INSTITUTO SUPERIOR TÉCNICO

EXAM OF STRUTURAL DINÂMICS AND EARTHQUAKE ENGINEERING

Integrated MSc course on Civil Engineering- 5th Year – 1st Semester

21st January 2011 – 1st Date

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Switch off your mobile phone. Identify all sheets of your exam with name and number. Deliver all problems in separate sheets Justify all answers. Consult the list of equations and data attached.

Duração: 2.5 horas

Problem 1 (10.0/20.0)

Consider the structural model shown in Figure 1. Assume the columns are axially rigid and with flexural stiffness (EI = 20 000 kNm^2), that beams are infinitely stiff and with uniformly distributed mass m =25 ton/m. The diagonal strut hás na axial stiffness EA = 10 000 kN (for both compressive and tensile forces)

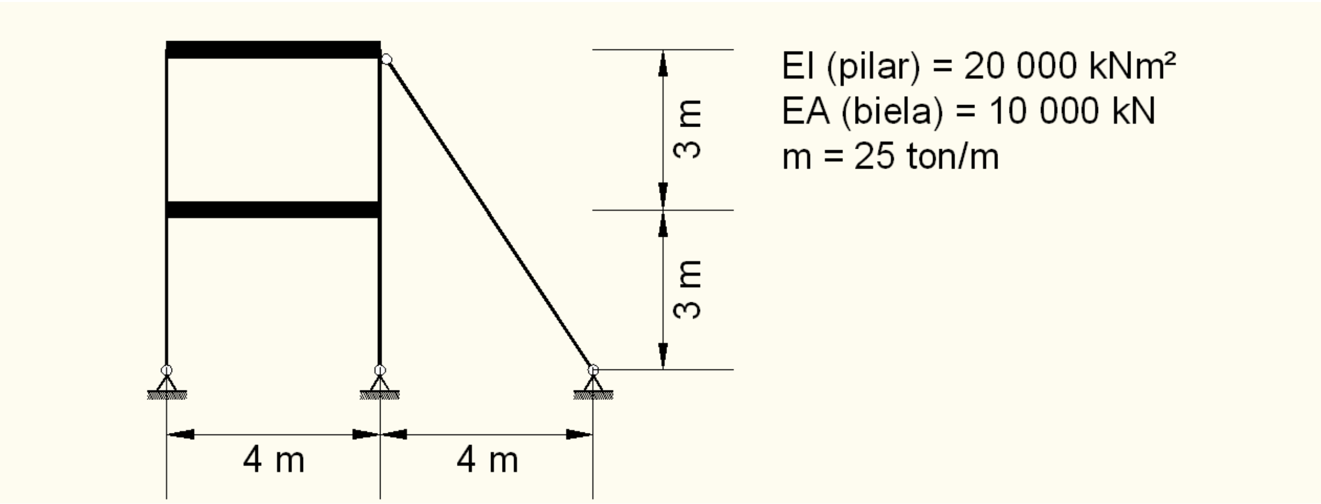


Figura 1.: Strutural model

Considering the horizontal displacements of the floors as the only relevant degrees of freedom, calculate:

a) (1.5 val.) The stiffness and mass matrices.

Note: if you can not calculate the stiffness matrix, from now onwards consider: $K = \begin{bmatrix} 22000 & -17500 \\ -17500 & 18000 \end{bmatrix}$ kN/m

b) (2.5 val.) The frequencies and vibration modes (use the characteristic equation)

Note: if you can not calculate these values from now onwards assume $f_1 = 0.7$ *Hz e* $f_2 = 3$ *Hz and* $\{v_1\}^T = \{0.9 ; 1\}$ $\{v_2\}^T = \{-1.1 ; 1\}$

Assume the structure is subjected to the horizontal component of the seismic action type 2, as defined in EC8 and in the portuguese National Annex. Assume the structure is of Importance Class II, it is located in zone 2.3 and that the foundation soil is type B. Consider a damping factor of 5% and a behavior factor (q factor) of 2.5.

c) (3.0 val.) Calculate the maximum base shear.

d) (2.0 val.) Calculate the maximum horizontal displacements of each floor.
e) (1.0 val.) Calculate the maximum horizontal reaction forces at the base of the columns.

