THE UNIVERSITY OF WESTERN ONTARIO
FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

COURSE NUMBER - CEE 490b - DYNAMICS OF STRUCTURES

FINAL EXAMINATION – APRIL 2003

TIME: 3 hours Intramural

INSTRUCTIONS: No. of Pages: 8

University policy states that CHEATING and plagiarism is a scholastic offence. The commission of a scholastic offence is attended by academic penalties, which might include expulsion from the program. If you are caught cheating, there will be no second warning.

1. Answer ALL four questions. The marks assigned to each question are shown in brackets below the question number. There is one "Bonus" question for additional marks.

2. The examination is 'closed book'.

   Note: Class notes, solutions to assignments and textbooks are not allowed.

3. During the examination the following may be used:
   a) 2 pages of Fact sheets provided with examination.

4. The use of an electronic calculator is permitted. A calculator that can store programs and information in advance of the examination may not be used.

5. Satisfactory performance with the written language is required.

6. If doubt exists as to the interpretation of any question, or if you consider that there is missing information, the candidate is urged to make a reasonable assumption and submit a clear statement of any assumption made with the final examination paper.

EXAMINER: Prof. P. King, P.Eng.

REVIEWER: Prof. J. Galsworthy, P.Eng

Marks

(25) **Question 1**

A cable-stayed pedestrian footbridge is modeled by three lumped masses as shown below. The first natural frequency is $f_o = 1$ Hz and the first mode is shown. The masses are 10,000 kg each. The damping ratio is 1%. The bridge is subjected to an earthquake with a power spectrum of vertical acceleration as shown. The duration of the strong motion of the earthquake is 30 seconds.

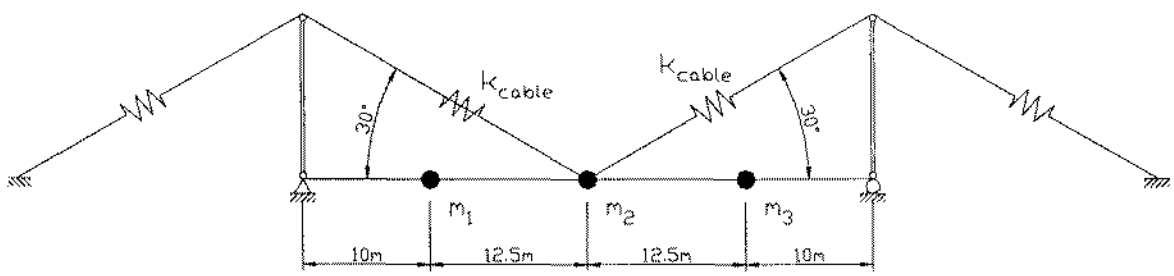
Assume that the towers are massless and that the cable stiffness from anchorage to tower top to deck is concentrated in an effective $k_{cable} = 400$ kN/m for the left half and right halves of the bridge.

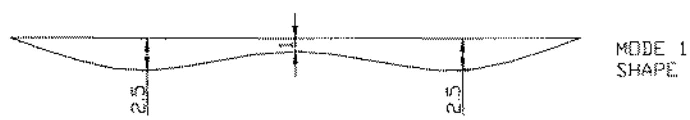
Analyze the first mode response to vertical earthquake excitation using the Random Vibration Approach and determine:

(10) i) The peak displacements of the bridge at masses 1,2 and 3

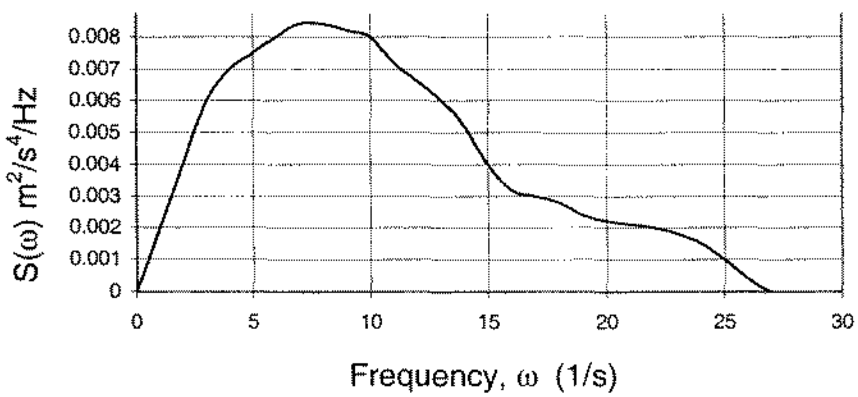
(10) ii) Equivalent Earthquake forces acting on the masses, the support reactions and the cable forces. [*Hint: The vertical component of an inclined cable is equal to:* $k_v = k_{cable} \sin^2\theta$]

