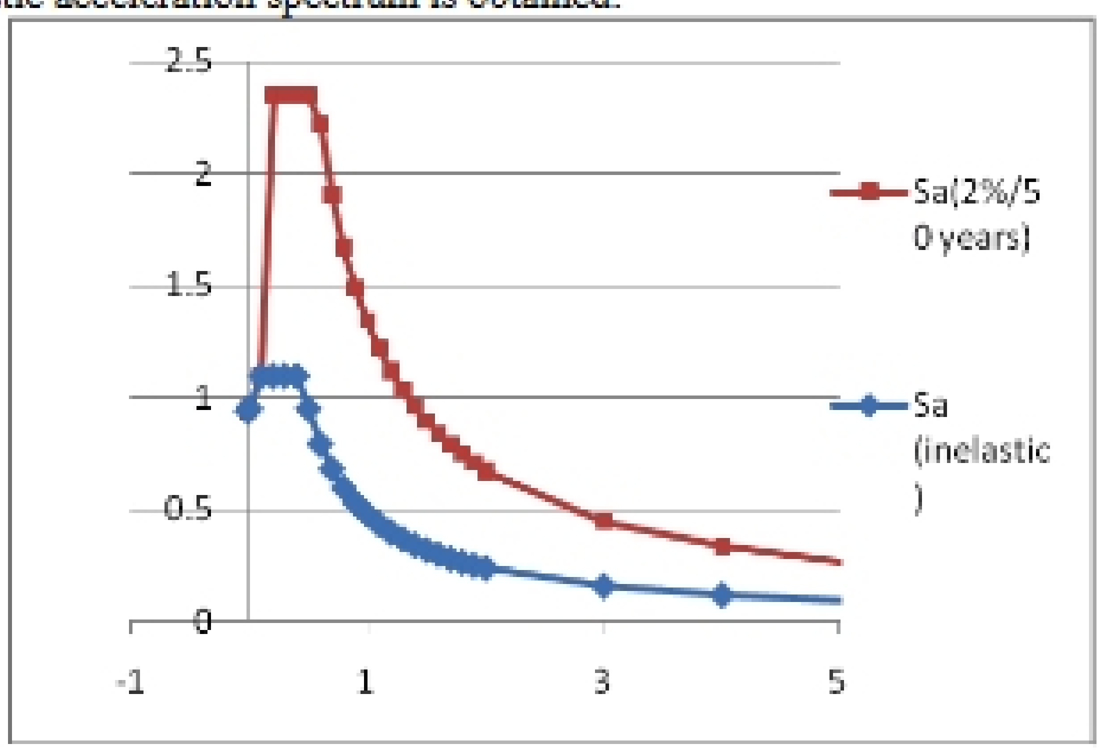
Problem 14 – Estimation of Inelastic Design Forces and Displacements

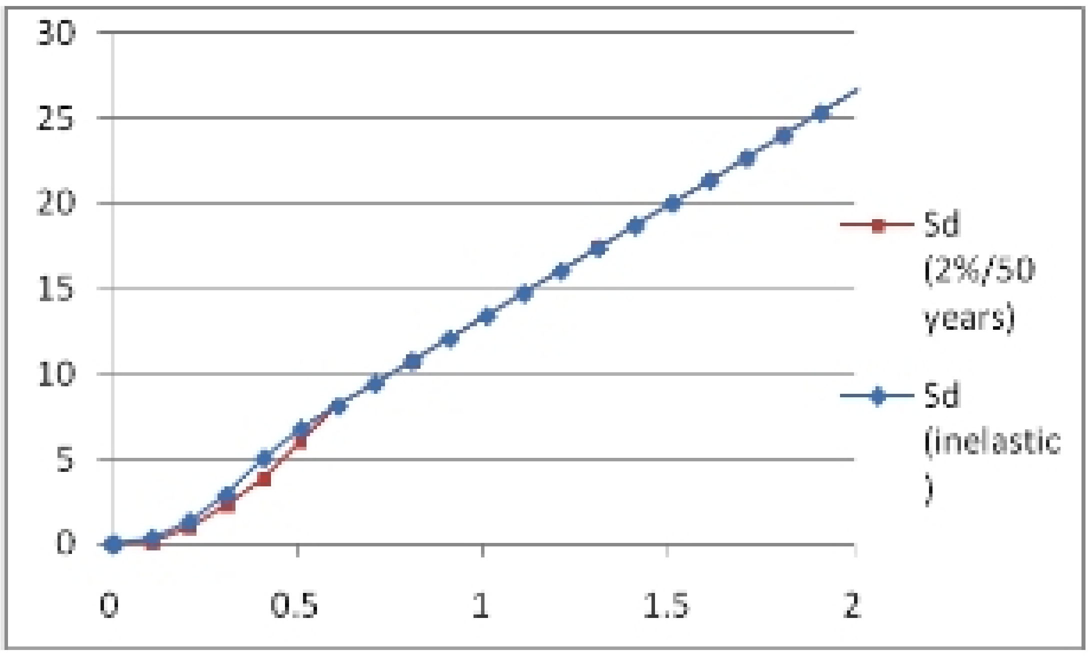
In this problem we perform a similar analysis as in Problem 13 but for the rare earthquake event (corresponding to the 2% in 50 yr PE hazard level) and a ductility demand of mu=6, or the ductility corresponding to our maximum R from problem 11. The collapse prevention performance goal is established for the structure under this rare event.

