DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

I SEMESTER 2020-2021 MINOR EXAM Time limit: 2 hrs.
CVL 441 STRUCTURAL DESIGN Max Marks = 25
Date: 08.11.2020 Time: 12:40 -14:40 hours Course Coordinator: Dr. Alok Madan

Instructions: (a) This is an 'open' book examination. Make realistic assumptions where necessary.
(b) Refer to Lecture Notes with Solved Examples published on Moodle website for the course till date. Limited content of IS codes of Structural Design Practice are uploaded as Reference Material on the Moodle website. ***Moodle web link for Online submission of Answer Scripts in .pdf format will close at 15:00 hours.***

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 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 provided in IS: 1893 – 2016:- (2 marks)

   $V_b = \frac{ZI}{2R}.\frac{S_a}{g}.W$, 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:

   $u(t) = \rho_0 \sin(\tilde{\omega} t - \theta)$, where $\rho_0 = amplitude\ of\ response = \frac{p_0}{k}.\left[(1-\beta^2)^2 + (2\xi\beta)^2\right]^{-1/2}$

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

   ξ = damping ratio of the system = $\frac{c}{2.m.\omega}$ (a measure of natural damping of system)

   m being the mass, *c* the damping constant, and *k* = spring constant, ω = natural circular frequency of free vibrations of the 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 masonry infilled reinforced concrete framed structure with floor slabs that act as rigid diaphragms (rigid in the horizontal plane) and a raft foundation. The building has equal story heights of 'z' m with a **plan and elevation shown in Figure 3**. The figure also illustrates the location of the equivalent 2-D (planar) frames or idealized plane frames. The numerical or linguistic values for data variables 'N', 'U', 'C', 'S' and 'z' and

Data specifically assigned to you is presented by referring to your Entry number in the Table 1 displayed on Pages 4 and 5. 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 = 0.120 m
Dead load due to Flooring and Finishing: 2.5 kN/ m^2
Dead load due to Roofing (terracing, tiling and finishing): 4.0 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

Calculate the design horizontal seismic coefficients in the two orthogonal principal directions i.e. the 'x' direction (denoted as A_{hx}) and the 'y' direction (denoted as A_{hy}) as well as the design vertical seismic coefficient (A_v) for the building using the response spectrum method as per IS: 1893 (Part I) – 2016 **using the numerical data specifically assigned to you**. (4 marks)

Assuming that the dead and live loads are uniformly distributed over the plan area, obtain the design horizontal seismic base shear V_BX in the *x* direction and the design horizontal seismic base shear V_By in the *y* direction for the building using the response spectrum method as per IS: 1893 (Part I) - 2016, if the building has a masonry infilled reinforced concrete frame structure (with brick infills). **Use numerical data specifically assigned to you**. (2 marks)

Calculate the story earthquake forces acting on various floors of the 3-D building frame in the *x* direction and *y* direction in accordance with the Indian seismic design code IS: 1893 (Part I) - 2016. Show the calculation of the story earthquake forces for each floor in a tabular format in a different table for each direction *x* and *y*. (4 marks)

Estimate the lateral earthquake forces on planar Frame 1-1 (idealized 2-D or plane frame in *x*-*z* plane for equivalent 2-D analysis) due to earthquake loading calculated assuming that all the plane frames spanning in the *x* direction have equal lateral stiffness are identical and the lateral story forces shared by the frames are proportional to their lateral stiffness. Show the lateral earthquake forces acting on idealized plane frame 1-1 with the computed values. (2 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 Page 4**. **Assume that K_x=K_y=K for all the columns.**
(b) 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 the lateral (horizontal) loads shared by (i) column A and (ii) column C under an **Earthquake Load of magnitude EL** acting at the floor level of the single-story building **at an angle of θ ° to the x axis. Assume that K_x=K_y=K for all columns.**

***Apply the following idealizations as simplifying assumptions that are also realistic*:**

- **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 slab area.** (7 marks)

