CEE287 Earthquake Resistant Design Prof. Eduardo Miranda

ASSIGNMENT 8

Due Wednesday, June 3rd, 2015

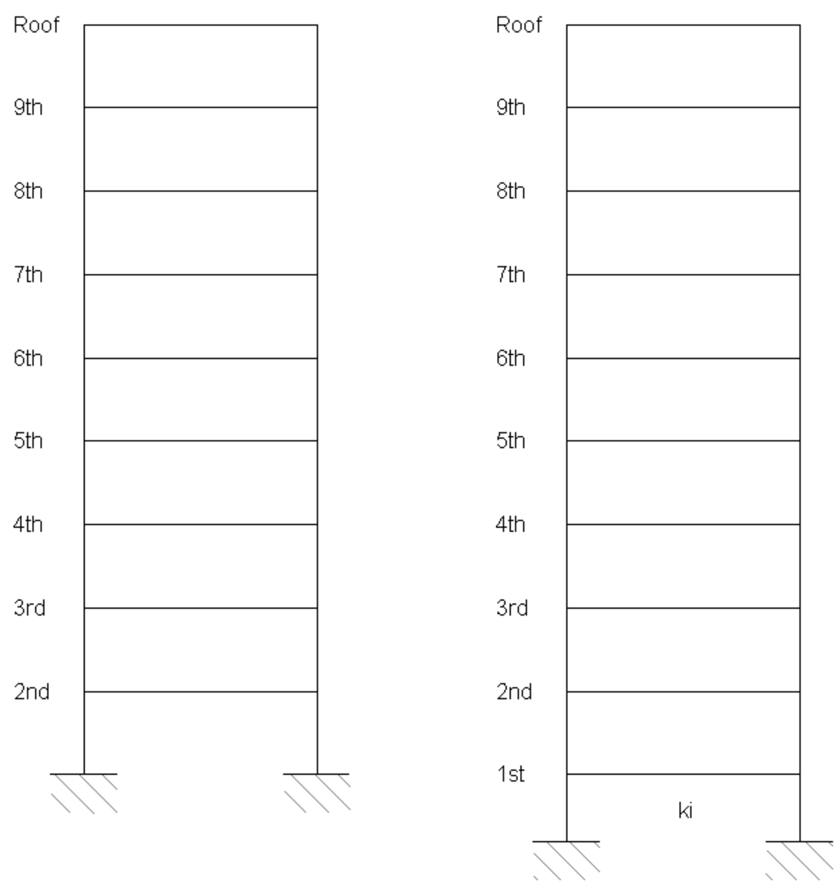
Objective:

(a) To learn how to design a seismically isolated structure by using RSA on a 2DOF system
(b) To gain an understanding of the influence of seismic isolation on structural response
(c) To compare the response of an isolated to a fixed base structure

PART A

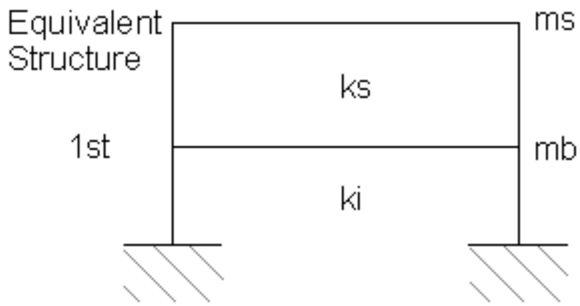
You are asked to seismically isolate the same 9-story building that you analyzed in Assignment #5. The original fixed base structure was 118 ft. tall with a total weight of 16,200 kips. The damping ratio of the structure was 3.5% for all modes, and the uniform stiffness along the height of the structure was 1,700 k/in. The mass is evenly distributed in the nine floors of the building.

To isolate the structure, you will add one floor level (with the same weight/mass as in each floor of the fixed base building) to the bottom of the building to act as our ground floor, and isolate that level. Below is shown a schematic diagram of both the fixed base and isolated structures.



First you are asked to determine the MAXIMUM lateral stiffness of the isolation system such that you will not exceed an interstory drift ratio of 0.5% under a design earthquake characterized by a design spectrum defined by S_{ds}=1.5, and S_{d1} =1. Assume that the structure will remain elastic so use R = 1, C_d = 1, and I = 1.

For getting a preliminary design you may convert convert the original fixed base structure to an equivalent 2DOF isolated structure to perform your preliminary design. You can assume that the isolated structure has an equivalent modal damping ratio of 10% for the first mode and 3.5% for the second mode. Use damping modification factors proposed by Lin and Chang (2003). The equivalent 2DOF structure is schematically shown below:



You can set the equivalent stiffness, k_s, of the 2DOF system to be equal to the generalized lateral stiffness of the fixed base structure. The latter can be computed using the stiffness matrix of your fixed base structure (of the fixed base shear building) and the first mode shape.

$$k_s = \phi_1^T K \phi_1$$

Similarly, you can set the equivalent, m_s, of the of the 2DOF system to be equal to the generalized mass of the fixed base structure. The latter can be computed using the mass matrix of your fixed base structure and the first mode shape as follows:

$$m_s = \phi_1^T M \phi_1$$

Please note that the values of both k_s and m_s depend on how you normalize the modes of vibration. However, regardless of how you normalize the modes, the ratio of these two quantities should not change (as well as the period of the fixed base equivalent SDOF which should be equal to that of the fixed base MDOF).