From problem 11, Rmax=2.8. Since our building is in the constant velocity range, for which R=mu, we should use mu=2.8 as our target ductility demand. This is much lower than the original target value of 6.

a. Using Newmark & Hall's method of developing inelastic spectra for a specified level of ductility, we proceed to modify the elastic spectra for the 2475-yr return period or 2% in 50 yr hazard level (developed in Problem 8). Here we have: $Sa_{0.2,inel} = Sa_{0.2,el} / R = 2.35/2.14 = 1.10$, where $R = \sqrt{2\mu - 1} = 2.14$ and $Sa_{1,inel} = S_{a1,el} / R = 1.355/2.8 = 0.48$, where $R = \mu = 2.8$. This corresponds to a corner period $T_c = Sa_{1.0,inel} / Sa_{0.2,inel} = 0.44\,\text{sec}$ and $T_0 = 0.2T_c = 0.09\,\text{sec}$. The following inelastic acceleration spectrum is obtained:



To calculate the displacement spectrum, the easiest option is to find the spectrum corresponding to the above acceleration spectrum, and multiply the values by mu (=2.8). Dividing by R and multiplying by mu is the equivalent to multiplying by gamma. This gives:

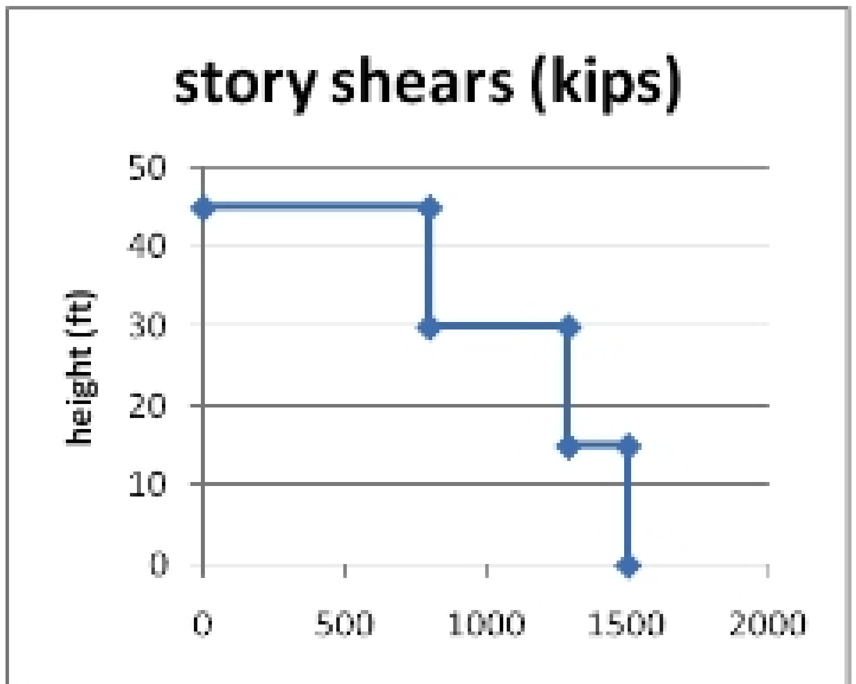


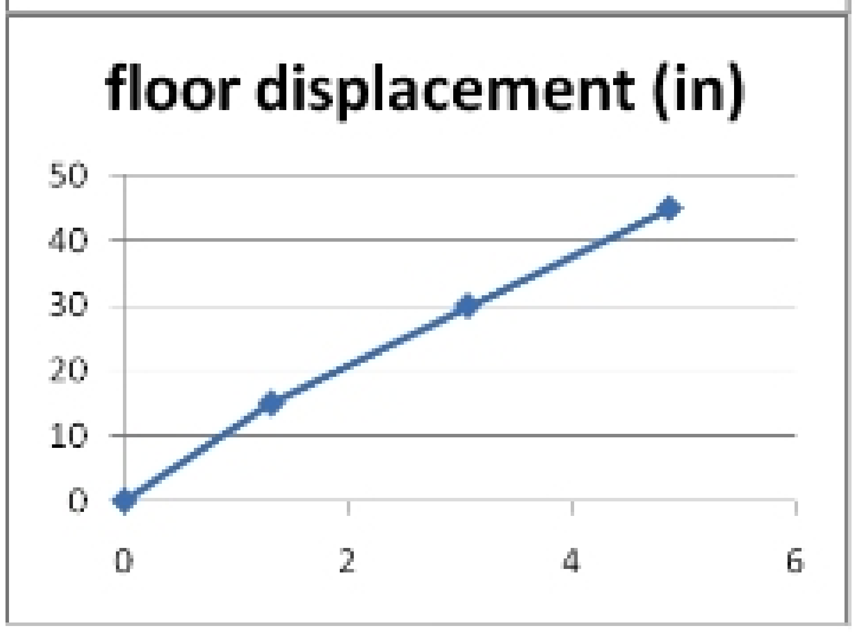
b. For a first-mode period of 0.79 sec, we obtain the following spectral values: $A_{1,inel}=S_{a,inel}(T_1)=0.597g$ and $D_{1,inel}=S_{d,inel}(T_1)=10.7$ in.

c. To simplify the calculations for story forces and floor displacements, we can scale the values obtained in Problem 12. For the forces we have a reduction factor of $S_{a,inel}(2\%in50)/S_{a,el}(50\%in30)=$ $0.597/0.52= 0.96$ and for the displacements we have and amplification factor of $S_{d,inel}(2\%in50)/S_{d,inel}(50\%in50\%)= 10.7/3.78= 2.83$. Since