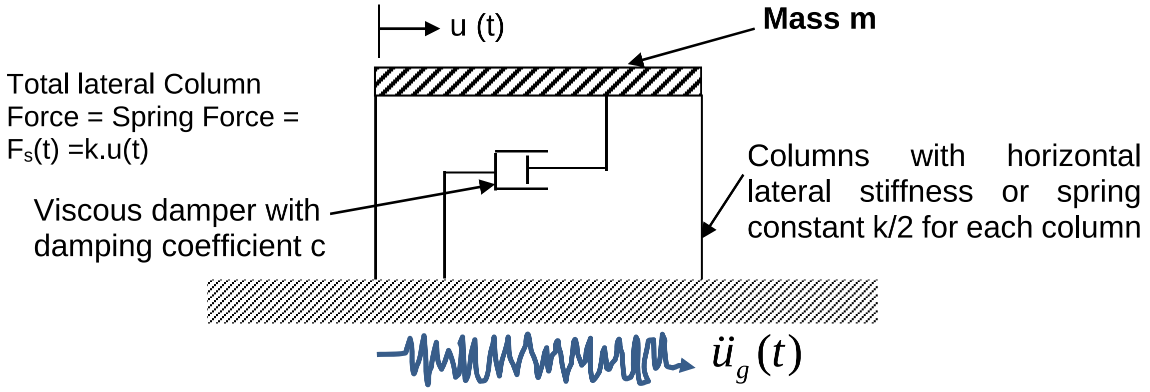

Figure 1: Single Degree-of-Freedom (SDOF) Single Story Frame Model

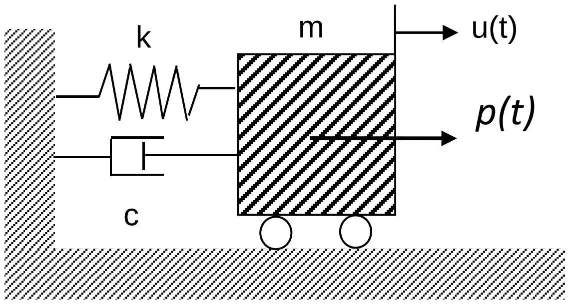

Figure 2: SDOF Mass-Spring-Dashpot oscillator

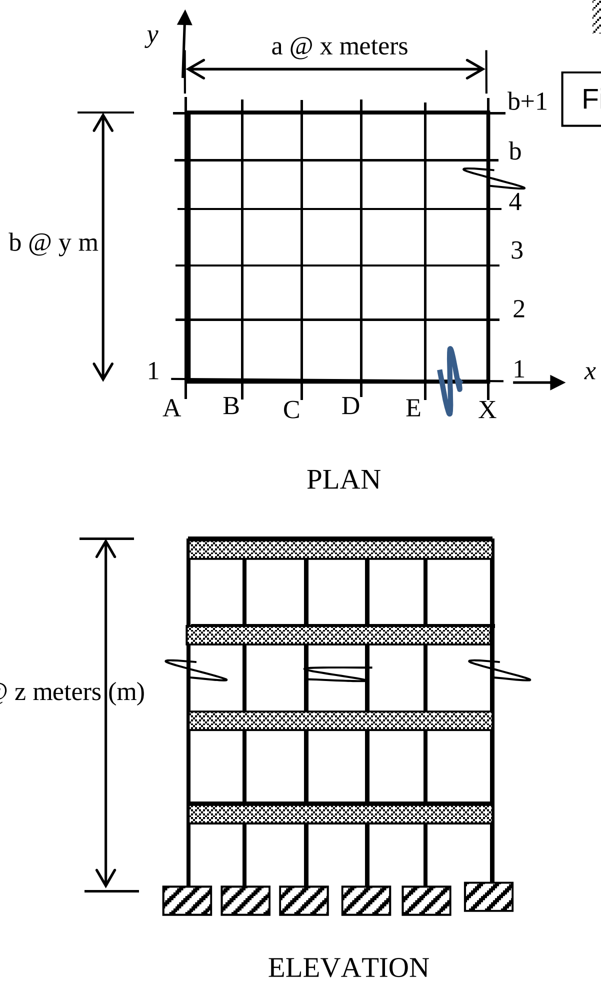

Figure 3

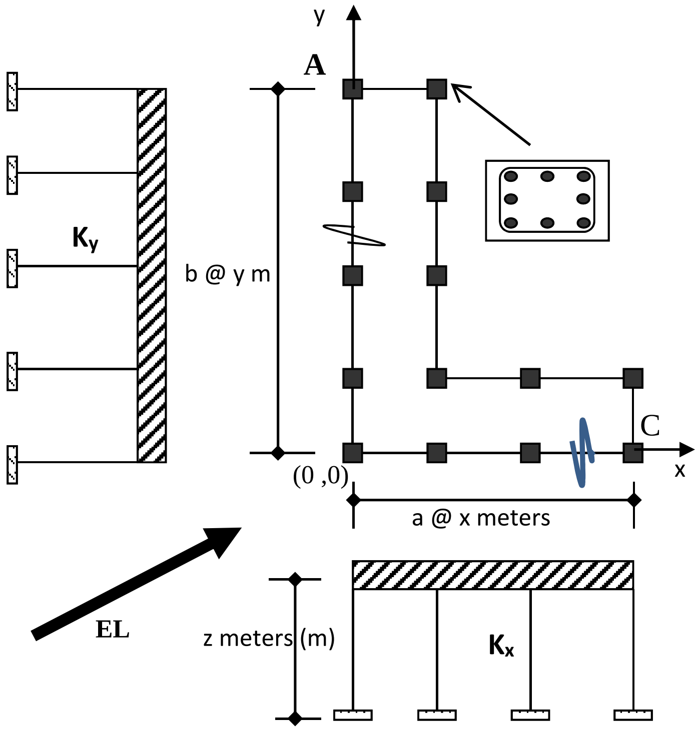

Figure 4

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 θ^o
2017CE10071	Residential	Delhi	Soft	7	4	6	4	6	5	200	30
2017CE10072	Residential	Delhi	Hard	8	3	6	5	6	4	100	60
2017CE10073	Residential	Delhi	Medium	6	4.5	5	4	6	5	300	30
2017CE10074	Residential	Delhi	Soft	9	3.5	6	5	6	4	400	60
2017CE10076	Residential	Delhi	Hard	11	4	6	4	6	5	500	60
2017CE10079	Residential	Shillong	Soft	9	3.5	5	4	5	6	300	30
2017CE10081	Residential	Shillong	Hard	11	3	6	5	5	5	400	60
2017CE10082	Residential	Shillong	Medium	7	4	6	4	5	6	500	60
2017CE10083	Residential	Shillong	Soft	8	3	5	7	6	5	200	30
2017CE10088	Residential	Shillong	Hard	6	4.5	5	6	6	4	100	60
2017CE10091	Office	Amritsar	Medium	8	4	6	5	6	6	400	60
2017CE10094	Office	Amritsar	Soft	9	3	6	6	6	5	500	60
2017CE10095	Office	Amritsar	Hard	10	4.5	5	6	6	5	300	30
2017CE10096	Office	Amritsar	Medium	11	3.5	5	7	6	7	200	30
2017CE10097	Office	Amritsar	Soft	7	4	6	7	5	7	100	60
2017CE10098	Office	Imphal	Medium	8	3	6	5	6	7	500	60
2017CE10099	Office	Imphal	Soft	6	4.5	6	6	6	7	300	30
2017CE10101	Office	Imphal	Hard	9	3.5	5	7	5	6	400	60
2017CE10102	Office	Imphal	Medium	11	4	6	6	5	7	100	60
2017CE10103	Office	Imphal	Soft	9	3.5	5	6	5	7	300	30
2017CE10104	Hospital	Patna	Medium	8	4	6	6	6	7	200	30
2017CE10105	Hospital	Patna	Soft	9	3	6	7	6	6	100	60
2017CE10108	Hospital	Patna	Hard	10	4.5	5	6	5	7	300	30
