a. Calculate the heaving period in still water.
b. Derive the differential equation for heaving motion in still water if the initial displacement from equilibrium position and the velocity of heaving motion at the instant of time $t=0$ are 0 and 1.5 m/s.
c. Calculate the maximum force exerted on the deck of the ship by a wave that weighs 1000 t.

Exercise 2 3

From the condition of equilibrium, the undamped heaving motion equation can be written as $(M+g)z + cz = 0$
The solution for this differential is $z = A \sin(\omega_z t) + B \cos(\omega_z t)$
After applying the initial condition $z(0) = 0$ and $\dot{z}(0) = 1.5$ we get $z(t) = 1.65 \sin(0.92 t)$
After applying the initial condition $z(0) = 1.65$ and $\dot{z}(0) = 0$ we get $z(t) = 1.65 \cos(0.92 t)$
The total force exerted on the deck of the ship by a wave is $F_{total} = F_{static} + F_{dynamic}$
 $F_{static} = (M+g)z = 1000 \times 9.81 = 9810 \text{ kN}$
 $F_{dynamic} = C \cdot z = 1000 \times 9.81 \times 1.65 = 16215 \text{ kN}$
The total force exerted on the deck of the ship by a wave is $F_{total} = 9810 + 16215 = 26025 \text{ kN}$

$$T_z = \frac{2\pi}{\omega_z}$$

heaving period in still water

Exercise 2 2

$\omega_z = \sqrt{\frac{C}{(M+g)}}$
 $T_z = \frac{2\pi}{\omega_z} = 2\pi \sqrt{\frac{(M+g)}{C}}$
If we put the following equalities, we obtain:
 $C = \rho g C_{wp} L B$ (known from the section restoring force)
 $M = \rho g L B T$ (known condition of the vessel)
where $C_{wp} = C_{bp}$

Exercise 2 4

The static force of the ship is equal to $m = 4.9 \times 10^6 \text{ kg}$
The dynamic force of the ship with respect to t is as follows: $z = 1.518 \sin(0.92 t)$
The maximum heaving acceleration is: $\ddot{z}_{max} = 1.518 \text{ m/s}^2$
The maximum force due to heaving applied from which is $F_{heaving} = m \times \ddot{z}_{max} = 0.619 \text{ kN} = 619 \text{ N}$
The total force exerted on the deck of the ship by a wave is $F_{total} = F_{static} + F_{dynamic}$
 $F_{static} = (M+g)z = 1000 \times 9.81 = 9810 \text{ kN}$
 $F_{dynamic} = C \cdot z = 1000 \times 9.81 \times 1.65 = 16215 \text{ kN}$
The total force exerted on the deck of the ship by a wave is $F_{total} = 9810 + 16215 = 26025 \text{ kN}$

FREE HEAVING MOTION ($F_0=0$)

$F_0=0 \rightarrow (M+a)\ddot{z} + b\dot{z} + cz = 0 \rightarrow$ Solution: $z = e^{-\gamma t} \cdot (C_1 \cos(\omega_d t) + C_2 \sin(\omega_d t))$

Damped Period: $T_d = \frac{2\pi}{\omega_d}$

decreasing constant $\gamma = \frac{b}{2(M+a)}$

circles freq. $\omega_d = \sqrt{\omega_n^2 - \gamma^2}$

Natural freq. of undamped oscillation $\omega_n = \sqrt{\frac{c}{M+a}}$

FORCED HEAVING MOTION

$(M+a)\ddot{z} + b\dot{z} + cz = F_0 \cdot \cos(\omega_e t)$

Solution: $z = e^{-\gamma t} (C_1 \cos(\omega_d t) + C_2 \sin(\omega_d t)) + z_a \cos(\omega_e t - \epsilon_2)$

OR steady state solution amplitude of forced motion for given

$z_a = z_{st} \times \mu_z$

z_{st} $\rightarrow$ static heaving amplitude

μ_z $\rightarrow$ magnification factor

$\mu_z = \frac{1}{\sqrt{(1-\lambda^2)^2 + 4\kappa^2\lambda^2}}$

$\lambda = \frac{\omega_e}{\omega_n}$

$\kappa = \frac{\gamma}{\omega_n}$

μ_z $\rightarrow$ dynamic factor

κ $\rightarrow$ non-dimensional damping factor

$\epsilon_2 = \tan^{-1} \left(\frac{2\kappa\lambda}{1-\lambda^2} \right)$

$\lambda = \sqrt{1-2\kappa^2} \rightarrow \mu_z$ gets max value

Exercise 3

Given:

- Length of the Ship: $L=157m$
- Maximum beam: $B=21.4m$
- Displacement Force: $\Delta=24587kN$
- Water Plane Area Coefficient: $C_{wp}=0.80$
- Water Density: $\rho=1.025 \text{ ton/m}^3=1025 \text{ kg/m}^3$
- Wave Amplitude: $\zeta_w=3.2m$
- The encountering Frequency: $\omega_e=1.29 \text{ rad/s}$
- Added mass: $=80\%$ of ship mass

The coefficient for damping is given non-dimensional form as $b/\sqrt{g L \Delta} = 1.7$

The amplitude for excitation force for heaving motion is given non dimensionally as $f_0 = \frac{F_0}{\rho g C_{wp} L B} = 0.17$

Find the heaving amplitude of the ship.

Exercise 3

Solution:

Mass of the Ship is equal to $M = \Delta/g = 24587/9.81 = 2506 \text{ ton}$

Added Mass: $M_a = 0.8 \times M = 2005 \text{ ton}$

Total Mass: $M_t = M + M_a = 4511 \text{ ton}$

Inertia Force: $F_i = 22860 \times 9.81 = 224256.6 \text{ kN}$

The damping coefficient is given as $b/\sqrt{g L \Delta} = 1.7 \rightarrow b = \frac{1.7 \times \sqrt{9.81 \times 157 \times 24587}}{1} = 5777.33 \text{ ton/s}$

The restoring force coefficient is equal to $c = \rho g C_{wp} L B = 1.025 \times 9.81 \times 157 \times 21.4 = 23584 \text{ ton/s}^2$

The non-dimensional amplitude for excitation force is given as $f_0 = \frac{F_0}{\rho g C_{wp} L B} = 0.17 \rightarrow F_0 = f_0 \times \rho g C_{wp} L B = 0.17 \times 1.025 \times 9.81 \times 157 \times 21.4 = 16037.1 \text{ kN}$

Exercise 3

Solution:

The natural frequency of heaving $\omega_n = \sqrt{\frac{c}{M_t}} = \sqrt{\frac{23584}{4511}} = 2.28 \text{ rad/s}$

The tuning factor is equal to $\lambda = \frac{\omega_e}{\omega_n} = \frac{1.29}{2.28} = 0.56$

The damping factor is equal to $\kappa = \frac{b}{2\sqrt{c M_t}} = \frac{5777.33}{2 \times \sqrt{23584 \times 4511}} = 0.126$

The magnification factor is equal to $\mu_z = \frac{1}{\sqrt{(1-\lambda^2)^2 + 4\kappa^2\lambda^2}} = \frac{1}{\sqrt{(1-0.31)^2 + 4 \times 0.0158 \times 0.31}} = 1.36$

The static heaving amplitude is equal to $z_{st} = \frac{F_0}{c} = \frac{16037.1}{23584} = 0.68 \text{ m}$

