This project uses a vibration-sensitive laboratory building designed for UC Merced based on ASCE 7-05. There are two buildings, we will only look at building A. Per the Design Criteria, the building has Seismic Occupancy Category III, with I_e = 1.25. The building has moment frames in the longitudinal direction and BRB frames in the transverse direction. The building has a basement and a connecting bridge, both of which we will ignore. The design details and basic plans are available in bCourses. Also provided are more detailed plans which you may or may not choose to use. There will be three due dates with incremental deliverables. Your group if free to use whichever software and details you like/think will give you the best (?) answer. During your analysis, please keep a detailed record of the modeling assumptions.

For these analyses we will ignore accidental torsional, which must be considered in practice.

PART I – due April 2

Problem 1 – Preliminary information

(a) For the site of the building, plot the ASCE 7-05 (not ASCE 7-16!) seismic response spectra at the MCE and design levels. Hint, see page 17 of the Design Criteria. Plot the corresponding displacement response spectrum.

(b) Select appropriate values of R, C_d, and Ω_o for the two orthogonal framing directions, that is, the moment frame and the buckling-restrained braced frame (BRBF) directions.

(c) Are there any ASCE 7 provisions for how to treat a building when it has two different framing systems in its two principal directions?

(d) Does the building have any vertical or horizontal irregularities? You may answer this question by inspection (no need for analysis).

(e) Assuming the answer to (a) is ***No***, what ASCE 7-16 analytical procedures are permitted for a new building? What ASCE 41-13 analytical procedures are permitted for an existing building?

(f) For this building what type of analysis might you suggest? For some nice guidance see ASCE 41 section 7.3.

Problem 2 – ELF procedure

(a) Create a linear model of the building in the software of your choice. From your model, calculate the mode shapes and fundamental periods T_{calc} in both directions. Model the diaphragm as rigid in-plane. It is acceptable to model the beams and columns as projecting to the joint centerlines – the added flexibility will approximate the flexibility associated with the beam-column joint panel zone. Give a *brief* description of your model.

(b) Calculate the approximate periods in both the moment frame and braced frame directions T_a for the building considering ASCE 7-16 Equation 12.8-7 (Section 12.8.2.1). Note that

Equation 12.8-8 may also be applicable. Calculate this latter value and note how it is applicable to the building (for example, in one direction versus the other) but don't use this period.

(c) ASCE 7-16 puts a limit (Section 12.8.2) on the maximum period C_uT_a you can use for determination of ELF design forces. Calculate this value considering the approximate periods from part (a).

(d) Compare T_{calc}, C_uT_a, and T_a for both systems by listing them in a table. Based on these periods, what is the maximum value of period that is permitted to be used to determine the design lateral forces for the ELF procedure for each system?

(e) Based on the answer to (d) calculate the minimum required seismic base shear V for each system type.

(f) Show how the design lateral forces from (e) are distributed over height of the frames.

(g) What is the maximum allowable story drift ratio (drift divided by story height) in the frames? See section 12.12.

(h) If the building is classified as being torsionally regular, is it necessary to apply accidental torsion (± 5% eccentricity) in determining the lateral drifts, or is drift determined at the center of mass?

(i) Using your computer model of the building, apply the design lateral forces one direction at a time. What are the resulting story drifts? See ASCE 7-17 equation 12.8-15. Are the drifts within allowable values? For this purpose, you must decide which lateral forces to use, that is, whether based on the minimum base shear or the response spectrum, and whether based on T_{calc}, C_uT_a, or T_a.

Problem 3 – Modal response spectrum analysis

(a) Using this method, is it necessary to have a nonlinear model for the building?

(b) From ASCE 7-16 Sect. 12.9.1.1, how many modes are necessary for the analysis in each direction?

(c) Use modal analysis following the instructions of Sect. 12.9.1.2 and 12.9.1.3 to find the base shear V_t in each of the building directions. The code says that V_t must not be less than V (section 12.9.1.4.1). Do the forces (and corresponding displacements) need to be scaled up?

(d) Find the resulting story drift demands. Are they within allowable values?

Problem 4 – Comparison of results

Fill out the information below and discuss why differences might arise.

Table 1: Drift results

	Floor 1	Floor 2	Floor 3	Floor 4	
ELF					
Modal Analysis					

Table 2: Modeling information

	Analysis software	T_{calc} or $T_{effective}$	Base shear V
ELF			
Modal Analysis			

PART II – due April 16

Problem 1: Nonlinear static procedure

Although not specified in ASCE 7, the nonlinear static procedure is outlined in ASCE 41 (Section 7.4.3) for existing buildings.

(a) To conduct a pushover analysis, is it necessary to have a nonlinear model for the building?

(b) Give a brief description of nonlinear model (hysteretic models? Fiber section? Location of hinges? Axial/shear interaction?). There are many ways to model, use your best judgement. Remember there is a balance between detail and efficiency, and also more detailed does not necessarily equal more accurate.

(c) What are the loading distributions for each direction if you want a 1^{st} mode pushover curve (give the external force at each floor relative to the base shear *V*).

(d) Conduct the pushover analyses, plotting the base shear versus the displacement of the roof of the building for each direction.

(e) On top of the pushover curves from (c), draw the idealized pushover curves (see ASCE 41-13 Fig. 7-3). What are the effective periods of the structure in each direction?

(f) From your linear model from Problem 3, what are the value for $\Gamma\Phi_{roof}$ for the 1^{st} modes? How well does it match the value for C_0 given in Table 7-5 of ACE 41?