(5) iii) The bending stress at masses 1 and 2 if the depth of the cross section of the bridge is $d = 1.2$m and its Bending Inertia in the vertical direction is 16.7×10^9 mm^4





Power Spectrum of Ground Vertical Acceleration



Marks

(25) **Question 2**

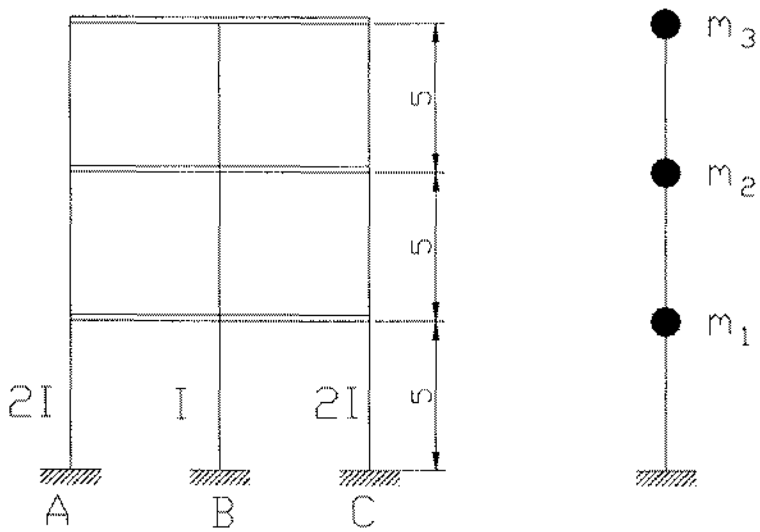
The three-storey shear building shown has masses $m_1 = m_2 = m_3 = 20{,}000\,kg$. The damping ratio is different in the 3 modes of vibration and is estimated to be: 0.5%, 1.0% and 2% for modes 1,2 and 3, respectively. The natural frequencies are: $f_1 = 0.5\,\text{Hz}$, $f_2 = 0.8\,\text{Hz}$ and $f_3 = 1.5\,\text{Hz}$.

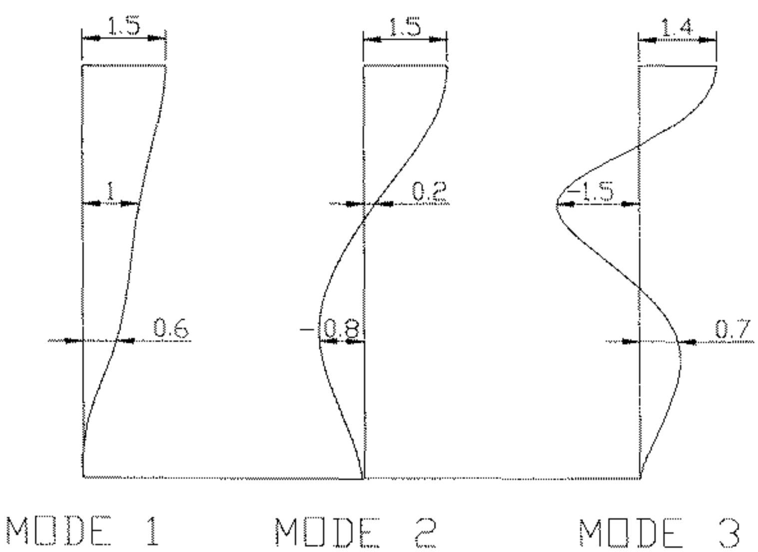
Determine the following effects of an earthquake with maximum acceleration of 20% of gravity and the Pseudo Velocity Spectral shapes as shown for the El Centro earthquake, see attached FACT SHEET. Include the effects of motion in all modes.

