University of Strathclyde Engineering

Department of

Naval Architecture, Ocean & Marine Engineering

NM404 Ship Structural Dynamics

6th December 2023 **TIME: 10:00** **2 hours**

Attempt ALL Questions

Calculators must not be used to store text and/or formulae nor be capable of communication. Invigilators may require calculators to be reset.

Question 1

(a) An impulsive force is applied to a spring-mass-damper system and initiates its free vibration with an initial velocity of 50 m/s, the displacement response of which is expressed as follows:

$$x(t) = A_0 exp(-\xi\omega_n t) cos\left(\sqrt{1-\xi^2}\omega_n t + \varphi_0\right)$$

where ω_n is the natural frequency, ξ is the damping ratio, t is time, φ_0 is the phase angle and A_0 is the initial displacement amplitude. It is known that the system mass is $M = 10kg$, system stiffness is $K = 6.4 \times 10^{-2}\ kN/mm$ and damping coefficient is 400 $N/(ms^{-1})$. Also note that the critical damping coefficient is $C_{cr} = 2M\omega_n$. Please determine the followings:

i. General expression of logarithmic decrement (δ) (*8 marks*)
ii. Natural frequency of the system in question (*2 mark*)
iii. Damping ratio of the system in question (*2 mark*)
iv. Phase angle of the system displacement response assuming $\varphi_0 < \pi$. Hint: the initial displacement of the system is zero (*2 mark*)
v. The time at which the system reaches maximum displacement (*6 marks*)

(20 marks)

(b) It is known that the magnification factor (M) of forced damped vibration is expressed as:

$$M = \frac{1}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\xi\left(\frac{\omega}{\omega_n}\right)\right]^2}}$$

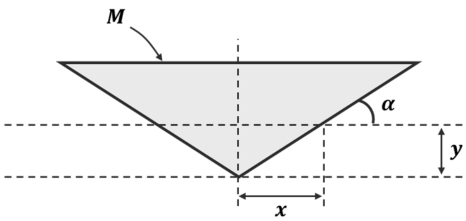
where ω is the driving force frequency. Please determine the maximum magnification factor for the system in Q1(a).

(12 marks)

PLEASE TURN OVER

Question 2

(a) Suppose that you are the principal naval architect in a maritime consultancy company, a client approaches you regarding the design of a high-speed craft against slamming. The hull form design can be simplified as below wedge shape.

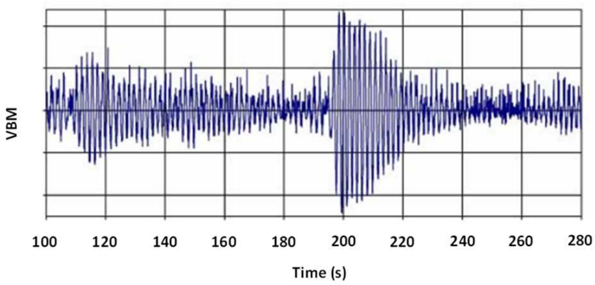


Applying von Karman momentum principle, please help your client to

i. Derive the general expression of maximum pressure. Given that initial impact velocity $= V_0$ and the accelerated fluid inertia $= 0.5\rho\pi x^2$ where ρ is the fluid density (*12 marks*).
ii. Outline the design principles against significant slamming (*4 marks*)
iii. Establish operational measures against significant slamming. Please provide an outline (*4 marks*).

(20 marks)

(b) You are approached by another client who operates a fleet of container ships featured with large bow flares. All these vessels are equipped with on-board structural monitoring devices to monitor the springing and whipping responses. Below is a sample of the monitoring data in which the low frequency component has been filtered out.



Please help your client to

i. Distinguish between springing and whipping for the sample monitoring data (during what time frame they occur) (*7 marks*)
ii. Outline the main characteristics of springing and whipping responses (*8 marks*)

(15 marks)

PLEASE TURN OVER

Question 3

The governing equation of free vibration in vertical direction of a uniform beam can be expressed as follows:

$$EI\frac{\partial^4 w(x,t)}{\partial x^4} + m\frac{\partial^2 w(x,t)}{\partial t^2} = 0$$

where $w(x,t)$ is the beam deflection in vertical direction. E is the modulus of elasticity of material, I is the second moment of area of beam's cross section, m is the mass of the beam per unit length (assumed constant). The solution to above equation can be given as:

$$w(x,t) = P(x)sin(\omega_n t)$$

where

$$P(x) = Asin(\kappa x) + Bcos(\kappa x) + Csinh(\kappa x) + Dcosh(\kappa x)$$

$$\kappa = \sqrt[4]{\frac{m\omega_n^2}{EI}}$$

(a) Please define the boundary conditions for above beam formulation in the context of ship vibration analysis. Hint: a ship should be considered as free-free beam (*4 marks*)

(b) Following above context, please prove $cos(\kappa L) \times cosh(\kappa L) = 1$ where L is the total length of the ship (*6 marks*).

(10 marks)

PLEASE TURN OVER

Question 4

For a barge with uniform cross section, please determine the corrected deflection curve (φ_{3cor}) of three-node bending vibration using generalised iterative *Stodola method* with the information given below.

x/L	0.1	0.3	0.5	0.7	0.9
W (Per unit length)	49	28	30	28	49
φ_{2cor}	1.05	-0.34	-0.92	-0.35	0.98
$y_{3assumed}$	0.77	1.26	0.00	-1.26	-0.77

You may find the following formulae useful:

$$^{0}\varphi_{3uncor} = \left[{}^{0}a_3 + ({}^{0}h_3 - {}^{0}a_3)\left(\frac{x}{L}\right) - {}^{0}y_3\right]$$

$$SF = 0 = {}^{0}a_3 \underbrace{\int_0^L W dx}_{k_1} + ({}^{0}h_3 - {}^{0}a_3)\underbrace{\int_0^L W\left(\frac{x}{L}\right)dx}_{k_2} - \underbrace{\int_0^L W\,{}^{0}y_3 dx}_{k_3}$$

$$BM = 0 = {}^{0}a_3 \underbrace{\int_0^L W\left(\frac{x}{L}\right)dx}_{k_2} + ({}^{0}h_3 - {}^{0}a_3)\underbrace{\int_0^L W\left(\frac{x}{L}\right)^2 dx}_{k_4} - \underbrace{\int_0^L W\left(\frac{x}{L}\right){}^{0}y_3 dx}_{k_5}$$

$$^{0}\varphi_{3cor} = {}^{0}\varphi_{3uncor} - \alpha_{23}\varphi_{2cor}$$

where

$$\alpha_{23} = \frac{\int_0^L W\,{}^{0}\varphi_{3uncor}\varphi_{2cor}dx}{\int_0^L W\varphi_{2cor}^2 dx}$$

(15 marks)

PLEASE TURN OVER

Question 5

Are the following statements true or false?

1) Two-node bending is the second-order mode shape of a beam (*1 marks*)
2) There are finite numbers of natural modes for a discrete system (*1 marks*)
3) Blade frequency is independent on the number of blades (*1 marks*)
4) Hydro-elasticity unifies seakeeping and structural vibration (*1 marks*)
5) Ship structural vibration will only negatively affect the structural integrity (*1 marks*)
6) The entrapped air during wave-body impact increases the impact force (*1 marks*)
7) A free damped system vibrates at natural frequency (*1 marks*)
8) Eigenvector defines the absolute response amplitudes (*1 marks*)

(8 marks)

END OF EXAMINATION PAPER