The heaving amplitude is $z_a = z_{st} \times \mu_z = 0.68 \times 1.36 = 0.92 \text{ m}$

~ ACCELERATED ROTATIONAL MOTION ~

⚠ JIRASTON YABIÇAPI

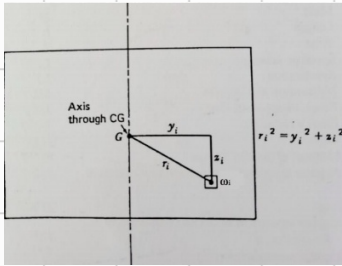
$$I = m \times b^2 \rightarrow \text{jiraston serisi}$$

$$= \frac{\Delta}{g} \times b^2$$

etimsellik non.

$$k^2 = \frac{\sum (w \cdot r^2)}{\Delta}$$

~ Rolling Jiraston Yarıçapı:

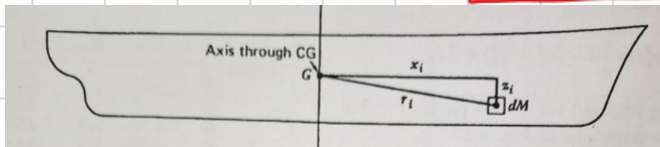


$$I_{xx} = \frac{1}{g} \cdot \sum [w \cdot (y_i^2 + z_i^2)]$$

g: grav. non. weight TCG VCG

$$k_{xx} = \sqrt{\frac{\sum [w \cdot (y_i^2 + z_i^2)]}{\Delta}}$$

~ Pitching Jiraston Yarıçapı:

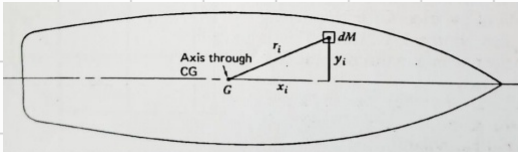


$$I_{yy} = \frac{1}{g} \cdot \sum [w \cdot (x_i^2 + z_i^2)]$$

LGG

$$k_{yy} = \sqrt{\frac{\sum [w \cdot (x_i^2 + z_i^2)]}{\Delta}}$$

~ Yawing Jiraston Yarıçapı:



$$I_{zz} = \frac{1}{g} \cdot \sum [w \cdot (x_i^2 + y_i^2)]$$

$$k_{zz} = \sqrt{\frac{\sum [w \cdot (x_i^2 + y_i^2)]}{\Delta}}$$

Exercise 1 → Vize soruları: 8 Ocak

A homogeneously loaded barge ($\Delta=5400$ kN) is considered to have 12 uniform divisions, each weighing 450 kN. Find the Radius of gyration for Rolling, pitching and yawing if the weights are considered to be centered at CG of each division, that is, assuming that the mass moment of inertia of each division about its own CG can be neglected (See Fig. 6) [1].

Given:
 Length of the barge : $L=30$ m
 Beam of the barge : $B=6$ m
 Depth : $D=4$ m
 Displacement : $\Delta=5400$ kN

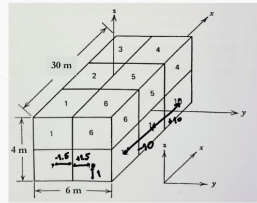


Fig. 6: Barge of 12 uniform divisions[1]

Exercise 1

Block	w_i	x_i	y_i	z_i	$w_i(x_i^2 + y_i^2)$	$w_i(y_i^2 + z_i^2)$	$w_i(x_i^2 + z_i^2)$
No:	[kN]	[m]	[m]	[m]	[ton.m ²]	[ton.m ²]	[ton.m ²]
1	450	-10	-1,5	1	45450	46012,5	46012,5
2	450	0	-1,5	1	1462,5	450	1012,5
3	450	10	-1,5	1	45450	46012,5	46012,5
4	450	10	1,5	1	45450	46012,5	46012,5
5	450	0	1,5	1	1462,5	450	1012,5
6	450	-10	1,5	1	45450	46012,5	46012,5
7	450	-10	-1,5	-1	45450	46012,5	46012,5
8	450	0	-1,5	-1	1462,5	450	1012,5
9	450	10	-1,5	-1	45450	46012,5	46012,5
10	450	10	1,5	-1	45450	46012,5	46012,5
11	450	0	1,5	-1	1462,5	450	1012,5
12	450	-10	1,5	-1	45450	46012,5	46012,5
Sum:					17550	365400	372150

$$k_{xx} = \sqrt{\frac{\sum [w_i \cdot (y_i^2 + z_i^2)]}{\Delta}} = \sqrt{\frac{17550}{5400}} = 1,803 \text{ m} \rightarrow \text{Rolling}$$

$$k_{yy} = \sqrt{\frac{\sum [w_i \cdot (x_i^2 + z_i^2)]}{\Delta}} = \sqrt{\frac{365400}{5400}} = 8,226 \text{ m} \rightarrow \text{Pitching}$$

$$k_{zz} = \sqrt{\frac{\sum [w_i \cdot (x_i^2 + y_i^2)]}{\Delta}} = \sqrt{\frac{372150}{5400}} = 8,302 \text{ m} \rightarrow \text{Yawing}$$

~ PITCHING MOTION IN REGULAR SEAS

added mass mom. of inertia

angular acceleration

angular velocity

angular displacement

$$(I_{yy} + \delta I_{yy}) \ddot{\theta} + b \dot{\theta} + c \theta = M_0 \cos(\omega_0 \cdot t)$$

general equation

$I_{yy} + \delta I_{yy}$: eq. inertia mom.
 b : canon. mom.
 c : def. lbs.
 $M_0 \cos(\omega_0 \cdot t)$: restoring mom.

DETERMINATION OF VIRTUAL MASS MOM. OF INERTIA ($I_{yy} + \delta I_{yy}$)

$$I_{yy} + \delta I_{yy} = (M + a) \cdot k_{yy}^2 = M' \cdot k_{yy}^2$$

virtual mass

Radius of gyration for pitching motion (k_{yy}) is between 0.24L - 0.26L generally.

Exercise 1

Given:
 Length of the model : L=5.85m
 Maximum beam : B=0.90m
 Draught : T=0.375m
 Model Speed : V=1.5m/s
 Direction of Ship Travel : $\psi=180^\circ$
 Ship Length= Wave Length: $\lambda=5.85m$
 Displacement : $\Delta=1250 \text{ kg}=1.25 \text{ ton}$
 Water Density : $\rho=1025 \text{ kg/m}^3$
 Longitudinal Center of Gravity (LCG)=+0.15m forward from midship.
 Longitudinal Center of Buoyancy (LCB)=+0.15m forward from midship.

Station No	a_c (kg)	x (m)
0	0	0
5	211.925	1.4625
10	211.925	2.925
15	195.623	4.3875
20	0	5.85

Find the added mass moment of inertia of a ship model for which the added mass was determined in Heaving Section.