(10) a) Maximum displacement at the top storey.

(8) b) Equivalent Earthquake forces at each storey.

(7) c) Maximum Bending Moment at the Base of Columns A and B.





Marks

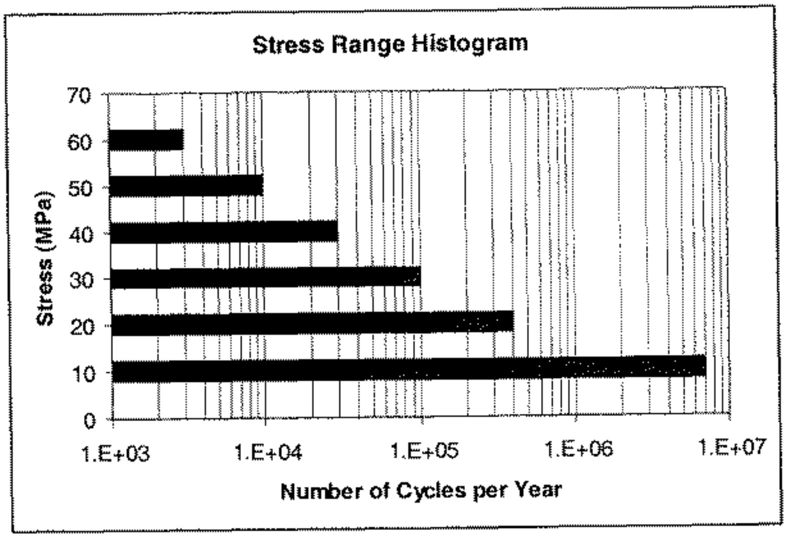
(25) **Question 3**

(5) a) Briefly discuss the process of fatigue, with emphasis on:
- Fatigue or Endurance Limit
- Fatigue Strength
- Allowable stress range and its dependence on detailing and surface finish

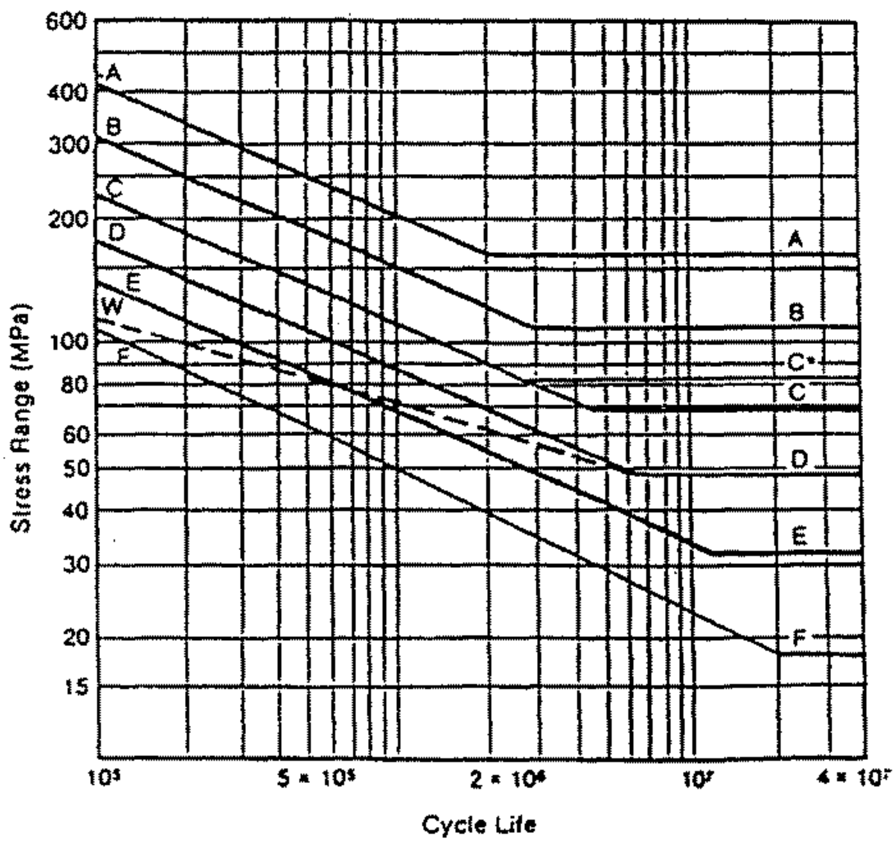
(5) b) Explain cumulative fatigue damage when loading cycles occur at different stress range values. How is this accounted for in design?