2017CE10111	Hospital	Patna	Soft	7	4.5	6	6	5	6	400	60
2017CE10112	Hospital	Patna	Hard	11	3.5	5	7	6	7	500	60
2017CE10116	Hospital	Itanagar	Soft	7	4	5	7	6	5	200	30
2017CE10117	Hospital	Itanagar	Hard	8	3	5	7	6	7	100	60
2017CE10124	Hospital	Itanagar	Medium	6	4.5	6	7	5	7	300	30
2017CE10125	Hospital	Itanagar	Soft	11	4.5	6	5	6	7	300	30
2017CE10129	Hospital	Itanagar	Hard	9	3.5	6	6	6	7	200	30
2017CE10130	School	Ambala	Hard	10	4.5	5	4	6	5	100	60
2017CE10131	School	Ambala	Medium	11	3.5	6	5	6	4	200	30
2017CE10132	School	Ambala	Soft	7	4	6	4	6	5	100	60
2017CE10134	School	Ambala	Medium	8	4	5	6	6	6	300	30
2017CE10135	School	Ambala	Soft	9	3	5	7	6	5	400	60
2017CE10136	School	Aizwal	Soft	7	4	6	5	6	7	400	60
2017CE10141	School	Aizwal	Hard	8	3	6	7	6	5	100	60
2017CE10143	School	Aizwal	Medium	6	4.5	5	7	6	7	300	30
2017CE10148	School	Aizwal	Medium	10	3.5	6	7	6	5	200	30
2017CE10157	School	Aizwal	Soft	9	4	5	6	6	6	500	60

Table 1 (Contd.): 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 θ^o
2017CE10163	Hostel	Dehradun	Soft	7	3	6	5	6	4	200	30
2017CE10166	Hostel	Dehradun	Medium	8	3.5	6	4	6	5	100	60
2017CE10167	Hostel	Dehradun	Soft	6	4	6	3	5	5	300	30
2017CE10168	Hostel	Dehradun	Soft	9	3.5	5	3	5	4	400	60
2017CE10171	Hostel	Dehradun	Hard	11	3	5	5	6	3	500	60
2017CE10172	Hostel	Srinagar	Medium	7	4	5	6	5	4	200	60
2017CE10173	Hostel	Srinagar	Soft	8	3	6	5	5	5	300	30
2017CE10174	Hostel	Srinagar	Hard	6	3.5	5	4	6	4	300	30
2017CE10175	Hostel	Srinagar	Medium	9	3.5	6	5	5	4	200	60
2016CE10267	Hostel	Srinagar	Soft	10	4.5	5	5	6	7	250	30
2014CE10360	Hostel	Srinagar	Soft	7	4	6	4	6	5	100	30