DETERMINATION OF DAMPING COEFFICIENT

$$b_{pitching} = \int_{-L/2}^{L/2} b_{rhearing} \cdot x^2 dx$$

RESTORING MOM. COEFFICIENT

$$\left. \begin{aligned} c \theta &= g g \theta \Delta \\ c \theta &= g g \theta \Delta \overline{BM}_L \end{aligned} \right\} \rightarrow \left. \begin{aligned} c &= g g \Delta \cdot \overline{BM}_L \\ &= \Delta \cdot \overline{GM}_L \end{aligned} \right\}$$

Exercise 1

Station No	a_c (kg)	x (m)	x^2 (m)	$a_c x^2$ (m)	SM	Product
0	0.000	0.0000	0.0000	0	1	0.000
5	211.925	1.4625	2.1389	309.9403	4	1239.761
10	211.925	2.9250	8.5556	619.8806	2	1239.761
15	195.623	4.3875	19.2502	858.2959	4	3433.184
20	0.000	5.8500	34.2225	0	1	0.000
						5912.706

492.7 kg m
 0.493 ton m

FREE PITCHING MOTION ($M_0=0$)

$$I_{yy}' \ddot{\theta} + b \dot{\theta} + c \theta = 0$$

or

$$\ddot{\theta} + 2r \dot{\theta} + \omega_\theta^2 \theta = 0$$

$$r = \frac{b}{2 \cdot (I_{yy} + \delta I_{yy})}$$

$$\omega_\theta = \frac{2\pi}{T_\theta} = \sqrt{\frac{\Delta \overline{GM}_L}{I_{yy} + \delta I_{yy}}}$$

natural freq.

Solution: $\theta = e^{-rt} (C_1 \cos(\omega_\theta t) + C_2 \sin(\omega_\theta t))$

$$\omega_d = \sqrt{\omega_\theta^2 - r^2}$$

$$T_d = \frac{2\pi}{\omega_d} = T_\theta \cdot \frac{1}{1 - \sqrt{1 - (r/\omega_\theta)^2}}$$

damped period

Exercise 2

Given:
 Length of the Ship : L=152m
 Radius of Gyration for Pitching: $k_{yy}=0.25 \times L$
 Longitudinal Metacenter Height: $\overline{GM}_L=152m$
 If the added mass moment of inertia is about 90% of the mass moment of inertia of the ship, find the natural frequency and pitching period.

Solution: natural frequency

$$\omega_\theta = \sqrt{\frac{\Delta \overline{GM}_L}{(I_{yy} + \delta I_{yy})}} = \sqrt{\frac{\Delta \times \overline{GM}_L}{\left(\frac{\Delta}{g} \times k_{yy}^2 + 0.9 \times \frac{\Delta}{g} \times k_{yy}^2\right)}} = \sqrt{\frac{g \times \overline{GM}_L}{1.9 \times k_{yy}^2}} = \sqrt{\frac{9.81 \times 152}{1.9 \times 38^2}} = 0.5435 \frac{\text{rad}}{\text{s}}$$

$$T_\theta = \frac{2\pi}{\omega_\theta} = \frac{2\pi}{0.5435} = 11.56 \text{ s}$$

pitching period

✚ Exciting Moments

$$M = M_0 \cdot \cos(\omega_e \cdot t)$$

amplitude of excitation non. → Non-dimensional form

$$f_0 = \frac{M_0}{\frac{1}{2} \rho g \zeta_a B L^2}$$

✚ Pitching in Waves

✚ Equation of motion of pitching in waves: $(I_{yy} + \delta I_{yy}) \ddot{\theta} + b \dot{\theta} + c \theta = M_0 \cdot \sin(\omega_e t)$

✚ Solution: $\theta = B \cdot e^{-\gamma t} \cdot \sin(\omega_e t + \gamma) + \theta_0 \cdot \sin(\omega_e t - \varepsilon_2)$ → for $\omega_e \neq \omega_0$

$\underbrace{\quad}_{\text{damped oscillation}} \quad \underbrace{\quad}_{\text{oscillation with the same circular frequency of excitation force for pitching}}$
 ans p. of forced motion

✚ Steady condition:

$$\theta_0 = \theta_{st} \times \mu_z$$

static pitching amplitude

magnification factor

$$\mu_z = \frac{1}{\sqrt{(1 - \Lambda^2)^2 + 4 \kappa^2 \Lambda^2}}$$

Tuning factor

Non-dimensional damping factor

$$\Lambda = \frac{\omega_e}{\omega_0}$$

Natural freq. of pitching

$$\kappa = \frac{\gamma}{\omega_0} \rightarrow \text{damping const.}$$

$$\varepsilon_2 = \tan^{-1} \left(\frac{2 \kappa \Lambda}{1 - \Lambda^2} \right)$$

$$\Lambda = \sqrt{1 - 2 \kappa^2} \rightarrow \mu_z \text{ gets max value}$$

Exercise 3

1

Length of the Ship : $L = 137 \text{ m}$
 Longitudinal Metacenter Height: $GM_L = 137 \text{ m}$
 Maximum beam : $B = 21.4 \text{ m}$
 Displacement Force : $\Delta = 124587 \text{ kN}$
 The Radius of Gyration of Pitching: $k_{yy} = 34 \text{ m}$
 Water Density : $\rho = 1.025 \text{ ton/m}^3 = 1025 \text{ kg/m}^3$
 Wave Amplitude : $\zeta_w = 3.2 \text{ m}$
 The encountering Frequency : $\omega_e = 1.005 \text{ rad/s}$
 Added Mass Moment of Inertia: 80% of mass moment of inertia of the ship
 The coefficient for damping is given non-dimensional form as $b \sqrt{g L / \Delta L^2} = 0.16$
 The amplitude for excitation force for heaving motion is given nondimensionally as $f_0 = \frac{M_0}{\rho g \zeta_a L^2 B} = 0.15$

Find the amplitude of pitching motion of the ship.

Exercise 3

2

Solution:
 Mass of the Ship is equal to $M = \Delta / g = 124587 / 9.81 = 12700 \text{ ton}$.
 Total Mass = Added Mass + Ship Mass $(M + a) = 0.8 \times M + M = 1.8 \times M = 22860 \text{ ton}$
 Virtual Mass Moment of Inertia $(M + a) k_{yy}^2 = 22860 \times 34^2 = 26426160 \text{ ton m}^2$
 The damping coefficient is given as $b \sqrt{g L / \Delta L^2} = 0.16 \rightarrow b = \frac{0.16 \Delta L^2}{\sqrt{g L}} = \frac{0.16 \times 124587 \times 137^2}{\sqrt{9.81 \times 137}} = 10205612 \text{ ton m}^2 \text{ s}^{-1}$
 The restoring force coefficient is equal to $c = \Delta \times GM_L = 124587 \times 137 = 17068419 \text{ ton m}^2 \text{ s}^{-2}$
 The non-dimensional amplitude for excitation force is given as $f_0 = \frac{M_0}{\rho g \zeta_a L^2 B} = 0.15 \rightarrow M_0 = f_0 \rho g \zeta_a L^2 B$
 $= 0.15 \times 1.025 \times 9.81 \times 3.2 \times 137^2 \times 21.4 = 1938604 \text{ kN}$

Exercise 3

3

Solution:

The natural frequency of pitching: $\omega_0 = \sqrt{\frac{c}{(M + a) k_{yy}^2}} = \sqrt{\frac{17068419}{26426160}} = 0.804 \text{ rad/s}$

The tuning factor is equal to $\Lambda = \frac{\omega_e}{\omega_0} = \frac{1.005}{0.804} = 1.25$

The damping constant is equal to $\kappa = \frac{b}{2(M + a) k_{yy}^2} = \frac{10205612}{2 \times 26426160} = \frac{10205612}{52852320} = 0.193$