(15) c) A welded connection in a building frame has the following stress range histogram.

Assess the number of years that may be expected before failure occurs for Category E and F wells details. Use the Design Curves for Allowable Stress Range shown below.



Design Curves for Allowable Stress Range for Weld Categories A to W

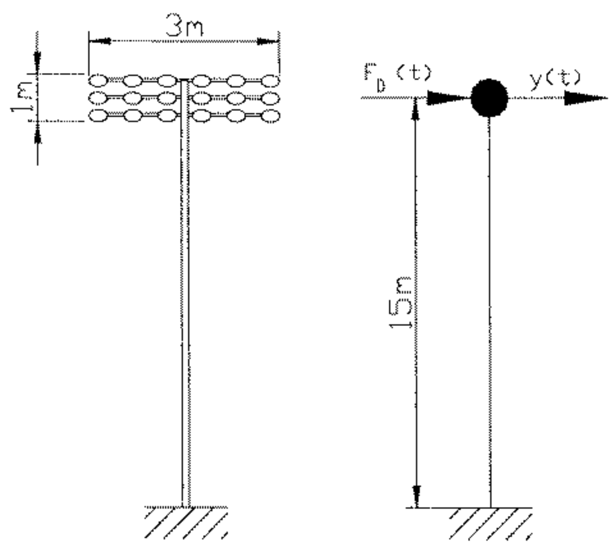


Marks

(25) **Question 4**

To estimate the drag response of the lamp standard shown below, approximate the structure as a single degree of freedom system. Neglect the wind load on the shaft of the lamp standard. Clearly state any assumptions you make and the reasoning behind them

Information on the structure and the wind at the site is as follows:



A = 3m x 1m (equivalent frontal area of lamp head assembly)
$C_D = 1.4$ (the effective drag coefficient of the lamp head assembly)
$\zeta = 0.5\%$ (the structural damping)
$f_o = 0.5\,\text{Hz}$ (the natural frequency)
$H = 15$ m
$M = 1000$ kg (the effective mass of the lamp head assembly)

$$F_D(t) = \frac{1}{2}\rho A C_D V_H^2(t)$$

$\rho = 1.25\ \text{kg/m}^3$ (the density of air)
$\overline{V}_H = 25$ m/s (the mean hourly wind speed)
$v(t) << \overline{V}$

$$\frac{fS_v(f)}{\sigma_v^2} = \frac{2}{3}\frac{x^2}{(1+x^2)^{4/3}}$$

where $x = \dfrac{1200f}{v}$

$I_v = \dfrac{\sigma_v}{\overline{V}_H} = 0.15$ (the Turbulence Intensity)

(5) a) Estimate the mean drag deflection of the lamp head.

(10) b) Develop a relationship between the power spectral density of $F(t)$ and the fluctuating wind speed $v(t)$.

(10) c) Estimate the hourly peak drag deflection.

