CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
JULY 2025 SEMESTER SESSION (7-WEEK)

SUBJECT CODE	:	**LNB31703**
SUBJECT TITLE	:	**SEAKEEPING AND MANOUVERING**
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	**BET (NAVAL ARCHITECTURE AND SHIPBUILDING) WITH HONOURS**
TIME / DURATION	:	**09.00 AM - 12.00 PM (3 HOURS)**
DATE	:	**17 SEPTEMBER 2025**

INSTRUCTIONS TO CANDIDATES

1. Please read **CAREFULLY** the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. This question paper consists of **TWO (2)** section; Section A and Section B.
4. Answer **ALL** question in Section A, and **THREE (3)** questions with at least one (1) question from question 4 or question 5.
5. Please write your answers on this answer booklet provided.
6. Answer **ALL** questions in English language **ONLY**.
7. Answer should be written in blue or black ink except for sketching, graphic and illustration.
8. Formula sheet, added mass coefficient and graph paper are appended.

THERE ARE 5 PAGES OF QUESTIONS, EXCLUDING THIS COVER PAGE.

SECTION A (Total: 40 marks)

INSTRUCTION: Answer ALL questions.
Please use the answer booklet provided.

Question 1

(a) The zig-zag test, also known as a 'Kempf' maneuver, is a critical test for understanding a ship's initial response to rudder inputs. Sketch and label the key components of the zig-zag maneuver, and describe the criteria that must be achieved during the test to analyze a ship's stability. (PLO2, SK3) (6 marks)

(b) The directional stability of a vessel is a fundamental aspect of its handling. Describe and illustrate with sketches **two** distinct methods used to assess this stability. (PLO2, SK3) (8 marks)

(c) To accurately evaluate the directional stability indices of a ship, it is essential to determine its hydrodynamic derivatives. Describe the application of a Planar Motion Mechanism (PMM) and its role in experimentally determining the hydrodynamic derivatives, Y_v and N_v. (PLO2, SK3) (6 marks)

Question 2

Naval Architecture engineer is tasked with analyzing the maneuvering characteristics of a new seagoing vessel design. To do this, a 1:100 scale model is tested in a towing tank filled with fresh water. The objective is to apply fundamental principles of hydrodynamics and scaling laws to analyze the experimental data and predict the full-scale vessel's behavior. The table below presents the experimental data for sway force and yaw moment in relation to varying sway velocities.

Sway velocity, V(m/s)	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4
Sway Force, Y(KN)	102	76	51	25	0	-25	-50	-77	-101
Yaw Moment, N(KN.m)	31	23	16	7.5	0	-7.5	-15.5	-22	-32

(a) Using the provided data, analyze the relationship between sway velocity, sway force, and yaw moment by plotting the data, and estimate the value of linear hydrodynamic derivatives, Yv and Nv. (PLO2, SK3) (10 marks)

(b) Apply the principles of scaling and dynamic similarity, determine the magnitude of the linear derivatives Yv and Nv full scale at the same Froude number. (PLO2, SK3) (10 marks)

SECTION B (Total: 60 marks)

INSTRUCTION: Answer only THREE (3) questions.
Please use the answer booklet provided.

Question 3

A model of a vessel is being tested to determine its hydrodynamic properties. The following particulars and sectional data have been recorded:

- Length of model, L = 3.132 m
- Max. beam, B = 0.548 m
- Draught, T = 0.208 m
- Density of water ρ =1000 kg/m^3
- Wave length = ship length = 3.132 m
- Model speed, u = 1.1611 m/s
- Displacement, Δ = 267.00 kg
- Direction of ship travel, μ = 180° (i.e. head sea)
- LCG = at amidship

Stn	Bn (m)	Tn (m)	Sn (m^2)
0	0.000	0.208	0.000
5	0.545	0.208	0.103
10	0.548	0.208	0.114
15	0.545	0.208	0.103
20	0.000	0.208	0.000

