DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

I SEMESTER 2021-2022 MINOR EXAM Time limit: 2 hrs.
CVL 441 STRUCTURAL DESIGN Max Marks = 25
Date: 19.09.2021 Time: 13:40 -15:40 hours Course Coordinator: Dr. Alok Madan

Instructions: (a) This is an 'open' book examination. Make realistic assumptions where necessary.

(b) ***Online submission of answer scripts is permitted in .pdf format only on the dedicated web link nested under the heading "September 19, 2021" on the Moodle website for the Course CVL 441. <u>You must write the exact data assigned to you for any Question in your Answer Scripts before writing the Solution to the Question to avoid a penalty.</u> <u>Moodle web link for Online Submission of Answer Scripts will close at 16:00 hours.</u>***

1. (a) Mathematically, based on Newton's second law, derive the governing 2nd order ordinary differential equation for the dynamic displacement response u(t) of the floor mass m, where u(t) is instantaneous **relative** displacement of the floor mass with respect to the ground, in the single story plane frame model with a rigid floor and inextensible columns shown in Figure 1 subjected to a time-variant earthquake ground acceleration $\ddot{u}_g(t)$. (2 marks)

Hint: Total or absolute acceleration of floor mass in the horizontal direction with respect to (w.r.t.) an inertial frame of reference = the algebraic sum of the relative acceleration of the floor mass w.r.t ground + the earthquake ground acceleration

Using the governing 2nd order ordinary differential equation obtained above, derive the theoretical basis for physical interpretation of the following code-specified formulation for calculating the horizontal seismic base shear as per IS: 1893 (Part I) – 2016:- (1 mark)

$V_b = \frac{ZI}{2R}.\frac{S_a}{g}.W$, where Z = Seismic Zone factor, I = Importance factor of the building

S_a = Spectral Acceleration from response spectra, W = Seismic weight of building

(b) Based on theory of ordinary differential equations, prove that the dynamic response of the single degree of freedom (s.d.o.f) mass-spring-dashpot oscillator shown in Figure 2 (analogy for the single story plane frame model with a rigid floor and inextensible columns shown in Figure 1) subjected to a harmonic (sinusoidal) input forcing function $\tilde{P}(t) = p_o \sin \tilde{\omega} t$ can be described by following relationship under steady state conditions: $u(t) = \rho_0 \sin(\tilde{\omega} t - \theta)$, in which

$\rho_0 = amplitude\ of\ response = \frac{p_0}{k}.\left[(1-\beta^2)^2 + (2\xi\beta)^2\right]^{-1/2}$

Phase lag angle $\theta = \tan^{-1}\left[\frac{2\xi\beta}{1-\beta^2}\right]$, where $\beta = \frac{\tilde{\omega}}{\omega}$ is the frequency ratio of the input forcing function

ξ = damping ratio of system = $\frac{c}{2.m.\omega}$, where m = mass, c = damping constant for natural damping

k = spring constant, ω = natural circular frequency of free vibrations of s.d.o.f system. (2 marks)

2. A 'N' story building with Functional Use 'U' or Occupancy is to be constructed in a City 'C' in India on Type 'S' soil as a brick infilled Reinforced Concrete Frame structure with floor slabs that act as rigid diaphragms (rigid in their own horizontal plane) and a raft foundation. The RC building frame has equal story heights of 'z' m with **plan and elevation shown in Figure 3**. The figure also illustrates the location of equivalent 2-D plane frames for simplified 2-D analysis. **Data on numerical or linguistic values for data variables 'N', 'U', 'C', 'S', 'z', 'a', 'x', 'b'** and **'y' specifically assigned to you is presented in Table 1 on Pages 4 and 5 by referring to your Entry number**. The remaining data for structural design is as follows:

Column sizes: 0.8 x 0.8 m Beam sizes: 0.3 x 0.7 m Slab thickness = 0.130 m

Dead load due to Flooring and Finishing: 2.5 kN/ m^2
Dead load due to Roofing (terracing, tiling and water proofing): 4.5 kN / m^2
Live load on Floors: as per IS:875 (Part II)-1987/2015 Live load on roof: as per IS: 875 (II)
Unit weight of concrete = 25 kN / m^3 Unit weight of brick masonry = 20 kN / m^3

(i) Calculate the design horizontal seismic force coefficients A_{hx} and A_{hy} for the Reinforced Concrete (RC) Building Frame (with brick infills) in the two orthogonal principal 'x' and 'y' directions of the building, respectively, along the horizontal 'x' and 'y' axes shown in the plan view of the RC frame in Figure 3 as per the Indian seismic design code IS: 1893 (Part I) – 2016. **Use the numerical data specifically assigned to you**. (3 marks)

(ii) Assuming that the dead and live loads are distributed over the plan area, obtain the design lateral earthquake forces or horizontal seismic base shears V_Bx and V_By for the **entire building** in the x and *y* directions, respectively, using **Response Spectrum Method** as per IS: 1893 (I) - 2016. **Use numerical data specifically assigned to you**. (3 marks)

(iii) Calculate the design horizontal story earthquake forces in kN acting on various floors of the 3-D Space Frame model of the building in the *x* direction as well as the *y* direction as per IS: 1893 (Part I) - 2016. Show the calculation of design story earthquake forces for each floor in a tabular format for each direction *x* and *y* in a different table. (2 marks)

(iv) Calculate the design story earthquake forces for the exterior 2-D plane frame A-A in the *y-z* plane spanning in *y* direction for simplified 2-D analysis assuming that the two exterior 2-D plane frames in the *y-z* plane each have twice the lateral stiffness of that of any interior 2-D plane frame in the *y-z* plane and the story earthquake forces shared by the plane frames are proportional to their lateral stiffness. Show the plane frame model in elevation using a neat sketch with computed values of design story earthquake forces. (2 marks)

(v) Calculate the design dead load and design live load as uniformly distributed loads (u.d.l.) of uniform intensity 'q_{DL}' and 'q_{LL}', respectively, in kN/m for a typical floor and roof of the equivalent 2-D plane frame 1-1 in the *x-z* plane spanning in *x* direction for simplified 2-D analysis of the plane frame model. Show the design dead loading and live loading as u.d.l on the elevation of the plane frame model along with the computed values of 'q_{DL}' and 'q_{LL}' in kN/m. **Use the numerical data specifically assigned to you**. (3 marks)

3. A single story reinforced concrete (RC) **building is L shaped in plan as shown in Figure 4** and consists of a RC flat slab constructed monolithically with RC columns that are all identical with their **lateral stiffness as K_x in x direction and their lateral stiffness K_y in y direction**.

(a) Mathematically, derive the analytical formulations for the coordinates of center of rigidity (C.R.) of the building (x_R, y_R) in terms of the lateral stiffness of the columns i.e. K_{xc} in *x* direction and K_{yc} in *y* direction and column coordinates x_c and y_c of column 'c', in general.

(b) Compute the numerical values of the coordinates of the center of rigidity (C.R.) of the building (x_R, y_R) for the given RC building shown in Figure 4 **using the numerical data specifically assigned to you in Table 1 by referring to your Entry number in the Table 1 displayed on Pages 4 and 5**. **Assume that K_x=K_y=K for all the columns.**

(c) Locate the **Center of Mass C.M. (x_M, y_M)** of the single floor **using the numerical data specifically assigned to you in Table 1 displayed on Pages 4 and 5**. Determine the numerical values of horizontal earthquake forces shared by **(i) column A** and **(ii) column C** due to a **Design Earthquake Load = EL** (in kN) acting at floor level of the single-story building **at an angle of α º to the x axis. Assume that K_x= K_y= K for all columns and,**

