CEE 227 -- Earthquake Resistant Design

In Problems 8 and 10, we developed a set of linear elastic response spectrum for use in design at our building site. One was based on an earthquake with a 50% probability of exceedence in 50 years (Problem 10) and the other corresponded to an earthquake with a 2% in 50 years probability of exceedence (Problem 8). The first of these spectra will be used subsequently in our building design considering a requirement to maintain serviceability following a frequent earthquake (continued occupancy), and the latter spectrum is intended to evaluate the collapse prevention limit state. However, the second response spectrum must be interpreted, since the structure will not be expected to remain elastic under such a rare event. Note however, that the structure must eventually satisfy some requirements associated with both spectra.

We will not see how higher modes affect nonlinear response until later in the course, but as we saw in earlier assignments, this structure responds primarily in its first mode. For the moment and, for this structure especially, it will suffice to consider only the first mode.

It is also worth noting in passing that the structure's dynamic characteristics being used here are still trial values based on member sizes resulting from the 1994 UBC design, and will thus change when we revise the design of the structure to reflect the new design spectra and criteria we are using. Thus, the overall design process is iterative and, consequently, a high degree of accuracy is not required at this stage. Nonetheless, these modal values provide a good starting point to assess the feasibility of our structure, and to conduct preliminary proportioning. In practice, the whole process will be repeated with new modal values (periods and mode shapes based on new member sizes) and revised masses until we converge upon an acceptable design satisfying all of our performance criteria.

Problem 12 - Estimation of Inelastic Design Forces/Displacements

For this problem, assume the structure responds only in its first mode (a single degree of freedom system), and to have a period, mass, modal and other characteristics considered previously.

a. Consider the 50% in 50-year earthquake hazard spectrum developed in Problem 10, determine:
   i. The story shears should we consider to design the structure for our continued occupancy requirements? Assume the structure remains elastic.

ii. What are the expected floor displacements and inter-story drifts (expressed in inches (or cm) as well as in the form of an interstory drift index obtained by dividing the interstory displacement by the corresponding story height)?

iii. Using your computer model of the structure (used to obtain mode shapes and periods), what are the maximum computed moments and shears in the beams at each floor, and in the interior and exterior columns in each story? [Here we do not need a moment or shear diagram, only a table of what the maximum value is for any location at a floor or story. This simplification is acceptable because we will make the beams at a floor equal in size. Similarly, the interior columns at a story will likewise be equal, as would the two exterior columns.

b. Here we will look at some of our results in part a.

i. How do your estimates of drift (in part a (ii)) for the 50% in 50-year hazard compare to a typical upper bound value for protection of partitions, such as 0.0025 times the story height? This drift is indicative of displacements that would start to cause damage to displacement sensitive nonstructural elements.

ii. If you want to reduce your computed drifts by 10%, qualitatively suggest what would you do to the structure (e.g., change mass, stiffness, damping, etc. and roughly by how much)? Do not do the dynamic or static analyses over again.

iii. What would you want to do to your elastic system conceptually, if you needed to reduce the accelerations in the structure by 10%?

> *Note:* We are not looking for a precise quantitative answer here, but an observation on what would be the most effective aspect of the structural system to change. For example, see how to interpret a Newmark-Hall or other spectrum in section 6 in the class notes to achieve your desired results. This approach is quite useful, but if you use more complicated spectral shapes (like Borzorgnia and Campbell) this is not so easy, but can be done using Matlab or a piece of graph paper.

Problem 13

The structure must simultaneously satisfy our design criteria for collapse prevention. Thus, we will now consider the elastic spectrum from Problem 8 targeted for the 2% in 50-year hazard level ground motion and the soil conditions at the site.

Consider a basic case where a maximum displacement ductility of 6 is to be targeted. This is a large ductility value, but we are targeting collapse prevention as our design criteria for this rare event. Other conditions (e.g., soil, periods, and so on) are the same as specified in the earlier assignments.

> *Note:* If we were to use the 10% in 50-year event, we would most likely use smaller allowable design ductility, such as 3 or 4, depending on the materials, details, and performance criteria adopted. You need not develop a spectrum for this case.

a. Use Newmark and Hall's method for modifying the elastic response spectrum you generated in Problem 8 to account for inelastic action. ***Important:*** Show both the force and displacement spectra.

b. For the estimated period of the structure, what are the pseudo-spectral acceleration and spectral displacement corresponding to the first mode?

c. Use these values in exactly the same manner as in Problem 12 (part a) above to estimate the story level shears, the maximum floor level lateral displacements, and the interstory drifts. Note, by using use the spectral pseudo-accelerations corresponding to your target ductility, you will obtain the force acting on the structure when you would like it to yield. The displacement of the structure corresponding to the yield force is the yield displacement. Thus, the maximum displacement of the structure is the yield displacement times the target ductility factor. Thus, use the story level forces to estimate the required maximum YIELD moments in (only) the beams at each story, and at the column base. We do not need beam or column shears, or column moments at locations other than the base, as these are force-protected elements, and we will later use a capacity design approach for beam shear, and to size the columns (other than at the base).

d. Repeat part b, and estimate the spectral accelerations and displacements at the fundamental period of the structure using:
   i. Use the method suggested by Miranda (this is representative of statistically derived methods)
   ii. Use the method suggested by Riddel, Hildalgo and Cruz (this is representative of simplified methods).
   iii. Use Newmark and Hall's method (this was done above in part b, but you need to include it here to do part iv below!).
   iv. Comment on the similarities and differences between R and γ values obtained using these different procedures. Comment on the advantages and disadvantages associated with using the different procedures.

e. Comment on how your answer to part "c" would change if you use one of the other methods (such as Miranda's method) instead of Newmark and Hall's method. Just outline the steps in the process. You need not do any calculations!

f. In Problem 10, you computed the maximum permitted R-value to simultaneously satisfy the 2% in 50-year hazard with an inelastic structure, and still have the structure respond elastically at the 50% in 50-year hazard level. Is the process we did above consistent with this result? If we keep a target ductility of 6, what is the likely consequence on the behavior of the structure?