(a) Using the provided sectional data and specialist knowledge of added mass coefficients (Use the added mass coefficient charts available as per attached), analyze and calculate the added mass for heaving in terms of the model mass. (PLO2, SK4) (10 marks)

(b) The model is now subjected to waves with a heading angle (μ) of 120 ° and wave amplitude, ζ_a = 0.06 m, determine the non-dimensionless amplitude for heaving force, f_o and calculate the exciting force for the heaving motion, F_o. Given the heaving exciting force is described by: (PLO2, SK4) (10 marks)

F = $F_o . \cos \omega_e t$ *and* $f_o = \dfrac{F_o}{(\rho g \zeta_a L.B)}$ (Nondimensional form)

$$f_o = \frac{2}{LB}\int_{-L/2}^{L/2} y_{(x)} \cos(kx\cos\mu)dx$$

Question 4

An ocean engineer is analyzing how waves behave and how they affect things in the water. To do this, they need to apply specialized knowledge of wave theory. The problems below ask you to use fundamental wave equations to solve real-world scenarios.

(a) Waves in the ocean follow a special formula called the dispersion relation: $\omega^2 = g.k \tanh (kd)$. This formula tells us how a wave's frequency (ω), wave number (k), and water depth (d) are all connected. Show how this formula simplifies to $c = g/\omega$ when the water is very deep. (PLO2, SK4) (5 marks)

(b) When a wave passes, the water particles move in circles. The formula for the horizontal speed of these particles is:

$$\underline{u} = \frac{\partial \phi}{\partial x} = \frac{gak}{\omega} \frac{\cosh k(z+d)}{\cosh kd} \sin(kx - \omega t)$$

Show how in shallow water, the particle velocity is simplified to $\underline{u} = \frac{ga}{\sqrt{gd}} \sin(kx - \omega t)$. After simplifying it, explain what happens to the particle's velocity, $\underline{u}$ as the water gets shallower and shallower. (PLO2, SK4) (7 marks)

(c) Imagine a group of waves traveling together. This group is 300 m long, and the individual waves inside the group are 30 m length.

i. Calculate the time taken for a component wave to travel the length of the group. (PLO2, SK4) (5 marks)

ii. Calculate how far the group of waves would move forward during this time. (PLO2, SK4) (3 marks)

Question 5

(a) An ocean engineer must perform a problem analysis on wave characteristics to design an offshore structure. This requires applying specialist knowledge of wave theory, including how water depth influences wave properties and the energy within a wave.

Using the dispersion relations, **determine the wavelength (λ),** of a wave with a **period (T) of 10 seconds** under water depth (*d*) of:

(i) 2000 m

(ii) 1 m

Assume water depth for shallow water is considered from *2m* and below. (PLO2, SK4)

(6 marks)

(b) Derive the formula for the kinetic energy of per unit area of the water surface which is equal to ¼ $\rho g a^2$. Where for a fluid element of mass $\rho.dx.dz$:

$$\text{K.E. of element } = \frac{1}{2}(\rho.dx.dz)(\underline{u}^2 + \underline{w}^2)$$

where u and w are the horizontal and vertical velocity components. For deep water, the velocity potential is given as;

$$\phi_\infty = -\frac{ga}{\omega}.e^{kz}\cos(kx - \omega t)$$

You may use trigonometric identities $\sin^2\theta + \cos^2\theta = 1$ to solve your derivation. (PLO2, SK4)