- **Floor slab acts as a rigid diaphragm**, the columns are inextensible (axially rigid) and the **Earthquake Load EL acts through center of mass (C.M.) of floor located at (x_M, y_M).**
- The **Dead and Live loads are uniformly distributed over the floor area.** (7 marks)

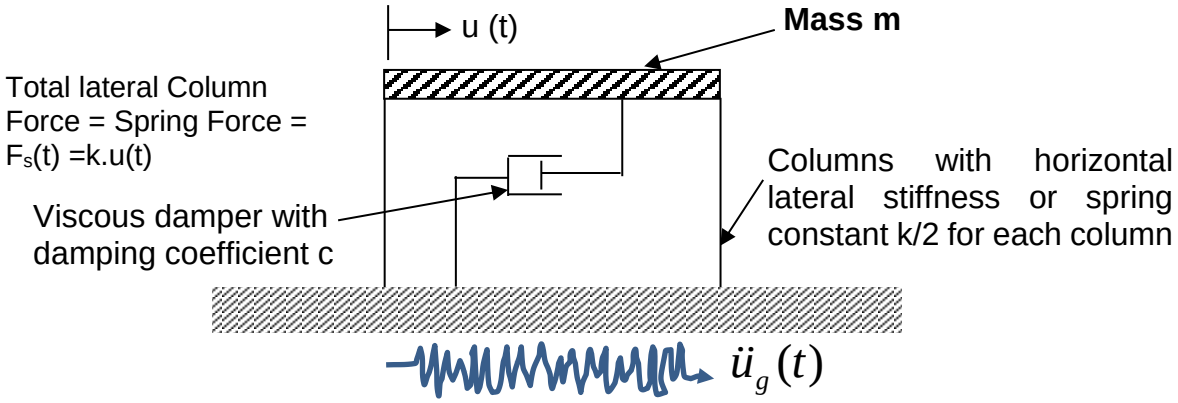


Figure 1: Single Degree-of-Freedom (SDOF) Single Story Frame Model

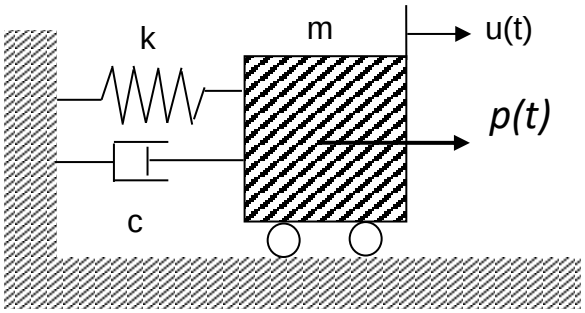
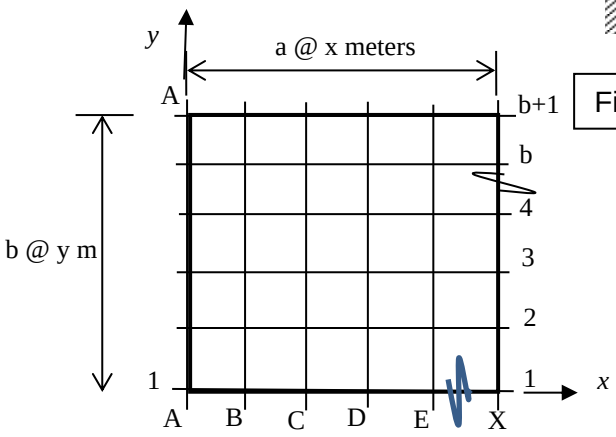
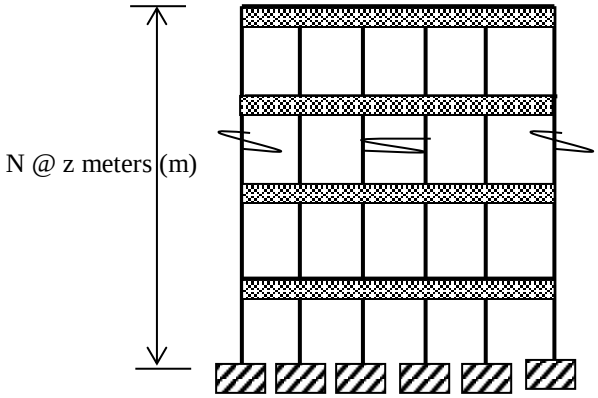