Problem 2 (4.5/20.0)

Considerer the structure of Figure 1 but with na infinitely stiff inclined strut (EA = ∞)

a) (2.0 val.) Calculate the frequency of vibration.
b) (2.5 val.) Assume that a force $F(t) = 10.\cos(15t)$ kN is applied at 1^{st} floor level. Calculate the maximum horizontal displacement at that level.

Problem 3 (5.5/20.0)

a) (1.0 val.) Why does the portuguese National Annex considers two types of seismic actions? What are the differences between the two types of action and which type of buildings (high-rise or low-rise) is more sensitive to each?

b) (1.0 val.) Describe and explain what are the main benefits of close spacing of confinement reinforcement bars in critical regions (plastic hinge zones) of reinforced concrete columns.

c) (1.5 val.) In pile-column of bridges (in which the column is the extension of the pile upwards) what is the best location for plastic hinges (assume the column-deck connection is hinged and there are no foundation beams connecting the piles below ground level)? Describe the design procedure including a qualitative description (make a drawing) of the pile-column bending moment diagram obtained from the linear analysis and the design bending moment diagram after application of Capacity Design.

d) (1.0 val.) Explain the difference between magnitude and intensity of na earthquake. Describe the respective scales. Is it possible to relate the seismic action in a givemn location with one of these scales? Which one and why?
e) Why the maximum bending moments and shear forces of columns of dual frame-wall systemsdon´t take place at ground floor?

$|K - p^2 M| = 0 \quad D = F\,M \qquad D\,V = \frac{1}{p^2} V$

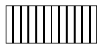
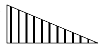
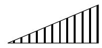
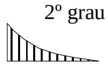
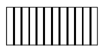
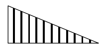
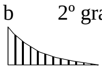
$V_i^T M V_j = \begin{cases} 0 & i \neq j \\ M_j & i = j \end{cases}$

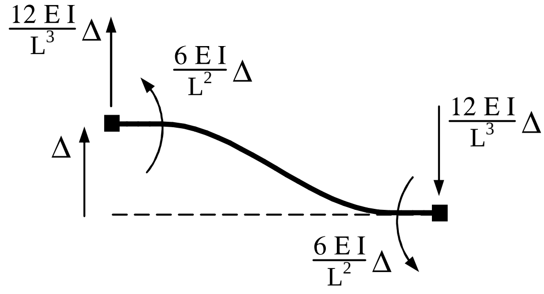
$V_i^T K V_j = \begin{cases} 0 & i \neq j \\ M_j\, p_j^2 & i = j \end{cases}$

$\phi_i = \frac{V_i}{\sqrt{V_i^T M V_i}} \qquad \overline{P}_{ix} = \phi_i^T M\, \mathbf{1}_x$

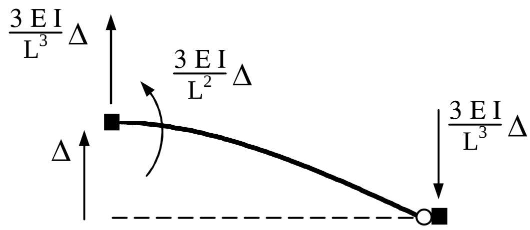
$\ddot{q}^{\,max}_{i\alpha} = \overline{P}_{i\alpha} S_{ai\alpha} \phi_i \qquad q^{\,max}_{i\alpha} = \overline{P}_{i\alpha} S_{di\alpha} \phi_I$

$S_{dj} = \frac{S_{aj}}{4\pi^2 f_j^2} \qquad r^{max} = \sqrt{\sum_j (r_j^{max})^2}$