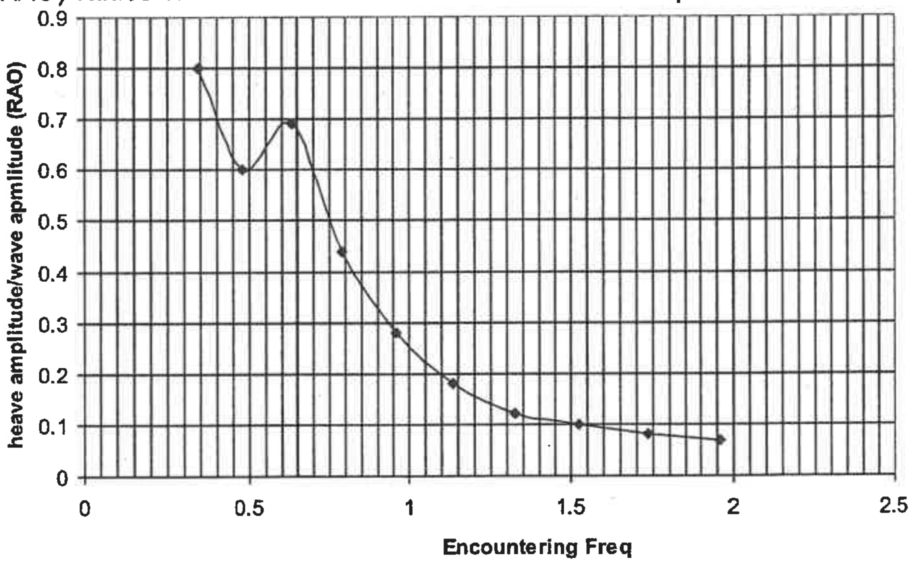
(14 marks)

Question 6

A naval architect is performing a problem analysis on the seakeeping performance of a vessel in irregular waves. The task requires specialist knowledge of spectral analysis to evaluate the ship behavior. The vessel is traveling at 10 knots in head seas, and the sea spectrum, S(ω), for this wave environment is provided in the table.

ω	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
S(ω)	0.2	2.0	4.05	4.3	3.4	2.3	1.5	1.0	0.7	0.5

If the encountering frequency is given by $\omega_E = \omega_w\left(1 - \frac{\omega_w V_S}{g}\cos\mu\right)$ and the Response Amplitude Operator (RAO) values of the vessel can be obtained from the Graph 5.1 below:



Graph 5.1: Response Amplitude Operator (RAO) for vessel heave motion

Hence, conduct the following calculations

a) Using your understanding of spectral analysis, calculate the heave response spectrum, by applying the given sea spectrum data and the vessel's RAO values. (PLO2, SK4)

(10 marks)

b) Plot a graph of the heave response spectrum against the encountering frequency, ω_e to visually represent the vessel's motion characteristics in the given seaway. (PLO2, SK4)

(4 marks)

c) Calculate the moment of the response spectrum, m_R which is the area under the curve and its significant response. (PLO2, SK4) (6 marks)

END OF EXAMINATION PAPER

FORMULA SHEET

Properties of Harmonic Waves in Deep Water

Surface profile (i.e. elevation of line of equal pressure at z = 0),

$\zeta = \zeta_a \cos(kx - \omega t)$

Wave velocity or celerity,

$$V_w = \frac{L_w}{T_w} = \frac{g}{\omega_w} = \left(\frac{gT^2{}_w}{2\pi}\right)$$

Wavelength, $L_w = \frac{2\pi V^2{}_w}{g} = \frac{2\pi g}{\omega_w^2} = \frac{gT_w{}^2}{2\pi}$

Wave Number,

$$k = \frac{2\pi}{L_w} = \frac{\omega_w{}^2}{g} = \frac{g}{V_w^2} = \frac{4\pi^2}{gT_w^2}$$

Wave Period, $T_w = \left(\frac{2\pi L_w}{g}\right)^{\frac{1}{2}}$

Energy per unit wave Surface, $E = \frac{1}{2}\rho\zeta_a^2$

Properties of Harmonic Waves in water of any depth

Elevation of lines of Equal Pressure,

$$\zeta = \zeta_a \frac{\sinh k(-z+d)}{\sinh kd} \cos(kx - \omega t)$$

Surface profile (i.e. elevation of line of equal pressure at z = 0),

$\zeta = \zeta_a \cos(kx - \omega t)$

Horizontal water velocity,

$$u = \zeta_a V_w k \frac{\cosh k(-z+d)}{\sinh kd} \cos(kx - \omega t)$$

Vertical water velocity,

$$w = \zeta_a V_w k \left(\frac{\sinh k(-z+d}{\sinh kd}\right) \sin(kx - \omega t)$$