Marks

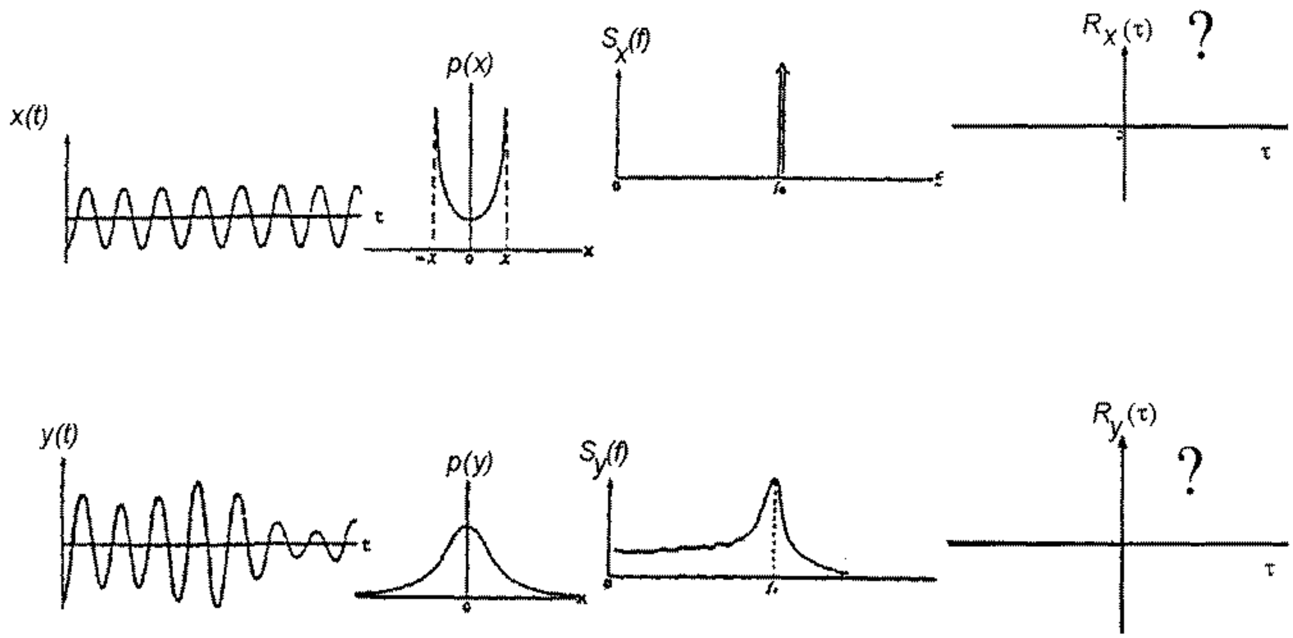
(10) **Bonus Question**

Typical time histories and the corresponding Probability Density and Power Spectral Density are shown for time dependent variables *x(t)* and *y(t)*.

a) Briefly describe what the variables *x(t)* and *y(t)* are like. Give one example of each, assuming *x(t)* and *y(t)* are structural responses due to wind excitation.

b) Sketch the form of the Autocorrelation Functions of *x(t)* and *y(t)* and explain your reasoning behind the form of these functions. Define the value of $R(\tau)$ is at $\tau = 0$, using the definition of the Autocorrelation Function.

c) Define the relationship between the RMS (i.e. standard deviation) and the maximum peak values of *x(t)* and *y(t)*.



FACT SHEET #1

- $$v = \left[\frac{\int_0^\infty f^2 S(f) df}{\int_0^\infty S(f) df} \right]^{1/2}$$

- If $y(t) = a \cdot x(t)$ then $S_y(f) = a^2 S_x(f)$

- $$g = \sqrt{2 \ln \upsilon T} + \frac{0.5772}{\sqrt{2 \ln \upsilon T}}$$

- $$\overline{y^2} = \frac{\pi}{4D} \sum_j \phi_{ij}^2 \frac{L_j^2}{M_j^2} \frac{S_a(\omega_j)}{\omega_j^3}$$

- $$\sigma_y^2 = \frac{\text{Constant}}{K^2} \int_0^\infty S_v(f) \cdot |\chi_a(f)|^2 \cdot |H(f)|^2 df$$

- $$u_{ij} = \frac{L_j}{M_j} \phi_{ij} S_d$$

- $$\sigma_y^2 = \frac{1}{K^2} \sigma_F^2 \left[1 + \frac{\pi}{4D} \frac{f_o S_F(f_o)}{\sigma_F^2} \right]$$

- $$\eta_j(t) = \frac{L_j}{M_j \omega_j^2} \frac{1}{\sqrt{\left(1 - \frac{\omega^2}{\omega_j^2}\right)^2 + 4\zeta^2 \frac{\omega^2}{\omega_j^2}}} \cos(\omega t + \phi_j)$$

