University of California at Berkeley
Civil and Environmental Engineering

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CEE 227 -- Earthquake Resistant Design

Homework Assignments

Problem 19 and 20 due April 30

In Problem 15, you developed a table of member design forces and shears corresponding (i) to elastic behavior under earthquake hazards with a 50% probability of exceedence in 30 years and (ii) to a displacement ductility of 6 under the very rare 2% in 50-year hazard level. The elastic analyses of the system using lateral forces based on the spectral analyses done in Problems 13 and 14 suggest that the serviceability criteria control the member design forces. Moreover, we would like the structure to satisfy some more stringent drift requirements than a conventional structure so that nonstructural damage may be limited. Thus, for the 50% probability of exceedence in 30-year event we would like the story drift index to be less than ¾%, and for the 2% in 50-year event we would like the story drift index not to exceed 4%. As noted, we cannot utilize the full potential ductility capacity of the structural system (e.g., a code value of R = 8) since we have imposed the continued occupancy requirement for the 50%/30 year event.

Problem 19 – "Re-Design" of 3-story moment frame building

In this problem, we will use the simple preliminary design equations developed in class for moment resisting frames to estimate quickly the size of ideal girders in the first floor level above the ground. The same procedure would be used for the other levels. Using capacity design concepts we would then design the columns (to achieve strong column-weak girder behavior) and connections (to place the plastic hinges in the beams). Thus, the column and connection sizes and strengths will generally only depend on the size of the girders selected for a particular building configuration. The girder size selected should allow the structure to satisfy drift and strength requirements for the 2%/50- and 50%/30-year excitations.

In this problem, we will assume the same conditions you had for problem 15.

We will use ASTM A992 hot rolled wide flange shapes for the beams and columns. These have a nominal F_y = 50ksi, F_u=65 ksi, R_y = 1.1, R_t = 1.1. We should use ϕ = 0.9 for flexure, except as noted below.

For the ratio of I_b/I_c for this problem, you may use the ratio represented by the girder (beam) and interior column sizes used in the original building design. This is just a starting point, and other ratios might be used in an actual design to optimize behavior.

The solution to Problem 15, you developed the minimum beam moment capacity and shear strength needed by the bottom floor girder to satisfy the continued occupancy and collapse prevention performance criteria. We need to determine size of the members needed to satisfy these requirements, and to estimate the member sizes needed to satisfy the drift requirements for the continued occupancy and collapse prevention criteria. The final member size selected must satisfy all of these criteria (generally the strongest and stiffest member is needed).

For the lowest floor in the building (only), using the solution for Problem 15:

a. Determine what plastic section modulus you need to support gravity only (say $Z = M_{gravity}/\phi F_y$). This is a minimum value of Z you can use in the selection of your member.

b. For the 50% in 30-year (continued occupancy) level earthquake, compute an acceptable value of girder Z_{co} so that the structure can be expected to remain elastic during the earthquake. Since this is a performance criteria (and not a code criteria) use the critical continued occupancy girder moment under the frequent earthquake $Z_{co}=M_{co}/(R_y F_y)$. In this case, we are taking ϕ to be 1 as we are looking for a realistic estimate, rather than a lower bound value.

c. Repeat part b, for the collapse prevention moments for the rare event. In this case, use $Z_{cp} = M_{cp}/(1.1(F_y+F_u)/2)$. Here, the controlling stress being used represents some degree of strain hardening (it is half way between a realistic estimate of the yield and ultimate stresses

d. Using the elastic design story shears for the 50% in 30 year hazard level, and the appropriate values of R_y and ϕ where needed, as well as an acceptable interstory drift of ¾%, compute using the methods described in class:
    i. The minimum depth of the girder such that it will not yield before the CO drift criteria is reached (you may assume the columns are 17 inches deep (based on a 14 inch column with two 1.5 inch thick flanges), and
    ii. The minimum girder I_{co} such that the structure satisfies the continued occupancy drift criterion for the 50%/30-year event.

    To do this part of the problem, you need an estimate of I_{girder}/I_{column}. This can be identified by trial and error, but for this problem, use the ratio corresponding to the ASCE 7-05 building design (first problem).

e. Repeat the basic process in part d for the 2% in 50 year hazard level to determine the minimum value of I_{cp} for a peak interstory drift ratio of 4% (used in FEMA 350 for steel moment frames) and ductility factor of 6. Use methods described in the class notes to identify the optimal depth for the beam (again assuming the column is 17 inches deep). ASCE 41 permits a drift of 5% at collapse prevention, but I feel this is excessive based on evidence in FEMA 350 and the performance objectives for this building.

f. From the answers above, prepare a combined table of design values for the girder at the first floor above the ground including:
   - Moments (Z_{co} and Z_{cp})
   - Moments of inertia ($I_{girder\text{-}co}$ and $I_{girder\text{-}cp}$; $I_{col\text{-}co}$ and $I_{col\text{-}cp;}$).

g. Using a table of AISC beam section properties, select a beam section that satisfies all of the property requirements listed above for the girders. Pick a section that is compact (i.e., flanges have a b_f/t_f ratio < 16). Does such a section exist? If so, what are the actual Z and I values for this beam? How much stronger is the section you pick than your required value? How much stiffer? In ONE sentence, comment on the size of this beam relative to that used in the 2005 AISC 7 designed building?

h. There are several capacity design checks we need to do, and lots of detailing (lateral bracing, etc.). We will not do these for this class. However, a good check at this time is to compute the shear demand on the beam. This is a capacity design check to be based on the actual member size you picked. Thus, the maximum shear in the beam at the collapse prevention limit state is given approximately by $0.5(1.2w_D+1.0w_L)L + 1.1Z_{actual}(F_y+F_u)/L_{ph}$, where L_{ph} is the distance between the centers of the plastic hinges at the two ends of the beam (say for a quick estimate 360" – d_{column} - d_{girder}). This is based on two hinges forming - one at each end of the beam (we will check this in the next problem). If Reduced Beam Sections (RBS (dog bone)) or other details shift the centers of the plastic hinge further from the face of the column, appropriately reduced values of L_{ph} should be used. For capacity design, the shear capacity of the beam would be computed using a standard ϕ for shear (0.9 typically) and the nominal value of shear capacity of a wide flange beam, $V_{nominal} = 0.6F_yA_{w}$. Use these relations to confirm that beam section you picked has a sufficient shear capacity. If the beam you selected would yield in shear before it forms the complete mechanism with two plastic hinges along the beam, resize the beam with a bigger shear area. Note that the use of a ϕ factor of 0.9 and R_y=1 for shear (i.e., R_y is omitted from the previous equation) and ϕ factor of 1.0 and R_{eff} > 1 for flexure is intended to make sure the beam yields in flexure before it yields in shear. It is not a big enough difference, however, to entirely prevent shear yielding in the beam at large lateral displacements of the frame when strain hardening would occur in the plastic hinges).

i. Briefly comment on which design criteria we considered (gravity, service drift, service strength, collapse prevention drift, collapse prevention strength, shear, etc) controls the design of your structure.