

Problem 3 – Preliminary Code-based Estimates of Seismic Design Forces

This is where we develop a set of actual forces, that we could use to design actual beams and columns, using equations such as $\phi M_n \geq M_u$. These forces are based on a prescriptive set of instructions that do not make a distinction between various performance goals. The forces are increased for structures with higher “importance,” but these higher forces do not necessarily correspond to better seismic performance.

1994 UBC Provisions

1. First, we estimate the period using the formula $T = 0.035 \cdot H^{0.75}$. This formula is based on linear regression analysis of numerous structures of various lateral systems. This formula purposely underestimates period, as to give a larger force demand for design. Using this period, and a height of 40.5 ft, we get a period $T = 0.56$ sec.
2. Now that we have an estimate of period, we can estimate the base shear, given the floor weights, the soil type, the location, and the importance. This equation is:

$$V = \frac{ZIC}{R_w} W \quad (1)$$

Where $C = 1.25S/T^{2/3}$ (not to exceed 2.75), $R_w = 12$ (for SMRF), $Z = 0.4$ (for Zone IV), and $S = 1.2$ (for S_2 for firm soils.) Plugging in $W = \Sigma W_i = 2,370 \text{ k} + 2,370 \text{ k} + 1,940 \text{ k} = 6,680 \text{ k}$, we get that the base shear for this building is $V = 490.5 \text{ k}$, or $7.34\% \text{ g}$. Let's not forget that this corresponds to working stress, not ultimate (i.e. no load factors.)

3. Now, we have an estimate for the design base shear, we can distribute this shear up the height of the building in a manner consistent with elementary dynamics, considering a single mode. The equation for the story force at a level x in the building is given by:

$$F_x = V \frac{w_x h_x}{\sum_i w_i h_i} \quad (2)$$

4. Where V is the base shear defined above, w_x is the weight of floor x , and h_x is the height above grade to floor x . Neglected here is the higher mode effects. Applying this equation, and multiplying by 1.4 to bring the forces to ultimate level, we get the following distribution of story forces and story shears in the building:

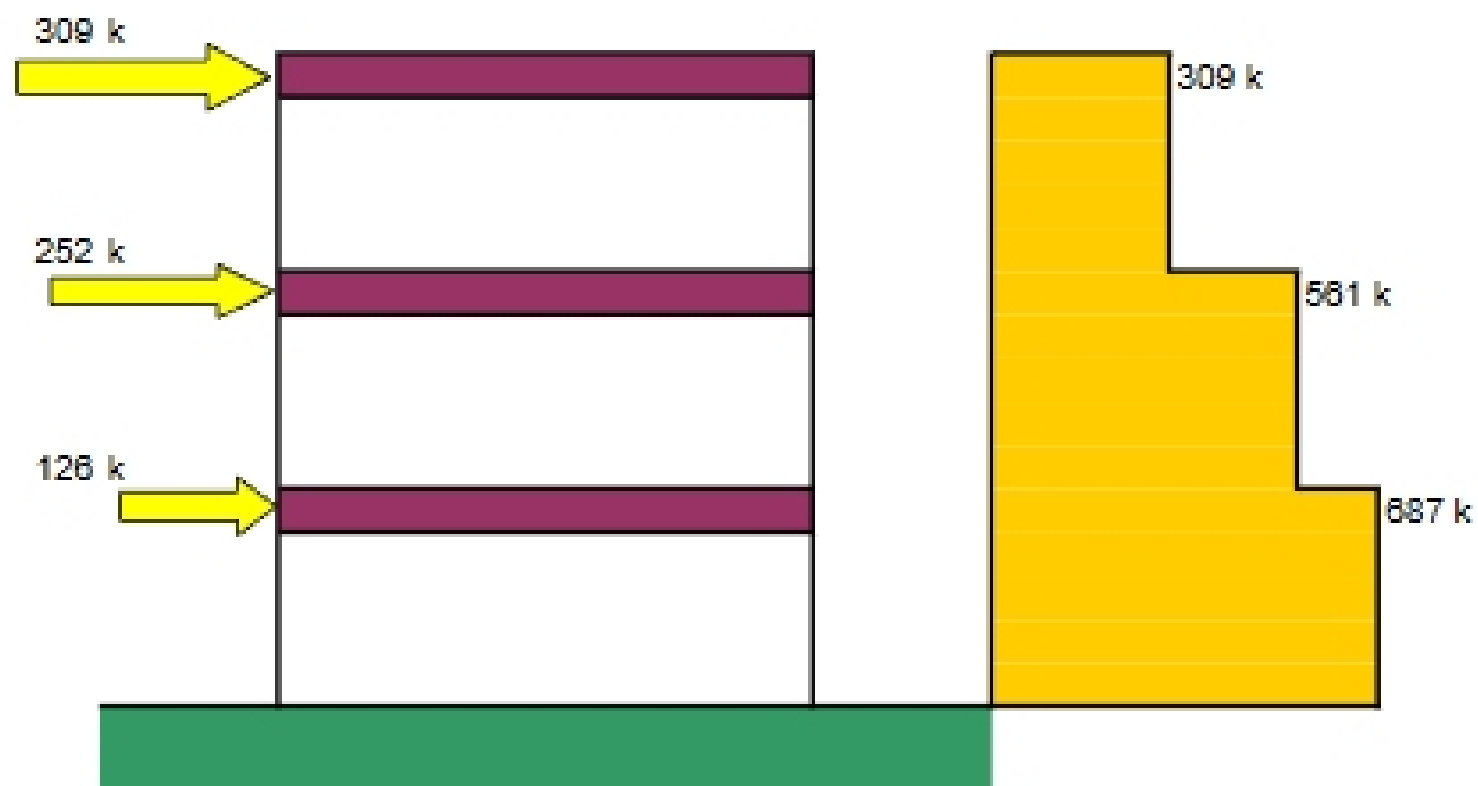


Figure 1: 1994 story forces and story shears (ultimate level)

1997 UBC Provisions

The 1997 UBC is the building code to which structures are currently designed in the State of California, as it is the basis for the 2001 California Building Code (CBC.) This is first set of provisions to recognize the effects of near-source ground motions, one reason for the increase in lateral forces for structures located within 15 km of a major fault.

Here we repeat parts 1 through 4 above, using the 1997 UBC provisions. We should recognize that the computation of story forces and story shears from above can simply be scaled by the 97 to 94 base shears.

The base shear equation for the 1997 UBC was modified to the following:

$$V = \frac{C_v I}{R T} W \leq \frac{2.5 C_a I}{R} W \quad (3)$$

Here, C_v is the constant velocity term, C_a is the constant acceleration term, I is as above, and R is 8.5 (for SMRF.) For Seismic Zone IV (in which Berkeley resides), $C_a = 0.44 N_s$, $C_v = 0.64 N_v$, ($N_s = 1.5$, $N_v = 1.28$ for distance to fault ≤ 2 km.) Throwing all this into the above equation for base shear, we get that $V = 1297$ kips, or 19.4% g . Note that this is an increase of 89% over the 1994 UBC, even including the factor to account for ultimate vs. working stress. This increase is due to a) the near source factors and b) higher peak ground acceleration for Zone IV.

We distribute the story forces and obtain story shears using the same set of equations as the 1994 UBC, described above. Doing this, we get the distribution of forces and shear up the height of the building as shown below.



Figure 2: 1997 story forces and story shears (ultimate level, as the code writers intended)

Okay, we have wrapped up forced based seismic design. The main thing to note here is that we have only considered forces, not displacements. The building code is primarily a force-based method, where drifts are checked at the end and compared to an arbitrary allowable drift. Also observe that the demands have increased significantly between 1994 and 1997. This does not mean that earthquakes decided to become more damaging to our built environment during these three years, only that the code writers sought to make the provisions more closely reflect the seismic demands observed in recorded earthquakes. In both cases, however, the design forces are based on assumptions which may not be valid depending on the structure being designed, and the true behavior may vary substantially. It is this premise on which we enter the next phase of these course, and attempt to develop a rational framework though which seismic design may be objectively applied.