The damping factor is equal to $\kappa = \frac{b}{2(M + a) k_{yy}^2} = \frac{10205612}{52852320} = 0.193$

The magnification factor is equal to $\mu_z = \frac{1}{\sqrt{(1 - \Lambda^2)^2 + 4 \kappa^2 \Lambda^2}} = \frac{1}{\sqrt{(1 - 1.25^2)^2 + 4 \times 0.24^2 \times 1.25^2}} = 1.2159$

The static heaving amplitude is equal to $\theta_{st} = \frac{M_0}{c} = \frac{1938604}{17068419} = 0.1136$

The heaving amplitude is $\theta_0 = \theta_{st} \times \mu_z = 0.1136 \times 1.2159 = 0.1381 \text{ rad}$

virtual mass mom. of inertia

ROLLING MOTION IN REGULAR SEAWAY

$$\underbrace{I \cdot \ddot{\phi}}_{\text{inertial mom.}} + \underbrace{b \cdot \dot{\phi}}_{\text{damping mom.}} + \underbrace{c \cdot \phi}_{\text{restoring mom.}} = \underbrace{M_0 \cdot \cos(\omega_0 t)}_{\text{exciting mom.}}$$

VIRTUAL MASS MOMENT OF INERTIA

$$(I_{xx} + \delta I_{xx}) = (M + a) \cdot k_{xx}^2 \rightarrow \text{inversion output}$$

$$I' = M' \cdot k_{xx}^2 \rightarrow \text{virtual mass}$$

WAVE MAKING DAMPING COEFFICIENT

Damping coefficient per unit length:

$$b_n = \frac{g^2 \bar{A}_\phi^2}{\omega_0^3} \left(\frac{B_n}{z} \right)^2$$

width of section

$$\bar{A}_\phi = \frac{F_a}{\phi_a(B_n/2)}$$

$$b = \int_{-L/2}^{L/2} b_n dx$$

Damping coefficient from experiments in calm water:
(from excitation equation)

$$b = \frac{K_1 \cdot T_0 \cdot \Delta \cdot \overline{GM_T}}{\pi^2}$$

or

$$K_1 = \frac{\pi^2 \cdot b}{T_0 \Delta \overline{GM_T}}$$

RESTORING MOMENT COEFFICIENT

$$c \phi = \Delta \overline{GZ} \rightarrow c = \rho g \nabla \cdot \Delta \overline{GM_T}$$

ROLLING IN CALM WATER

$(C = \Delta \overline{GM}_T)$

Equation: $(I_{xx} + \delta I_{xx})\ddot{\phi} + b\dot{\phi} + \Delta \overline{GM}_T \phi = 0 \leftrightarrow \ddot{\phi} + 2r\dot{\phi} + \omega_\phi^2 \phi = 0$

$r = \frac{b}{2(I_{xx} + \delta I_{xx})}$

$\omega_\phi = \frac{2\pi}{T_\phi} = \sqrt{\frac{\Delta \overline{GM}_T}{(I_{xx} + \delta I_{xx})}}$

Solution: $\phi = e^{-rt} (C_1 \cdot \cos(\omega_d t) + C_2 \cdot \sin(\omega_d t))$

$\omega_d = \sqrt{\omega_\phi^2 - r^2}$

$T_d = \frac{2\pi}{\omega_d} = T_\phi \cdot \frac{1}{\sqrt{1 - (r/\omega_\phi)^2}}$

Example 1:

The ship has a length of 160m and has a displacement force of 156960 kN. The radius of gyration of $k_{xx}=7.5m$, a transverse metacentric height GM of 0.8m and If the coefficient for roll damping moment expression, b has value of 108000 KNms while the ship is rolling in still water. The added mass moment of inertia is 20% of the mass moment of inertia of the ship in this case of rolling.

Find the natural and damped period of roll.

$(I_{xx} + \delta I_{xx}) = \frac{\Delta}{g} k_{xx}^2 + \delta I_{xx} = 1.2 \frac{156960}{9.81} 7.5^2 = 1080000 \text{ ton m}^2$

$\omega_\phi = \frac{2\pi}{T_\phi} = \sqrt{\frac{\Delta \overline{GM}_T}{(I_{xx} + \delta I_{xx})}} = \sqrt{\frac{156960 \times 0.8}{1080000}} = 0.341$

$T_\phi = \frac{2\pi}{\omega_\phi} = \frac{2\pi}{0.341} = 18.426s$

$r = \frac{b}{2(I_{xx} + \delta I_{xx})} = \frac{108000}{2 \times 1080000} = 0.05$

$T_d = \frac{2\pi}{\omega_d} = \frac{2\pi}{\sqrt{\omega_\phi^2 - r^2}} = T_\phi \cdot \frac{1}{\sqrt{1 - (r/\omega_\phi)^2}} = 18.426 \cdot \frac{1}{\sqrt{1 - (0.05/0.341)^2}} = 18.627s$

Example 2:

A ship has a radius of gyration of $k_{xx}=8m$, a transverse metacentric height GM of 2m and a displacement force of 147150 kN. If the coefficient for roll damping moment expression, b has value of 87480 KNms while the ship is rolling in still water, determine the amplitude of roll after three complete oscillations if the ship was initially inclined at 6.5° (ie when $t=0$, $\phi = 6.5^\circ$ and $d\phi/dt=0$). The added mass moment of inertia is 20% of the mass moment of inertia of the ship in this case of rolling.

Example 2: Solution

$\phi(t) = e^{-rt} (C_1 \cos \omega_d t + C_2 \sin \omega_d t) = e^{-0.0378t} (C_1 \cos(0.5028t) + C_2 \sin(0.5028t))$

When the initial condition $\phi(0)=6.5^\circ$ is put into the above equation, C_1 is found to be equal to 6.5

When the first derivative of the above equation is taken, the below equation is obtained;

$\dot{\phi}(t) = -r e^{-rt} (C_1 \cos \omega_d t + C_2 \sin \omega_d t) + e^{-rt} (-C_1 \omega_d \sin(\omega_d t) + C_2 \omega_d \cos(\omega_d t))$

When the initial condition $\dot{\phi}(0)=0$ is put into the above equation, C_2 is found to be equal to $rC_1/\omega_d = 0.0378 \times 6.5 / 0.5028 = 0.487$

$\phi(t) = e^{-0.0378t} (6.5 \cos(0.5028t) + 0.487 \sin(0.5028t))$

Example 2: Solution

$M = 147150 / 9.81 = 15071.36 \text{ ton}$

$M' = 1.2 \times 15071.36 = 18085.63 \text{ ton}$

$I' = M' (k_{xx})^2 = 18085.63 \times 8^2 = 1157480 \text{ ton m}^2$

$\omega_\phi = \sqrt{\frac{\Delta \overline{GM}_T}{I}} = \sqrt{\frac{147150 \times 2}{1157480}} = 0.5042$

$r = \frac{b}{2(I_{xx} + \delta I_{xx})} = \frac{87480}{2 \times 1157480} = 0.0378$

$\omega_d = \sqrt{\omega_\phi^2 - r^2} = \sqrt{0.5042^2 - 0.0378^2} = 0.5028 \text{ rad/s}$