Wave Velocity or celerity,

$$V_w = \left(\frac{gL_w}{2\pi} \tanh kd\right)^{\frac{1}{2}}$$

Note: for shallow water ($d \langle \frac{L_w}{20}$),

$V = \sqrt{gd}$

Velocity Potential

The mathematical expression for ϕ (velocity potential) satisfying the boundary conditions :

$$\phi_d = -\frac{g.a}{\omega} . \frac{\cosh k(z+d)}{\cosh kd} . \cos(kx - \omega t)$$

Wave Relationships

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

$$\therefore \lambda = T . \sqrt{\frac{g}{k} \tanh\ kd}$$

$$= T . \sqrt{\frac{g}{2\pi} \lambda \tanh\left(\frac{2\pi d}{\lambda}\right)}$$

$$= T . \sqrt{\lambda} \sqrt{\frac{g}{2\pi} \tanh\left(\frac{2\pi d}{\lambda}\right)}$$

$$\therefore \sqrt{\lambda} = T . \sqrt{\frac{g}{2\pi} \tanh\left(\frac{2\pi d}{\lambda}\right)}$$

$$\therefore \lambda = T^2 . \frac{g}{2\pi} \tanh\left(\frac{2\pi . d}{\lambda}\right)$$

Encountering Frequency

$$\omega_E = \omega_w \left(1 - \frac{\omega_W V_S}{g} \cos \mu\right)$$

Heaving Motion

For the steady condition the amplitude of the forced heaving motion z_a is given by:

$z_a = z_{st} . \mu_z$

Where, z_{st} = static heaving amplitude = $\frac{F_o}{c}$

μ_z = magnification factor = $\frac{z_a}{z_{st}}$

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

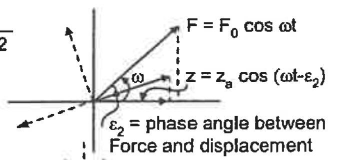
k = non-dimensional damping factor

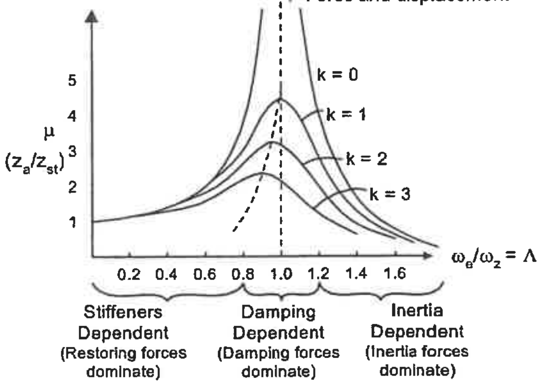
$$= \frac{v}{\omega_z}$$

and $v = \frac{b}{2(m+a_z)}$, $\omega_z = \sqrt{\frac{c}{(m+a_z)}}$

ϵ_z = phase angle between the exciting force and the motion

$$= \tan^{-1}\frac{2k\Lambda}{1-\Lambda^2}$$





Magnification Factor vs Tuning Factor

Where Λ = tuning factor

$$= \frac{\text{Freq. of encounter}}{\text{Nat. freq.}}$$

$$= \frac{\omega_e}{\omega_z}$$

Added Mass, Damping, Restoring Coefficient and Exciting Forces for Heaving Motions

where $B_n = 2r$ and a_n = added mass of ship section

$$C = \frac{a_n}{\rho\pi\frac{B_n^2}{8}} \quad \text{or} \quad a_n = C.\frac{\rho\pi B_n^2}{8}$$

C for Lewis-form section is obtained from graph provided. as a function of the (draught/beam) ratio and the area coeff. of the section as well as a function of circular frequency of oscillation.