(g) Using Eq 7-28, what are the story drift demands for each floor in each direction?

Problem 2: Linear time history analysis

For Problems 2 a suite of 11 ground motions have been uploaded to bCourses along with an excel file giving the appropriate factors to scale them to a design level earthquake ($2/3MCE_R$) by which they must be multiplied for the analysis. You do not need to use the vertical (UP) component of the ground motions.

(a) To conduct linear time history analysis, is it necessary to have a nonlinear model for the building? Is it necessary to have a three dimensional model? Why?

(b) Using your linear building model from Part I, run the building under the eleven ground motions provided in bCourses.

(c) For ground motion, list in a table what is the inelastic design base shear in each direction using ASCE 7 eq. 12.9-1.

(d) Ignoring torsion, should the drift demands be modified from the linear time history outputs in the same way as the base shears were? In the table from (c) add the drift demands for each floor?

(e) To the table add the average base shear and drift ratios (of each floor and each direction) over the 11 motions.

(f) Can the results of the floor level absolute accelerations found from the analysis be used to estimate demands on nonstructural content? Why or why not?

Problem 3: Nonlinear time history analysis

For NLTH analysis, ground motions should be scaled to the MCE_R. A suite of 11 ground motions have been uploaded to bCourses along with an excel file giving the appropriate factors to scale them to a MCE_R by which they must be multiplied for the analysis. You do not need to use the vertical (UP) component of the ground motions.

(a) Give a brief description your nonlinear model (hysteretic models? Fiber section? Location of hinges? Axial/shear interaction?).

(b) Run the building under the eleven ground motions provided in bCourses.

(c) What is the maximum allowed story drift using this analysis (see ASCE 7 section 16.4.1.2). Why might it be different that the other analysis methods?

(d) What are the story drift demands for each floor in each direction (give for each ground motion and the average over all motions)?

(e) What are the absolute acceleration demands for each floor in each direction (give for each ground motion and the average over all motions)?

Problem 4: Comparison of results

How do your drift demand predictions compare between the all of the analysis methods? Fill out the following table and discuss why differences might arise.

Table 1: Drift results

	Floor 1	Floor 2	Floor 3	Floor 4
DBE				
ELF				
Modal analysis				
Nonlinear pushover				
Linear TH				
MCE_R				
NLTH				

Problem 5: FEMA P-58 loss analysis

There are a variety of software that can do computations based on the FEMA P-58 methodology (PACT – free but not very user friendly, SP3 – very user friendly but relatively expensive). We will use SimCenter's PBE tool (free and moderately easy to use).

- Under GI (General Information) input the basic building information.
- Ignore SIM (Simulation), EVT (event), and FEM – these can be used to run analyses *within* your P-58 analysis rather than separately as we are.
- Ignore UQ (Uncertainty Quantification) – this can be used to add uncertainty into your models if you are using SIM, EVT, and FEM.
- Under DL (Damage and Loss) – choose FEMA P58
  - General
    - Response description
      - Input the EDP data from your <u>nonlinear time history analyses</u>.
      - For EDP distribution keep "lognormal"
      - For basis keep "all results"
      - Keep a large number (>1000) of realizations
    - Additional uncertainty: discussion can be found in FEMA P-58-1 Section 5-10.
      - Use Table 5-3 for additional ground motions uncertainty.
      - Use Eq 5-1 with Tables 5-1 and 5-2 to determine the additional model uncertainty. Note that FEMA P-58 suggests that the model uncertainty from Eq 5-1 be limited to 0.5. Remember to state all your assumptions in your model description.
    - Detection limits: not all model results are to be trusted. If your software or modeling assumptions make predictions beyond a certain limit suspect (for example if you have large lateral displacements but are not including PDelta loading which might cause stability problems) then you should include them here. for this exercise, you can leave both blank.
    - Damage model
      - Irreparable residual drift: keep the default values
      - Collapse probability: keep "estimated", leave prescribed value empty, and keep basis as "sampled EDP"
      - For collapse limits: set drift to 0.05 (5% drift) and leave acceleration blank
    - Loss model
      - Replacement cost: use an estimate of $170 per square foot
      - Assume a 2 year replacement time.
      - The occupancy type is research laboratories
      - From FEMA P-58-1 Table 3-1 the peak occupancy should be 3 people per 10000 sq ft.
  - Input all components expected in the building. Estimates of the building content can be found from the "normative quantity estimation tool" found here: <u>https://femap58.atcouncil.org/supporting-materials</u>
  - Ignore Collapse Modes and Dependencies

(a) Provide a list of all inputs (EDPs, uncertainties, content, etc.).

(b) What are the expected and +1 standard deviation costs and downtime under the design event?

Problem 6: Describe in a short paragraph what topic your group will explore for Part III (see below).

PART III – due May 5

In this portion of the project, your group should explore something you are interested in. Use your results from Parts I and II as a starting point. You should spend roughly the same time on Part III as you spent on Part II. Ideas include (<u>but are certainly not limited to</u>!):

- Redesign and evaluate the effect (including performance, damage, and downtime) of:
    - using a different lateral load resisting system.
    - designing with a higher importance factor. Does the resulting performance meet what is expected from the higher factor?
    - isolating the structure or using damping.
- How does modeling of the foundation and soil structure interaction affect the performance?
- Include uncertainty quantification in your performance and loss analysis. What variables have the largest contribution to the variation in performance?
- Explore the difference between HAZUS and FEMA P-58 loss analyses. Describe the background for HAZUS, variations in assumptions and information needed, and difference in performance prediction outputs.