When you compute the interstory drift ratio in the equivalent structure, you can assume that the equivalent structure height = 2/3 of the height of the roof the fixed base structure.

When you compute the Interstory drift ratio in the equivalent 2DOF structure, you will need to take into account that interstory drift demand in the MDOF will not be evenly distributed but rather will be larger in certain stories than in other so in order to find the limiting IDR in the upper floor of the 2DOF that leads to an adequate control of the peak IDR in the MDOF you need to convert this back to what the corresponding peak IDR would be in the full structure. You can do this as follows:

From your class note you know you can estimate the peak interstory drift ratio in a linear MDOF building as

$$IDR_{\max,MDOF} \cong \beta_1 \beta_2 \frac{S_{d1}}{H_{roof}}$$

where S_{d1} is the peak displacement of a single degree of freedom system with a period of vibration equal to the fundamental period of the structure, H_{roof} is the total building height and β_1 and β_2 are amplification factors given by

$$\beta_1 = \Gamma_1 \phi_{1,roof}$$

$$\beta_2 = \max\left[\frac{H_{roof}\left(\phi_{1,j} - \phi_{1,j-1}\right)}{H_{story}\phi_{1,roof}}\right]$$

Similarly, for a fixed base equivalent SDOF the peak interstory drift ratio will be

$$IDR_{\max,SDOF} = \frac{S_{d1}}{H_{SDOF}}$$

Since in this case we are assuming that

$$H_{SDOF} = \frac{2}{3} H_{roof}$$

then the relationship between the peak interstory drift in the MDOF and the equivalent SDOF is given by

$$\frac{IDR_{\max,MDOF}}{IDR_{\max,SDOF}} \cong \frac{\beta_1\beta_2 \dfrac{S_{d1}}{H_{roof}}}{\dfrac{3S_{d1}}{2H_{roof}}} = \frac{2}{3}\beta_1\beta_2$$

To summarize the steps you will need to perform to design the isolation stiffness, k_i:

1. Convert the fixed base structure to an equivalent 2 DOF structure with k_s, m_s, k_i, and m_b,
2. Determine the value of k_i that will result in the peak Interstory drift ratio in the fixed base structure less than 0.5%.
3. Convert k_i from the equivalent 2 DOF structure back to a stiffness of the isolated level in the full isolated structure.

If you use the equivalent 2 DOF structure please show all calculations for your equivalent structure properties. Report the k_i for the equivalent 2 DOF structure that you determined would be required for the peak IDR in the full structure to not exceed 0.5% drift. Also report the actual stiffness required for the isolation system in the full structure.

Alternatively, you can obtain the lateral stiffness of the isolation system by remembering that the shear model is a systems of lateral springs in series and using the Rayleigh method to obtain an estimate of the period of vibration of the isolated structure and then refining the initial value by solving the eigenvalue problem.

PART B

Now that you have computed the required stiffness at the isolation level, you will perform a response spectrum analysis on the new isolated building and compare it to the results of a response spectrum analysis conducted on the fixed base structure. Here you are asked to do RSA on the 10 and 9 DOF structure and not the equivalent 2DOF that you used to design the isolation system. Use the design spectrum given in Part A for both the isolated and fixed base structure. Again you can assume that the isolated structure has an equivalent modal damping ratio of 10% for the first mode and 3.5% for the second mode. Please report the following:

1. Stiffness and Mass matrices of your isolated and fixed base structures.
2. Comparison plot of Story Displacements for the isolated vs. fixed base structure.
3. Comparison plot of Interstory Drift Ratios for the isolated vs. fixed base structure. You do not need to report an IDR at the isolation level since we have not designed the height of this level, only its stiffness.
4. Comparison plot of the Story Shear Forces for the isolated vs. fixed base structure.
5. Comparison plot of the peak floor acceleration for the isolated vs. fixed base structure. Use the modal absolute acceleration method from Miranda and Taghavi (2005).

PART C

Conduct a modal response history analysis on both the isolated and fixed base structure using the same ground motion from Assignment 6, but now scaled by a factor of 5. Report the following:

1. Comparison plot of Story Displacements for the isolated vs. fixed base structure.
2. Comparison plot of Interstory Drift Ratios for the isolated vs. fixed base structure. You do not need to report an IDR at the isolation level since we have not designed the height of this level, only its stiffness.
3. Comparison plot of the Story Shear Forces for the isolated vs. fixed base structure.
4. Comparison plot of the peak floor acceleration for the isolated vs. fixed base structure.

PART D – Summary

The last part of the homework will be to summarize your results in tables and comment on them. A few things to think about and potentially comment on:

1. What are the differences in response between the isolated and fixed base structure?
2. When you compute the peak interstory drift ratio in the isolated structure using RSA, is it the same as the interstory drift ratio you designed for? Why might there be differences?
3. What percentage of the lateral deformation is concentrated in the isolation system in the seismically isolated structure?
4. What are the differences in results between the RSA and the RHA? Why are the magnitudes of response different?
5. Given that the isolated structure has significant performance benefits over the fixed base structure, why do you think that seismic isolation is not more common in the United States? Name at least three steps that could be taken to make isolation more common.