Example 2: Solution

$\phi(t) = e^{-0.0378t} (6.5 \cos(0.5028t) + 0.487 \sin(0.5028t))$

$T_d = 2\pi/\omega_d = \frac{2\pi}{0.5028} = 12.5s$

$t = 3T_d = 37.5s$

$\phi(37.5) = e^{-0.0378 \times 37.5} (6.5 \cos(0.5028 \times 37.5) + 0.487 \sin(0.5028 \times 37.5))$

$= 0.2423 \times (6.5 \times 1 + 0.487 \times 0.0054) = 1.576$

EXCITING MOMENT

$M = M_0 \cdot \cos(\omega_e t + \epsilon_1)$

Non-dimensionally:

$f_0 = \frac{M_0}{\frac{1}{2} \rho g \gamma_a L B^2 T}$

For beam seas ($\gamma = 90^\circ$) $\rightarrow M_0 = \rho g \gamma_a \overline{GM}_T$

Rolling mom. (M_ϕ) for any angle: $M_\phi = C \cdot \alpha_m \cdot \sin(\omega_e t)$

$\alpha_m = \alpha'_m \cdot \sin(\delta)$

ROLLING IN A REGULAR SEAWAY

$(C = \Delta \overline{GM})$
 $(M_{\phi} = C \phi_m \cdot \sin(\omega_{\phi} t))$

Eq. of motion: $(I_{xx} + \delta I_{xx}) \ddot{\phi} + b \dot{\phi} + \Delta \overline{GM} \phi = \Delta \overline{GM} \phi_m \sin(\omega_{\phi} t)$

Solution: $\phi = e^{-\gamma t} (C \cos(\omega_d t) + D \sin(\omega_d t)) + \phi_a \sin(\omega_e t - \varepsilon_2)$
free and damped *oscillation with same freq. of excitation*
torque for pitching

Amplitude of forced rolling motion (ϕ_a): $\phi_a = \phi_{st} \times M_{\phi}$ → *magnification factor*

$M_{\phi} = \frac{1}{\sqrt{(1-\lambda^2)^2 + 4\kappa^2\lambda^2}}$
 $\phi_{st} = \frac{M_0}{C}$ → *static rolling ang.* *amp. of exciting wave*
 $\lambda = \frac{\omega_e}{\omega_{\phi}}$ $\kappa = \frac{r}{\omega_{\phi}}$

$\varepsilon_2 = \tan^{-1} \left(\frac{2\kappa\lambda}{1-\lambda^2} \right)$

$\lambda = \sqrt{1 - 2\kappa^2} \rightarrow M_{\phi}$ gets max value

Given: $T_{\phi} = 15s$ → *roll period*
 $V = 25$ knots
 $\lambda = 270m$
 Determine the heading of the ship relative to the waves when the largest Rolling would be expected.
 Sonon den baharidilimisa en bəht gəlpə → *keçirəni fırtınanın digər fırtınası*
 cəst olmağın dönədə olar.
 $\omega_c = \omega_{\phi}$

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Example 3: Solution

$\Lambda = \frac{\omega_e}{\omega_{\phi}} \approx 1.0$ *wave freq.*
 That is when $\omega_e = \omega_{\phi}$ → *resonant freq.*
 where $\omega_e = \omega_w - \frac{\omega_{\phi}}{g} V \cos(\chi)$ and χ is the heading angle relative to the waves.
 Then we can write the following expression:
 $\omega_{\phi} = \omega_e = \omega_w - \frac{\omega_{\phi}}{g} V \cos(\chi)$
 Thus $\cos(\chi) = \frac{(\omega_w - \omega_{\phi})g}{\omega_{\phi}^2 V}$

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Example 3: Solution

$\omega_{\phi} = \frac{2\pi}{T_{\phi}} = \frac{2\pi}{15} = 0.419 \text{ rad/s}$ → *roll freq.* → $\omega_c = 0.419$
 $\omega_w = \sqrt{\frac{2\pi g}{\lambda}} = \sqrt{\frac{2\pi \times 9.81}{270}} = 0.478 \text{ rad/s}$
 $V = 25 \times 0.5144 = 12.86 \text{ m/s}$
 $\cos(\chi) = \frac{(\omega_w - \omega_{\phi})g}{\omega_{\phi}^2 V} = \frac{(0.478 - 0.419) \times 9.81}{0.478^2 \times 12.86} = 0.197$
 $\chi = \arccos(0.197) = 78.64^\circ$ → *heading angle*

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Example 4: Solution

Using the given values of the coefficients of the equation of motion, we obtain for the damping and Rolling frequencies:
 $\gamma = \frac{0.0724}{2} = 0.0362 \text{ s}^{-1}$ and $\omega_{\phi} = \sqrt{0.164} = 0.405 \text{ rad/s}$
 $\lambda = \frac{\omega_e}{\omega_{\phi}} = \frac{0.419}{0.405} = 1.034$ and $\kappa = \frac{0.0092}{0.405} = 0.0227$
 $\lambda^2 = 1.069$ and $4\kappa^2\lambda^2 = 0.0039$
 $\lambda^2 - 1 = 0.069$ and $1 - \lambda^2 = -0.069$
 $\lambda^2 - 1 = 0.069$ and $1 - \lambda^2 = -0.069$
 $\lambda^2 - 1 = 0.069$ and $1 - \lambda^2 = -0.069$

Example 4: Solution

$\phi_a = \phi_{st} \sin(\omega_e t) = 0.206 \times \sin(0.419 t) = 0.206 \sin(0.419 t)$
 $\phi = \phi_a \sin(\omega_e t) = 0.206 \sin(0.419 t)$
 Note: The value of ϕ_a is the same as the value of ϕ_{st} in the following equation [1].
 $\phi = e^{-\gamma t} (C \cos(\omega_d t) + D \sin(\omega_d t)) + \phi_a \sin(\omega_e t - \varepsilon_2)$

MOTION IN IRREGULAR SEAWAY

? Response of a ship in irregular seas follows the same statistical laws as waves

Ex:

The rolling amplitudes (double, i.e. Peak to peak) of a ship in an irregular seaway measured, and the results are presented in Table 1. Find the average and significant rolling motion [1].

Table 1: Rolling Amplitudes versus Number of Occurrence [1]

Double Amplitude of Rolling Angle [deg]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Number of Occurrence	1	4	7	10	13	8	12	10	8	7	5	2	4	3	1	0	2	2	0	1

Double Amplitude of Rolling Angle [deg]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Number of Occurrence	1	4	7	10	13	8	12	10	8	7	5	2	4	3	1	0	2	2	0	1
Product 1	1	8	21	40	65	48	84	80	72	70	55	24	52	42	15	0	34	36	0	20
Product 2																				
Sum of Products																				
Average Roll																				
Significant Roll																				

33 add along

PREDICTION IN AN IRREGULAR SEAWAY

Step 1: A suitable standard wave spectrum is selected.

Step 2: Wave spectrum as encountered by the ship is obtained

$$S(\omega_0) = \frac{S(\omega_w)}{\sqrt{1 - \left(\frac{4\omega_w V}{g}\right)^2 \cos^2 \theta}}, \quad \omega_0 = \omega_w - \frac{\omega_w^2 V}{g} \cdot \cos \theta$$

Step 3: Amplitude of motion (pitch, heave, roll) is obtained.

Roll $\Rightarrow \phi_a = \phi_{st} \times \mu_\phi$

$$\mu_\phi = \frac{1}{\sqrt{(1-\lambda^2)^2 + 4\lambda^2 \eta^2}}$$

Step 4: Response Amplitude Operator (RAO) is obtained.