Area coeff. of section,

$$\beta_n = \frac{\text{Section Area}}{B_n \times T_n} = \frac{S_n}{B_n \times T_n}$$

<u>Damping, b</u>

The damping coeff., b can be calculates similar to the case of added mass.

Damping coeff. per unit length, b_n =

$$\frac{\rho.g^2 \bar{A}^2}{\omega_e^3}$$

<u>Restoring coefficient, C</u>

$$C = \rho g A_W$$

$$= \rho.g.L.B.C_W$$

Where C_W is waterplane area coeff.

<u>Exciting Force</u>

$F = F_o.\cos \omega_e t$

and $f_o = \frac{F_o}{(\rho g \zeta_a.L.B}$ (Nondimensional form)

$$f_o = \frac{2}{LB}\int_{-L/2}^{L/2} y_{(x)} \cos(kx\cos\mu)dx$$

Pitching Motion

$\theta_a = \theta_{st}.\ \mu_\theta$

Where, θ_{st} = static pitch amplitude = $\frac{M_o}{c}$

μ_θ = magnification factor = $\frac{\theta_a}{\theta_{st}}$

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

k = non-dimensional damping factor

$= \frac{v}{\omega_\theta}$

The solution of the equation of motion is

$\theta = B\ e^{-vt} \sin(\omega_d.t + \gamma) + C \sin(\omega_e t - \epsilon_2)$

which, for a steady-state condition (when the first term dies out with time t), is

$\theta = \theta_a \sin(\omega_e.t - \epsilon_2)$ since $C = \theta_a$

or

$$\theta = \frac{\theta_{st}}{\sqrt{(1-\Lambda^2)^2 + 4k^2\Lambda^2}} \sin(\omega_e t - \epsilon_2)$$

ϵ_2 = phase angle between the exciting force and the motion = $\tan^{-1} \frac{2k\Lambda}{1-\Lambda^2}$

The phase angle bet. wave motion and pitching motion,

$$\epsilon = \epsilon_1 + \epsilon_2$$

Virtual Mass Moment of Inertia, Damping, Restoring Coefficient and Exciting Moment

Virtual Mass Moment of Inertia, a

$a\ = (m + \delta m) \times k_{yy}^2$

$\quad = \frac{\Delta'}{g}.k_{yy}^2$

Damping, b.

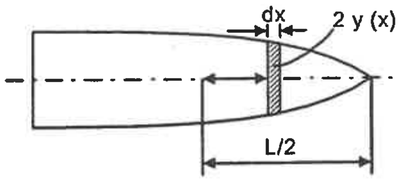
$$b'_{pitch} = \frac{b.\sqrt{gL}}{\Delta_B L^2}$$

Normally,

$$b'_{pitch} = \frac{b}{\rho.\nabla.(L/4)^2\sqrt{g/L}}$$

Where,
$\Delta = \rho\nabla = kg$
$L = m$
$g = m/s^2$

Restoring Moment Coefficient, c



Restoring Moment

$= c\theta = \rho.g.\theta. \int_{-L/2}^{L/2} x^2.2y_{(x)}.dx$

$= \rho.g.\theta.I_y$

$c\ = \Delta_B.GM_L$

Exciting Moment for Pitching, M_θ

$M_o = 2\rho.g.\zeta_a \int_{-L/2}^{L/2} y_{(x)}.x.\sin(kx.\cos\mu).dx$

Non-dimensional amplitude of pitching moment,

$$f_o = \frac{M_o}{\frac{1}{2}.\rho.g.\zeta_a.B.L^2}$$

$$= \frac{4}{B.L^2}\int_{-L/2}^{L/2} y_{(x)}.x.\sin(kx\cos\mu).dx$$

Rolling Motion

Amplitude of roll motion

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

Virtual mass moment of Inertia

$I_v\ = \ M.k_{xx}^2 + \delta\ I_{xx}$

$\quad = \ (\Delta + \delta\Delta)\ k_{xx}^2$

Restoring moment coefficient

$c = \Delta g GM_T$

Tuning factor

$$\Lambda = \frac{\omega_e}{\omega_\phi}$$

The damping factor is $\kappa = \frac{\upsilon}{\omega_\phi}$ where

$$\upsilon = \frac{b}{2a}$$

Static roll deflection

$$\phi_{st} = \frac{M_o}{c}$$

$$\mu_\theta = magnification\ factor = \frac{\phi_a}{\phi_{st}}$$

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

Motion In Irregular Waves

For heave response;