Figure 2: SDOF Mass-Spring-Dashpot oscillator



PLAN



ELEVATION

Figure 3

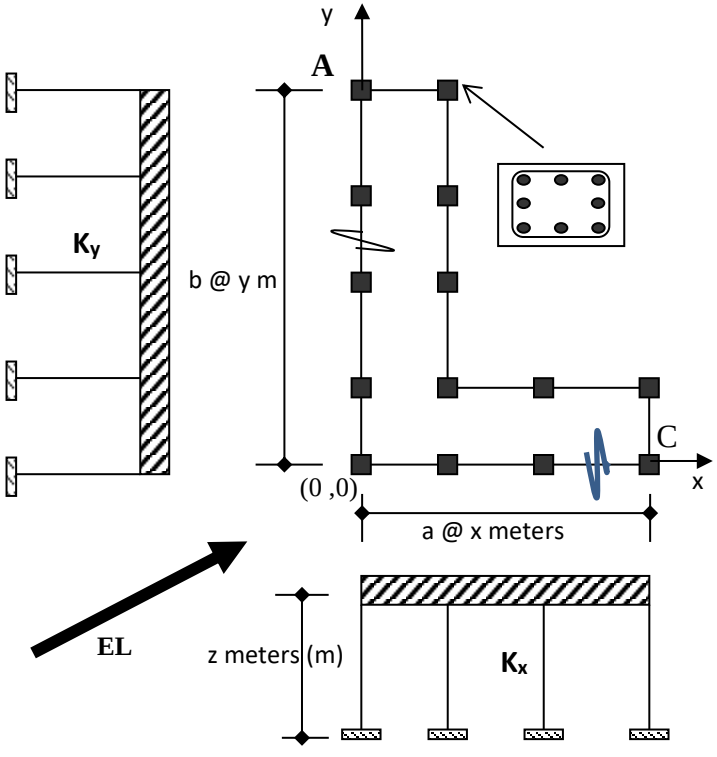


Figure 4

Table 1: Data for Questions 2 and 3 with Different Values of the Numerical and Linguistic Variables assigned specifically to each student

Note: No credit of marks (zero marks) will be given if you do not use the data specifically assigned to you that is specified in the row of your Entry Number in the following Table 1