- $$L_j = \sum_{i=1}^{n} \phi_{ij} m_i$$

- $$M_j = \sum_{i=1}^{n} \phi_{ij}^2 m_i$$

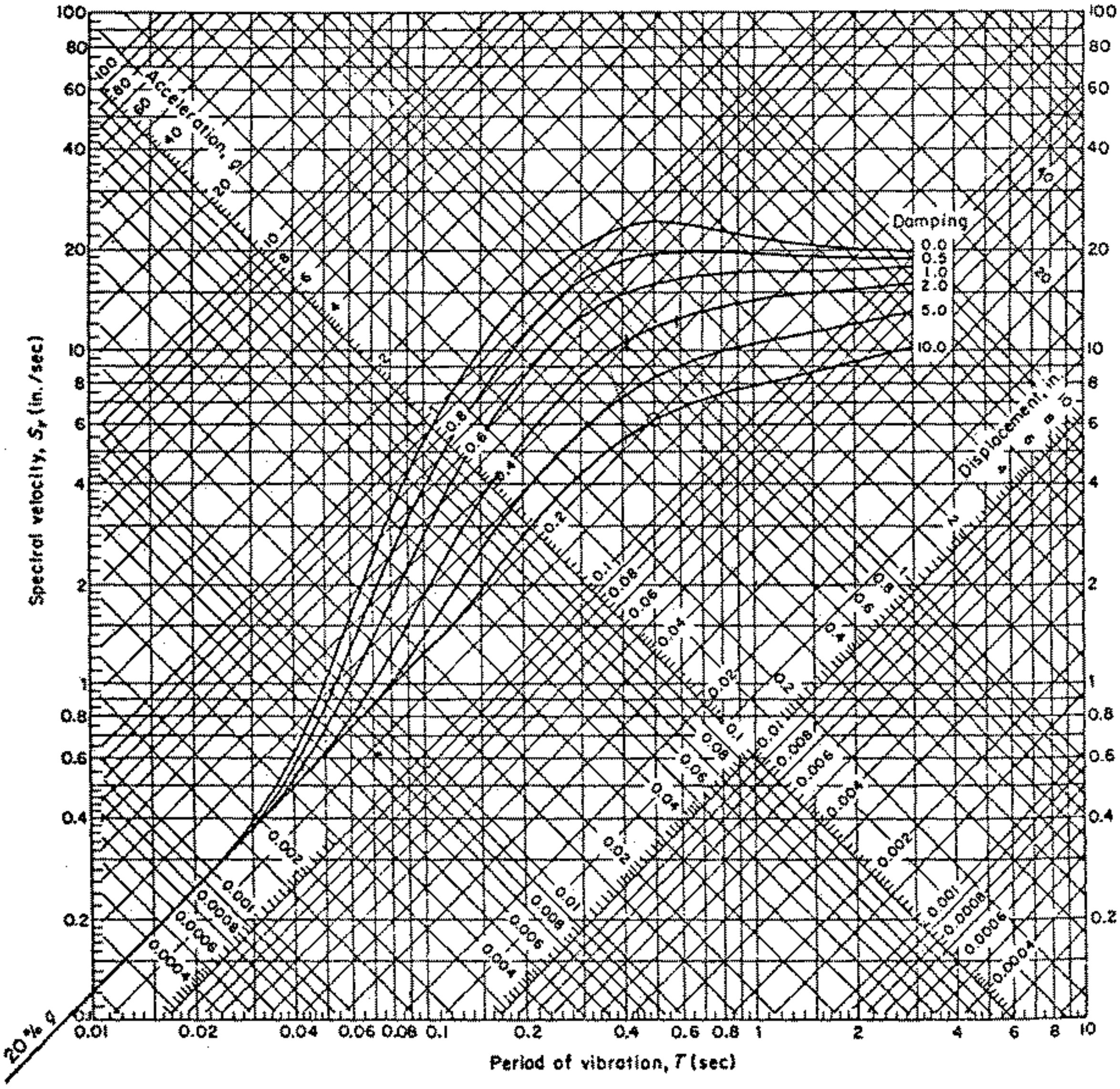
- $$\ddot{u}_{ij} = \frac{L_j}{M_j} \phi_{ij} S_{a(j)}$$

- K (fixed-fixed) $= 12EI/L^3$

- K (fixed-pinned) $= 3EI/L^3$

FACT SHEET #2

Combined Earthquake Response Spectra - El Centro 20%g



Note: Structural Damping in above plot, is given in percent-of-critical

- E N D -