$$m_o = \frac{1}{3} \text{ x C.I. x } \Sigma f(S_R(\omega_E))$$

$$\overline{H}_1 = 2.50\ m_o^{1/2}$$

$$\overline{H}_{1/3} = 4.00\ m_o^{1/2}$$

$$\overline{H}_{1/10} = 5.10\ m_o^{1/2}$$

$$RAO = \frac{\text{Heave Amplitude}}{\text{Wave Amplitude}}$$

For roll response;

$$(\phi)_1 = 1.253\ m_o^{1/2}$$

$$(\phi)_{1/3} = 2.00\ m_o^{1/2}$$

$$(\phi)_{1/10} = 2.545\ m_o^{1/2}$$

$$RAO = \frac{Roll\ Amplitude}{Wave\ Amplitude}$$

Manoeuvrability - Notation Of Force And Moment Derivatives

The following standard notation is used:

e.g. $\frac{\partial Y}{\partial v} = Y_v,\ \frac{\partial N}{\partial \dot\psi} = N_{\dot\psi},\ \frac{\partial N}{\partial \delta_R} = N_{\delta R}$

etc.

Also, for planar motions, $\dot\psi \equiv r$ and $\ddot\psi \equiv \dot r$

Non-dimensional derivatives:

$$m' = \frac{m}{\frac{\rho}{2}L^3};\ v' = \frac{v}{U};\ \dot v' = \frac{\dot v L}{U^2};\ x_G' = \frac{x_G}{L}$$

$$I_z' = \frac{I_z}{\frac{\rho}{2}L^5};\ r' = \frac{rL}{U};\ \dot r' = \frac{\dot r L^2}{U^2}$$

$$Y_v' = \frac{Y_v}{\frac{\rho}{2}L^2U};\ Y_r' = \frac{Y_r}{\frac{\rho}{2}L^3.U};\ N_v' = \frac{N_v}{\frac{\rho}{2}L^3.U};\ N_r' = \frac{N_r}{\frac{\rho}{2}L^4.U}$$

$$Y_{\dot v}' = \frac{Y_{\dot v}}{\frac{\rho}{2}L^3U};\ Y_{\dot r}' = \frac{Y_{\dot r}}{\frac{\rho}{2}L^4.U};\ N_{\dot v}' = \frac{N_{\dot v}}{\frac{\rho}{2}L^4.U};\ N_{\dot r}' = \frac{N_{\dot r}}{\frac{\rho}{2}L^5}$$

$$Y_{\delta R}' = \frac{Y_{\delta R}}{\frac{\rho}{2}L^2U^2};\ N_{\delta R}' = \frac{N_{\delta R}}{\frac{\rho}{2}L^3.U^2}$$