the structure is in the displacement preserved range ($\gamma=1$ or $S_{d,inel}=S_{d,el}$), the maximum displacement demand is obtained directly from the inelastic displacement spectra. The story forces, shears, displacements, drifts and bending moments of the building frame for the rare event, based on the inelastic response spectrum obtained above are presented below:

Story	Story Shear (kips)
1	1440
2	1238
3	767

Story	Floor displacement (in)	Inter-story drift (in)	Interstory drift index
1	3.73	3.73	0.0207
2	8.69	4.97	0.0276
3	13.80	5.11	0.0284





d. In this part we investigate additional methods of estimating inelastic spectral accelerations and displacements. The results of the spectral acceleration $S_{a,inel}$, spectral displacement $S_{d,inel}$, force reduction factor R_μ, and displacement amplification factor γ_μ, obtained from Miranda (statistically derived), Riddel, Hidalgo and Cruz (simplified), and Newmark & Hall methods are summarized in the table below:

Method	Sa inelastic (g)	Sd inelastic (in)	R(mu)	gamma(mu)
Miranda	0.52	8.89	3.27	0.85
Riddel, Hidalgo, and Cruz	0.61	10.4	2.8	1
Newmark and Hall	0.60	10.7	2.8	1

Note that Miranda is a bit lower on forces and displacements, while Riddel, Hidalgo & Cruz give results very close to Newmark & Hall results. These differences are all less than 20%, therefore the simplest procedure could be used to obtain the force and displacement demand on the building structure. The Miranda method is recommended since it provides a smooth relation for R and γ, is based on statistical data obtained from a large number of ground motions, and it considers soil conditions at the building site.