For rolling motion, $RAO = \left(\frac{\phi_a}{\zeta_a}\right)^2 \left[\frac{deg}{m}\right]^2$

For pitching motion, $RAO = \left(\frac{\theta_a}{\zeta_a}\right)^2 \left[\frac{deg}{m}\right]^2$

For heaving motion, $RAO = \left(\frac{z_a}{\zeta_a}\right)^2 \left[\frac{m}{lm}\right]^2$

For relative bow motion, $RAO = \left(\frac{s_a}{\zeta_a}\right)^2 \left[\frac{m}{lm}\right]^2$

Step 5: Motion Amplitude Spectrum is obtained. Rollings $\Rightarrow S_\phi(\omega_0) = S_\zeta(\omega_0) \times RAO$

Step 6: Area under the motion Amplitude Spectrum is obtained (Stress)

Given

Length of the ship, L=137m.

The radius of gyration for rolling, k_{xx} =9.4m.

The transverse metacenteric height, GM_T =1.76m.

Displacement force, Δ =124587kN

The added mass moment inertia for rolling is 20% of the mass moment inertia of the ship.

If the ship is travelling with a speed of 20knots at angle of 150° to the line of wave crests in a seaway of significant wave height 5.6m, determine the significant rolling motion.

$$\omega_e = \omega_w - \frac{\omega_w^2 V}{g} \cos(\chi)$$

Step 1-2:

ω_w	ω_e	$S_\xi(\omega_w)$	$S_\xi(\omega_e)$
0.20	0.236	0.000	0.000
0.30	0.382	0.002	0.001
0.40	0.545	1.654	0.958
0.50	0.727	5.200	2.725
0.60	0.927	4.708	2.253
0.70	1.145	3.086	1.359
0.80	1.381	1.874	0.764
0.90	1.636	1.138	0.432
1.00	1.908	0.707	0.251
1.10	2.199	0.453	0.151
1.20	2.508	0.299	0.094
1.30	2.835	0.203	0.061
1.40	3.180	0.141	0.040
1.50	3.543	0.101	0.027
1.60	3.925	0.073	0.019

If we put the values in the expression of ω_e , we obtain;

$$\omega_e = \omega_w - \frac{\omega_w^2 (20 \times 0.5144)}{9.81} \cos(150^\circ) = \omega_w \times (1 + 0.9082 \omega_w)$$

The values of ω_e and $S_\xi(\omega_e)$ are given in Table 2 respectively.

$$S(\omega_e) = \frac{S(\omega_w)}{\sqrt{1 - \left(\frac{4 \omega_e V}{g}\right) \cos(\chi)}}$$

The roll amplitude of steady motion can be either determined by the following formulas or experiments.

$$\phi_a = \phi_{st} \times \mu_\theta$$

Step 3:

where ϕ_{st} , the static rolling amplitude is equal to the ratio of the amplitude of Exciting Moment(M_θ) to restoring constant (c). The magnification factor, μ_θ is determined by the following formula [1]:

$$\mu_\theta = \frac{1}{\sqrt{(1 - \Lambda^2)^2 + 4 \kappa^2 \Lambda^2}}$$

ω_w	ω_e	ϕ_a/ξ_a (deg/m)
0.20	0.236	0.144
0.30	0.382	1.391
0.40	0.545	0.554
0.50	0.727	0.341
0.60	0.927	0.239
0.70	1.145	0.197
0.80	1.381	0.171
0.90	1.636	0.171
1.00	1.908	0.148
1.10	2.199	0.148
1.20	2.508	0.128
1.30	2.835	0.098
1.40	3.180	0.115
1.50	3.543	0.066
1.60	3.925	0.075

Step 4: $\phi_a = \phi_{st} \times \mu_\theta$

Example 2

RAO $\times S_\xi(\omega_e)$

Step 5-6:

ω_e	$S_\xi(\omega_e)$	RAO	$S_\theta(\omega_e)$	SM	$S_\theta(\omega_e)$
0.25	0.000	0.0431	0.0000	1	0.0000
0.50	0.557	0.409	0.2280	4	0.9120
0.75	3.019	0.099	0.2990	2	0.5980
1.00	1.858	0.0506	0.0940	4	0.3760
1.25	1.022	0.0344	0.0352	2	0.0704
1.50	0.595	0.0269	0.0160	4	0.0640
1.75	0.325	0.0194	0.0063	2	0.0126
2.00	0.186	0.0151	0.0028	4	0.0112
2.25	0.121	0.0118	0.0014	2	0.0029
2.50	0.093	0.0108	0.0010	4	0.0040
2.75	0.056	0.0108	0.0006	1	0.0006

0.25 to 2.75 deg/s
values

Exp

Finalde girass ilk 4 adim verilecek!!

ω_e	ϕ_a/ξ_a (deg/m)	RAO (deg/m)
0.236	0.144	0.021
0.382	1.391	1.935
0.545	0.554	0.307
0.727	0.341	0.116
0.927	0.239	0.057
1.145	0.197	0.039
1.381	0.171	0.029
1.636	0.171	0.029
1.908	0.148	0.022
2.199	0.148	0.022
2.508	0.128	0.016
2.835	0.098	0.010
3.180	0.115	0.013
3.543	0.066	0.004
3.925	0.075	0.006

Step 4:

Roll: $\phi_a = \left(\frac{\phi_{st}}{3}\right)^2$

Average roll amplitude, $\phi_{avg} = 1.253\sqrt{m_0} = 0.52^\circ$

Mean of one-third highest amplitudes, $\phi_{1/3} = 2\sqrt{m_0} = 0.83^\circ$

Mean of one-tenth highest amplitudes, $\phi_{1/10} = 2.545\sqrt{m_0} = 1.05^\circ$

$$m_0 = \int_{-\infty}^{\infty} S_\theta(\omega_e) d\omega_e$$
$$= \frac{0.25}{3} \times 2.0516$$
$$= 0.0171$$

DYNAMIC EFFECTS

SUBJECTS OF INVESTIGATION

The study of dynamic effects involved chiefly the following investigations [1]:

- Frequencies of occurrence of deck wetness and slamming
- Magnitude of impact pressure caused by slamming
- Response of ship bottom plating to slam impact
- Hull response (stress and accelerations) due to slamming
- Freeboard and Deck Wetness
- Severity of Green Water on the deck
- Determination of added resistance in a seaway operation

VERTICAL MOTION

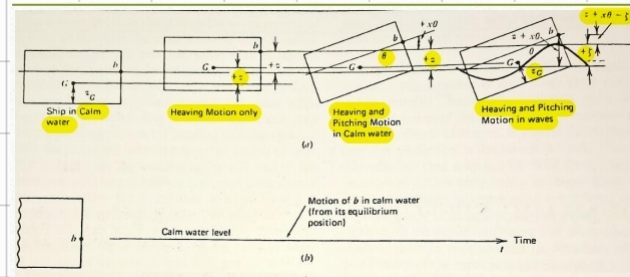
Bow motion, described by $z_b \rightarrow z_b = z + \zeta \cdot \sin \theta \rightarrow z_b \approx z + \zeta \theta$ for small angles

$$\begin{matrix} +z & +\theta \\ \updownarrow & \updownarrow \\ -z & -\theta \end{matrix}$$

displ. of heaving

pitching angle (rad)

horizontal distance of the point from CG



From heaving and pitching in regular seas $\rightarrow z = z_a \cdot \cos(\omega_0 t + \epsilon_z)$, $\theta = \theta_a \cdot \cos(\omega_0 t + \epsilon_\theta)$

$$z_b = z + \zeta \sin \theta \rightarrow z_b = z_{ba} \cdot \cos(\omega_0 t + \epsilon_b)$$

$$z_{ba} = \sqrt{z_a^2 + (\xi \theta_a)^2 + 2 z_a \xi \theta_a \cos(\epsilon_z - \epsilon_\theta)}$$