The Stability Criterion

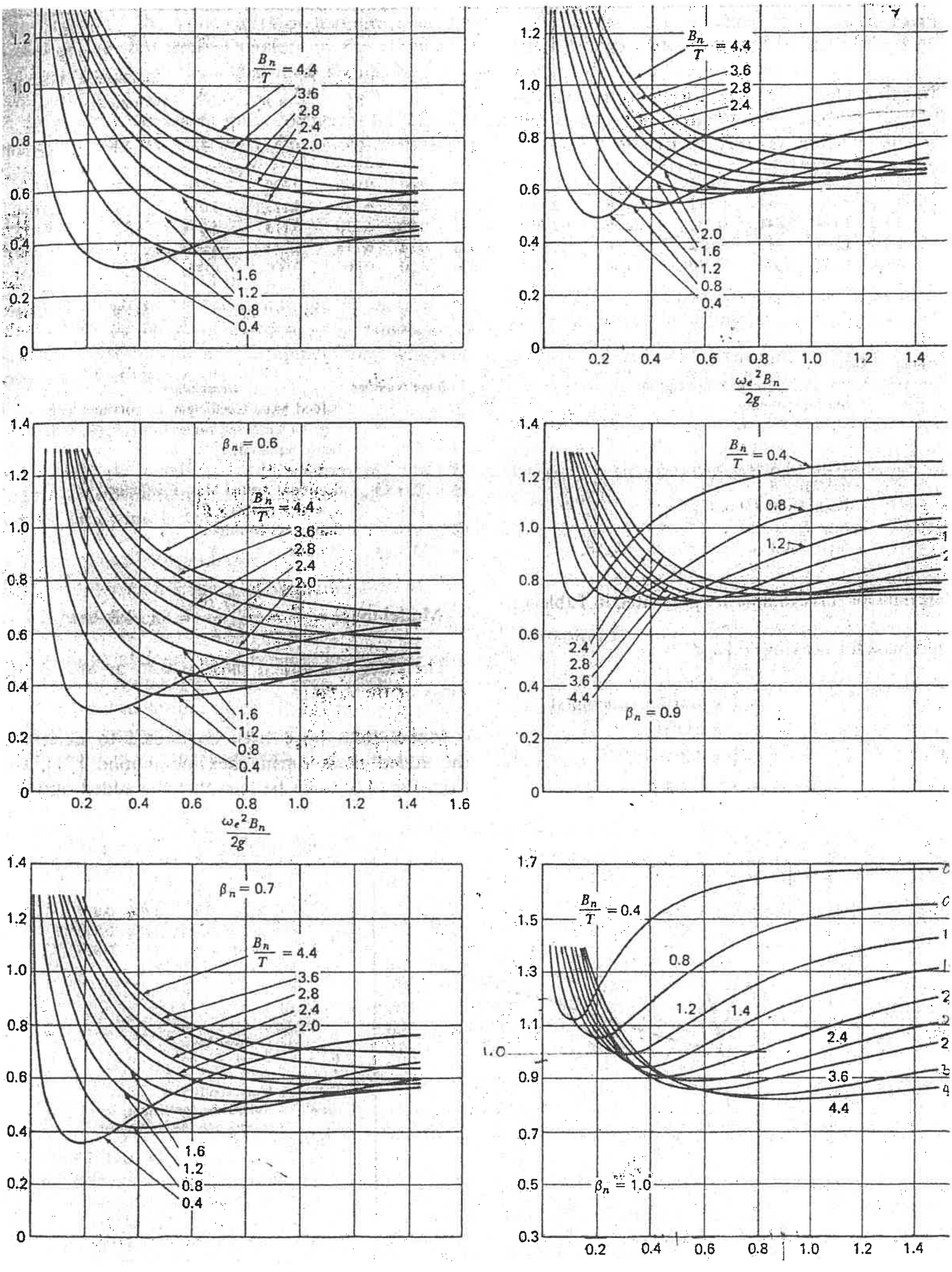
For directional stability,

$Y_v' N_r' - (Y_r' - m')N_v' > 0$ (Non-dimensionalised form)

OR

$Y_v\ (N_r - m x_G u)$ - $N_v\ (Y_r - mu) > 0$

(Origin is not at cg)



$\frac{B_n}{T} = 4.4$
3.6
2.8
2.4
2.0
1.6
1.2
0.8
0.4
$\frac{\omega_e^2 B_n}{2g}$
$\beta_n = 0.6$
$\beta_n = 0.9$
$\beta_n = 0.7$
$\beta_n = 1.0$
$\frac{B_n}{T} = 0.4$
1.4