Entry Number ***(Marks will be awarded only for using own data)***	**Data relevant and applicable to Question 2 only**				**Data relevant and common to Questions 2 and 3 both**					**Data relevant to Question 3 only**	
	U (Use)	C (City)	S (Soil type)	N	z (m)	a	x (m)	b	y (m)	EL (kN)	Angle α^o
2015CE10316	Group Housing	Amritsar	Hard	11	4	6	4	6	5	500	60
2016CE10256	Group Housing	Amritsar	Soft	9	3.5	5	4	5	6	300	30
2016CE10279	Group Housing	Amritsar	Hard	11	3	6	5	5	5	400	60
2016CE10287	Group Housing	Amritsar	Medium	7	4	6	4	5	6	500	60
2017CE10109	Group Housing	Amritsar	Soft	8	3	5	7	6	5	200	30
2018CE10071	Group Housing	Amritsar	Hard	6	4.5	5	6	6	4	100	60
2018CE10072	Group Housing	Delhi	Medium	8	4	6	5	6	6	400	60
2018CE10077	Group Housing	Delhi	Soft	9	3	6	6	6	5	500	60
2018CE10082	Group Housing	Shillong	Hard	10	4.5	5	6	6	5	300	30
2018CE10083	Group Housing	Shillong	Medium	11	3.5	5	7	6	7	200	30
2018CE10085	Business Office	Imphal	Soft	7	4	6	7	5	7	100	60
2018CE10091	Business Office	Imphal	Medium	8	3	6	5	6	7	500	60
2018CE10092	Business Office	Imphal	Soft	6	4.5	6	6	6	7	300	30
2018CE10099	Business Office	Imphal	Hard	9	3.5	5	7	5	6	400	60
2018CE10102	Business Office	Imphal	Medium	11	4	6	6	5	7	100	60
2018CE10106	Business Office	Patna	Soft	9	3.5	5	6	5	7	300	30
2018CE10109	Business Office	Patna	Medium	8	4	6	6	6	7	200	30
2018CE10111	Business Office	Patna	Soft	9	3	6	7	6	6	100	60
2018CE10112	Business Office	Patna	Hard	10	4.5	5	6	5	7	300	30
2018CE10113	Business Office	Patna	Soft	7	4.5	6	6	5	6	400	60
2018CE10115	Assembly Hall	Itanagar	Hard	11	3.5	5	7	6	7	500	60
2018CE10116	Assembly Hall	Itanagar	Soft	7	4	5	7	6	5	200	30
2018CE10117	Assembly Hall	Itanagar	Hard	8	3	5	7	6	7	100	60
2018CE10121	Assembly Hall	Itanagar	Medium	6	4.5	6	7	5	7	300	30
2018CE10124	Assembly Hall	Itanagar	Soft	11	4.5	6	5	6	7	300	30
2018CE10132	Assembly Hall	Ambala	Hard	9	3.5	6	6	6	7	200	30
2018CE10140	Assembly Hall	Ambala	Hard	10	4.5	5	4	6	5	100	60
2018CE10142	Assembly Hall	Ambala	Medium	11	3.5	6	5	6	4	200	30
2018CE10146	Assembly Hall	Ambala	Soft	7	4	6	4	6	5	100	60
2018CE10149	Assembly Hall	Ambala	Medium	8	4	5	6	6	6	300	30
2018CE10150	Telephone Exchange	Aizwal	Soft	9	3	5	7	6	5	400	60
2018CE10151	Telephone Exchange	Aizwal	Soft	7	4	6	5	6	7	400	60
2018CE10152	Telephone Exchange	Aizwal	Hard	8	3	6	7	6	5	100	60
2018CE10153	Telephone Exchange	Aizwal	Medium	6	4.5	5	7	6	7	300	30
2018CE10154	Telephone Exchange	Aizwal	Medium	10	3.5	6	7	6	5	200	30
2018CE10157	Telephone Exchange	Delhi	Soft	9	4	5	6	6	6	500	60
2018CE10158	Telephone Exchange	Delhi	Soft	7	3	6	5	6	4	200	30
2018CE10159	Telephone Exchange	Dehradun	Medium	8	3.5	6	4	6	5	100	60
2018CE10160	Telephone Exchange	Dehradun	Soft	6	4	6	3	5	5	300	30
2018CE10162	Telephone Exchange	Dehradun	Hard	9	3.5	5	3	5	4	400	60

Table 1 (Contd.): Data for Questions 2 and 3 with Different Values of the Numerical and Linguistic Variables assigned specifically to each student

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	U (Use)	C (City)	S (Soil type)	N	z (m)	a	x (m)	b	y (m)	EL (kN)	Angle α^o
2018CE10164	Power Company	Srinagar	Hard	11	3	5	5	6	3	500	60
2018CE10169	Power Company	Srinagar	Medium	7	4	5	6	5	4	200	60
2018CE10170	Power Company	Srinagar	Soft	8	3	6	5	5	5	300	30
2018CE10171	Power Company	Srinagar	Hard	6	3.5	5	4	6	4	300	30
2018CE10172	Power Company	Srinagar	Medium	9	3.5	6	5	5	4	200	60
2018CE10175	Power Company	Srinagar	Soft	7	4	6	4	6	5	100	30