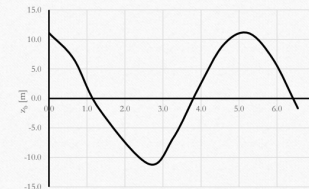
$$\tan \epsilon_b = \frac{z_a \sin(\epsilon_z) + \xi \theta_a \sin(\epsilon_\theta)}{z_a \cos(\epsilon_z) + \xi \theta_a \cos(\epsilon_\theta)} \rightarrow \epsilon_b \text{ bulunur}$$

Example 1:

Given:

Length of the ship, $L=137\text{m}$
 Draught of the ship, $T=7.62\text{m}$
 Freeboard of the ship, $f=6.1\text{m}$
 Ship Speed, $V_s=20\text{knots}=10.288\text{m/s}$
 Wave length, $\lambda=128\text{m}$
 Wave height, $h_w=6.1\text{m}$
 Heading angle, $\chi=180^\circ$
 From the experimental results;
 $z_s=1.524\text{m}$ $\theta_s=0.15\text{rad}$ $\epsilon_z=-40^\circ$ $\epsilon_\theta=15^\circ$ and $\xi=68.5\text{m}$ distance from the bow of the ship
 Determine the vertical motion of the bow.

$\lambda=128$	m	$\omega_0=0.694$	rad/s	$V=10.288$	m/s	$\chi=180$	°	$z_s=1.524$	m	$\theta_s=0.15$	rad	$\epsilon_z=-40.000$	°	$\epsilon_\theta=15.000$	°	$\xi=68.500$	m	$\omega_0=1.20$	rad/s
n	ω/ω_0	u_x	$z=\xi z_s \cos(\omega_0 t + \epsilon_z)$	$\theta=\xi \theta_s \cos(\omega_0 t + \epsilon_\theta)$	$z_b=z+\theta$														
0.00	0.000	0.000	1.167	9.925	11.092														
0.25	0.655	0.785	1.518	5.138	6.656														
0.50	1.310	1.571	0.980	-2.659	-1.680														
1.00	2.620	3.142	-1.167	-9.925	-11.092														
1.25	3.275	3.927	-1.518	-5.138	-6.656														
1.50	3.930	4.712	-0.980	2.659	1.680														
1.75	4.586	5.498	0.133	8.898	9.031														
2.00	5.241	6.283	1.167	9.925	11.092														
2.25	5.896	7.069	1.518	5.138	6.656														
2.50	6.551	7.854	0.980	-2.659	-1.680														



$$z_{ba} = \sqrt{z_a^2 + (\xi \theta_a)^2 + 2 z_a \xi \theta_a \cos(\epsilon_z - \epsilon_\theta)} = 11.219\text{m}$$

$$\tan \epsilon_b = \frac{z_a \sin(\epsilon_z) + \xi \theta_a \sin(\epsilon_\theta)}{z_a \cos(\epsilon_z) + \xi \theta_a \cos(\epsilon_\theta)} = 0.151 \quad \epsilon_b = 0.150 \text{ rad.}$$

are 1m (0.151)

VERTICAL VELOCITY AND ACCELERATION

$$z_{\dot{\zeta}} = z_{\dot{\zeta}a} \sin(\omega_0 t) \rightarrow \text{se deriztime}$$

$$\dot{z}_{\dot{\zeta}} = \omega_0 \cdot z_{\dot{\zeta}a} \cos(\omega_0 t) \rightarrow \text{vertical velocity}$$

$$\ddot{z}_{\dot{\zeta}} = \ddot{z}_{\dot{\zeta}a} \cdot \sin(\omega_0 t) \rightarrow \text{vertical acceleration}$$

amp. of vertical velocity

$$\dot{z}_{\dot{\zeta}}^2 = \dot{z}_a^2 + \xi \dot{\theta}_a^2 + 2 \xi \dot{z}_a \dot{\theta}_a \cos(\epsilon)$$

$$\ddot{z}_{\dot{\zeta}}^2 = \ddot{z}_a^2 + \xi \ddot{\theta}_a^2 + 2 \xi \ddot{z}_a \ddot{\theta}_a \cos(\epsilon)$$

amp. of vertical acceleration

! BAĞIL BAŞ HAREKET (RELATIVE BOW MOTION)

Position of the bow in relation with the waves $\rightarrow S_b = z_b - z_a$

z_b ve z_a aynı yerlere $\rightarrow S_b = z_{ba} \cos(\omega_e t + \varepsilon_b) - z_a \cdot \cos(k_e x - \omega_e t)$

$$S_b = S_{ba} \cdot \cos(\omega_e t + \varepsilon_s)$$

$$s_{ba} = \sqrt{z_{ba}^2 + (\zeta_a)^2 - 2 z_{ba} \zeta_a \cos(k_e x - \varepsilon_b)}$$

$$\tan \varepsilon_s = \frac{\zeta_a \sin(k_e x) - z_{ba} \sin(\varepsilon_b)}{\zeta_a \cos(k_e x) - z_{ba} \cos(\varepsilon_b)}$$

ε_s bilinir.

! RELATIVE BOW MOTION IN IRREGULAR SEAS

Spectral density of the relative bow motion in irregular seas (S_s) $\rightarrow S_s = S_z + \frac{\pi L}{1} S_\theta - S_\varphi$

S_z is spectral density for the wave spectrum,

S_z is spectral density for the response spectrum of heaving motion

S_θ is spectral density for the response spectrum of pitching motion

Example 2: $\rightarrow$ çizelge deli

Find the significant relative bow motion of a 122m shipsteaming at 20 knots in head seas in a long crested seaway with a significant wave height of 5.64m. The following values are available for the ship from tests in regular waves of a corresponding model:

ω_e	$S_z(\omega_e)$	RAO (S_z/ζ_a^2)
0.4	0.09	0.0
0.6	1.21	0.4
0.8	2.51	1.7
1.0	2.00	5.1
1.2	1.39	8.3
1.4	0.93	6.0
1.6	0.51	2.6
1.8	0.33	1.8
2.0	0.23	1.4

3 Correction factor heads
Example 2: Solution

ω_e	ω_e^2	$S_z(\omega_e)$	$\omega_e^2 S_z(\omega_e)$	SM	Product
0.4	0.16	0.000	0.000	1	0.000
0.6	0.36	0.483	0.174	4	0.696
0.8	0.64	4.264	2.729	2	5.458
1	1	10.187	10.187	4	40.747
1.2	1.44	11.566	16.656	2	33.311
1.4	1.96	5.574	10.925	4	43.702
1.6	2.56	1.329	3.401	2	6.802
1.8	3.24	0.585	1.896	4	7.585
2	4	0.325	1.301	1	1.301
				SUM	139.602
				$m_2 =$	9.307