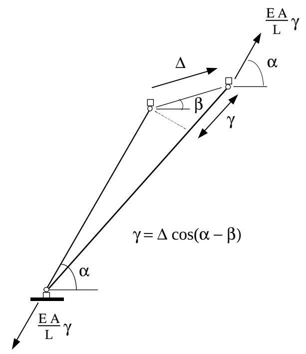
M / $\overline{M}$	 a, L	 a, L	 a, L	 a, 2º grau, L
 b, L	abL	$\frac{1}{2}$ abL	$\frac{1}{2}$	$\frac{1}{3}$ abL
 b, L		$\frac{1}{3}$ abL	$\frac{1}{6}$ abL	$\frac{1}{4}$
 b, 2º grau, L			$\frac{1}{12}$ abL	$\frac{1}{5}$ abL



$$p^2 = g\,\frac{\int_o^{\ell} m(x)\, q_G(x)\, dx + \sum_i M_i\, q_G(x_i)}{\int_o^{\ell} m(x)\, [q_G(x)]^2\, dx + \sum_j M_j\, [q_G(x_j)]^2}$$



$$p^2 = \frac{\int_o^{\ell} EI(x)\,[\psi''(x)]^2\, dx + \sum_i K_{\Delta i}\,[\psi(x_i)]^2 + \sum_j K_{\theta j}\,[\psi'(x_j)]^2}{\int_o^{\ell} m(x)\,[\psi(x)]^2\, dx + \sum_m M_m\,[\psi(x_m)]^2 + \sum_n I_{\theta n}\,[\psi'(x_n)]^2}$$



$\beta_1 = \frac{1}{\sqrt{(1 - \varpi^2)^2 + (2\,\zeta\,\varpi)^2}} \qquad \overline{\omega} = \frac{\omega}{p}$

$\beta_2 = \sqrt{1 + (2\zeta\varpi)^2}\ \text{x}\ \beta_1 \qquad \beta_3 = \beta_1\ \text{x}\ \varpi^2 \qquad p_d = p\sqrt{1 - \zeta^2}$

$$q(t) = e^{-\zeta pt}\,(q_0 \cos(p_d\, t)) + \frac{\dot{q}_0 + \zeta\, p\, q_0}{p_d}\, \text{sen}(p_d\, t) + \frac{e^{-\zeta pt}}{M\, p_d} \int_0^t e^{\zeta p \tau}\, Q(\tau)\, \text{sen}\,(p_d\,(t - \tau))\, d\tau$$

Design Spectra according to EC8 and the portuguese National Annex (2008)

$$0 \le T \le T_B : S_d(T) = a_g \cdot S \cdot \left[\frac{2}{3} + \frac{T}{T_B} \cdot \left(\eta \cdot 2{,}5/q - \frac{2}{3} \right) \right]$$

$$T_B \le T \le T_C : S_d(T) = a_g \cdot S \cdot \eta \cdot 2{,}5/q$$

$$T_C \le T \le T_D : S_d(T) = a_g \cdot S \cdot \eta \cdot 2{,}5 \left[\frac{T_C}{T} \right] / q$$

$$T_D \le T \le 4s : S_d(T) = a_g \cdot S \cdot \eta \cdot 2{,}5 \left[\frac{T_C T_D}{T^2} \right] / q$$

$$a_g = a_{gR} \times \gamma_I$$

$$\eta = \sqrt{\frac{10}{5+\xi}}$$

Tipo de solo	A	B	C	D	E
$V_{s,30}$(m/s)	>800	360-800	180-360	<180	aluviões
N_{SPT}(pancadas/30cm)		>50	15-50	<15	

Acção sísmica Tipo 1		Acção sísmica Tipo 2	
Zona Sísmica	a_{gR} (m/s^2)	Zona Sísmica	a_{gR} (m/s^2)
1.1	2,50	2.1	2,50
1.2	2,00	2.2	2,00
1.3	1,50	2.3	1,70
1.4	1,00	2.4	1,10
1.5	0,50	2.5	0,80

Zonas Sísmicas 2.1, 2.2 e 2.3

Tipo de Terreno	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,1	0,25	2,0
B	1,35	0,1	0,25	2,0
C	1,5	0,1	0,25	2,0
D	1,8	0,1	0,3	2,0
E	1,6	0,1	0,25	2,0

Coeficientes de Importância γ_I

Classe de Importância	Acção sísmica Tipo 1	Acção sísmica Tipo 2	
		Continente	Açores
I	0,6	0,8	0,8
II	1,0	1,0	1,0
III	1,6	1,3	1,2
IV	2,1	1,6	1,4