Example 2: Solution

ω_e	$S_z(\omega_e)$	$(S_z/\zeta_a^2)^2$	$S_z(\omega_e)$	SM	Product
0.4	0.09	0	0.000	1	0.000
0.6	1.21	0.4	0.483	4	1.932
0.8	2.51	1.7	4.264	2	8.528
1	2.00	5.1	10.187	4	40.747
1.2	1.39	8.3	11.566	2	23.133
1.4	0.93	6	5.574	4	22.297
1.6	0.51	2.6	1.329	2	2.657
1.8	0.33	1.8	0.585	4	2.341
2	0.23	1.4	0.325	1	0.325
				SUM	101.961

$$m_0 = \frac{1}{3} \times \Delta \omega_e \times SUM = \frac{1}{3} \times 0.2 \times 101.961 = 6.797$$

$$s_{a1/3} = 2 \sqrt{m_0} = 2 \sqrt{6.797} = 5.214m$$

Example 2: Solution

ω_e	ω_e^2	$S_z(\omega_e)$	$\omega_e^2 S_z(\omega_e)$	SM	Product
0.4	0.026	0.000	0.000	1	0.000
0.6	0.130	0.483	0.063	4	0.250
0.8	0.410	4.264	1.747	2	3.493
1	1.000	10.187	10.187	4	40.747
1.2	2.074	11.566	23.984	2	47.968
1.4	3.842	5.574	21.414	4	85.655
1.6	6.554	1.329	8.707	2	17.413
1.8	10.498	0.585	6.144	4	24.577
2	16.000	0.325	5.203	1	5.203
				SUM	225.307
				$m_4 =$	15.020

$$\varepsilon^2 = \frac{m_0 m_4 - m_2^2}{m_0 m_4} = \frac{6.797 \times 15.020 - 9.307^2}{6.797 \times 15.020} = 0.152$$

$$CF = \sqrt{1 - \varepsilon^2} = \sqrt{1 - 0.152} = 0.921$$

$$s_{a1/3} = 2 \times \sqrt{m_0} \times CF = 2 \times \sqrt{6.797} \times 0.921 = 4.803m$$

DECK WETNESS AND SWELLING

Static Swell up → Static Keel (Freeboard design)

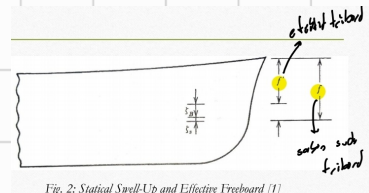


Fig. 2: Static Swell-Up and Effective Freeboard [1]

$$f'(l) = f(l) - h_s(l)$$

$$h_s(l) = \bar{z}_p + \bar{z}_s$$

Approximate formula → $\frac{h_s}{L} = k_1' \cdot F_n^2$

$$k_1' = k_1 \left(\frac{D}{L_s} \right)$$

DECK WETNESS

Dynamic Swell up

dynamic swell up

$$h_d(l) = k_2 \cdot s(l) \cdot \omega_0 \sqrt{\frac{L}{g}}$$

$$h_d(l) = k_2 \cdot L \cdot \frac{\dot{s}(l)}{\sqrt{g L}}$$

$$s(l) = z - l\theta - \bar{z}$$

$$k_2 = \frac{1}{3} (C_D - 0.55)$$

Relative freeboard in waves

$$h'(l) = f'(l) - h_d(l) + s(l)$$

Probability of Deck wetness

$$P\{s \geq f(l)\} = e^{-f'(l)^2 / (k \cdot m_{0s})}$$

Number of Deck Inappings per Hour

$$N_T = \frac{P_F}{T} \cdot 3600$$

Number of Deck wetness each second

$$N_w = \frac{1}{2\pi} \sqrt{\frac{2 m_{0s}}{2 m_{2s}}} \times P_F$$

Example 3

Let the probability of shipping green water for a tanker 0.05 or 5%. If the average pitching period 5sec, how often will the bow of the ship be submerged per hour.

$$N_T = \frac{P_F}{T_0} \times 3600 = \frac{0.05}{5} \times 3600 = 36$$

Example 4

Assuming a relative bow motion in an irregular seaway as in Example 2. Find the frequency deck wetness for a 122m ship with an effective freeboard of 7.32m. (See Example 2 for $m_{0s} = 6.797 \text{ m}^2$ and $m_{2s} = 9.307 \text{ m}^2/\text{s}^2$).

$$P\{s \geq 7.32\} = P_F = e^{-7.32^2 / (2 \times 6.797)} = 0.0194$$

$$P\{s \geq f(l)\} = e^{-f'(l)^2 / (k \cdot m_{0s})}$$

$$N_w = \frac{1}{2\pi} \sqrt{\frac{2 m_{0s}}{2 m_{2s}}} \times P_F = \frac{1}{2\pi} \times \sqrt{\frac{2 \times 6.797}{2 \times 9.307}} \times 0.0194 = 0.0026$$

or 9.36 occurrences per hour.

SLAMMING

→ No 2 objects → Pressure on bottom plating

Stress in main structure due to vibration (whipping)

weight f.

weight of wedge

force of the rudder
the hull
on wedge

$$F_i + F_d + (F_b - F_w - F_s) = 0$$

inertia
force
damping
f.



kolaylı 94 in wedge (kanc)
formu bas basen kabolu

Slamming Pressure Dist, Slamming Max Pressure → So, 1st

Probability of slamming →

$$\text{Prob}\{\text{slam}\} = e^{-\left[\frac{T^2}{2m_{0s}}\right] + \left[\frac{v_0^2}{2m_{2s}}\right]}$$

usage for low velocity

freq under
resonance
spectrum

critical value of relative velocity (threshold velocity)

$$v_0 = \sqrt{\frac{g \cdot b}{2\pi} - V_s^2}$$

ship speed

width of pond

α Freq. of slamming per unit time →

$$N_s = \frac{1}{2\pi} \sqrt{\frac{m_{2s}}{m_0}} \times \text{Prob}\{\text{slam}\}$$

Example 5

Given:

For a similar ship which has a length of 158.5m, the threshold velocity $v_0 = 3.658 \text{ m/s}$.

$$m_{0s} = 28.1 \text{ m}^2$$

$$m_{2s} = 14.2 \text{ m}^2/\text{s}^2$$

Predict number of slams for 167.6m ship with a draught of 5.21m during 30min operation.

$$\text{The threshold velocity of our ship is } v_0 = 3.658 \sqrt{\lambda} = 3.658 \times \sqrt{\frac{167.6}{158.5}} = 3.762 \text{ m/s}$$

$$v_{01} = v_{02} \sqrt{\frac{L_1}{L_2}}$$

buysu geniden
orayla bolumu

Example 5: Solution

$$\text{Prob}\{\text{slam}\} = e^{-\left[\frac{T^2}{2m_{0s}}\right] + \left[\frac{v_0^2}{2m_{2s}}\right]} = e^{-\left(\frac{5.21^2}{2 \times 28.1} + \frac{3.762^2}{2 \times 14.2}\right)} = 0.3748$$

$$N_s = \frac{1}{2\pi} \sqrt{\frac{m_{2s}}{m_{0s}}} \times \text{Prob}\{\text{slam}\} = \frac{1}{2\pi} \sqrt{\frac{14.2}{28.1}} \times 0.3748 = 0.0424$$

0.0424 × 1800 = 76.32 slams within the period of 30min.

