The Effect of Seismic Isolation on a Fixed Structure Building

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Seismic isolation is one of the most popular methods of protecting buildings from major earthquakes by absorbing most of the shock from the earthquake so that it doesn't damage the building. Seismic isolation can protect the building from collapsing, and protect major parts of the building, like the pipe and electrical systems, and the things inside the building. To protect the building, bearings are implemented into the base of the building as it is being built. These bearings are generally made of lead, rubber, and steel, and are very flexible so that they can absorb the shock from the earthquakes.

The bearings move back and forth when the ground moves, taking the shock of the earthquake instead of letting it go into the building.

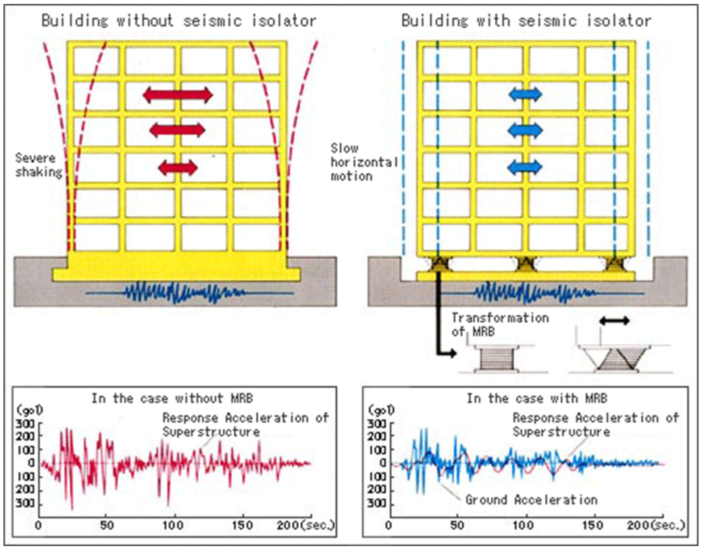


Figure 1. Models showing how buildings shake when subjected to ground motion. The second model shows the difference with a seismic isolator.

Every building has basic characteristics, like a time period and a level of stiffness. Time period is the building's natural period of oscillation when subjected to ground movement, like an earthquake. Each building moves naturally back and forth during an earthquake, so the amount of time it takes for the building to make one oscillation and return to its initial position is its time period. Typically, shorter time periods mean a building is very stiff, and longer time periods mean a building is more flexible. If a building is more flexible, it is safer in the event of an earthquake. This is the goal with seismic isolation. The equation to find the time period is: 2(M/K), where m = mass and k = stiffness.

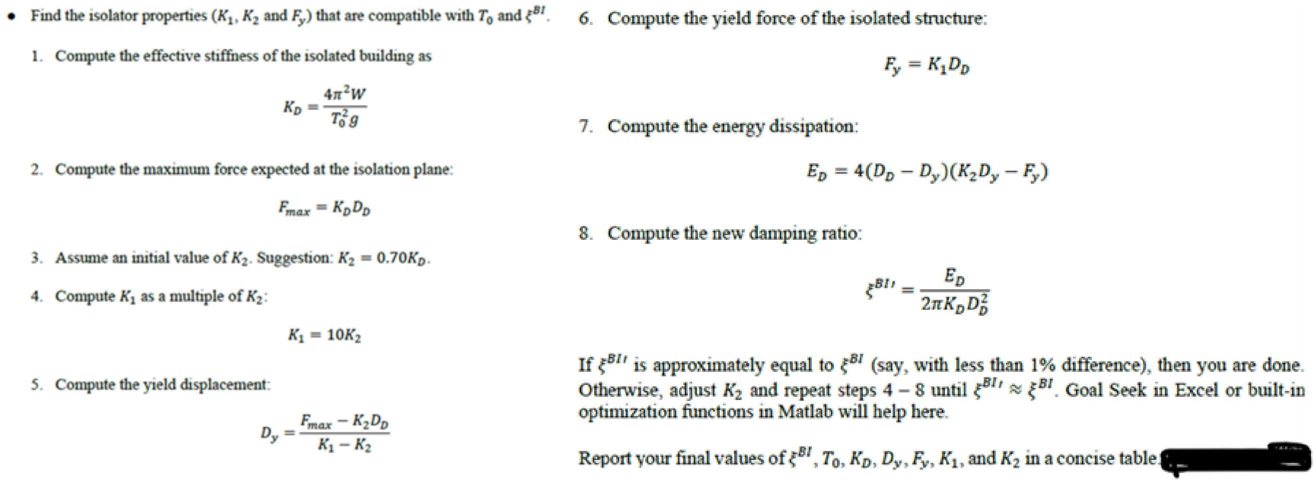
The stiffness of a building is the amount of force it takes to displace the building by any amount. When buildings take a lot of force to be displaced, they are very stiff, and if it only takes a little force then it is not very stiff. Typically, very rigid buildings are more susceptible to damage during earthquakes because they will only allow for a little displacement before becoming damaged. The formula to find a column's stiffness is (12EI)/L3, where E = young's modulus, I = area moment of inertia, and L = length.

Young's Modulus is how easily the material will stretch or deform. It is basically the material's stress over strain. For our model, the material is steel. The young's modulus of steel is around 200 GPa (gigapascals).

The area moment of inertia is the deflection of the material under loading. The equation for the area moment of inertia is (bh)3/12, where b = base and h = height.

L is just the length of the beam. Because L is in the denominator, the equation gets smaller the larger L is - as you increase L the stiffness will decrease faster (because L is raised to the power of 3).

Using these equations, we created a basic fixed structure. It had 2 columns with a weight on top, and was 1 story. This way, we could simulate what would happen when implementing ground motion on a fixed structure. We then had to add bearings on our structure, implementing seismic isolation, and run the same ground motion to see how the building's conditions were different. To do this, we had to find the seismic isolation properties and set a target displacement for the building. There are a couple of calculations we had to go through to get a damping ratio for the bearings. To calculate this quickly and efficiently, we used an excel spreadsheet.



- Find the isolator properties (K_1, K_2 and F_y) that are compatible with T_0 and ξ^{BI}.
  1. Compute the effective stiffness of the isolated building as

$$K_D = \frac{4\pi^2 W}{T_0^2 g}$$

  2. Compute the maximum force expected at the isolation plane:

$$F_{max} = K_D D_D$$

  3. Assume an initial value of K_2. Suggestion: $K_2 = 0.70K_D$.
  4. Compute K_1 as a multiple of K_2:

$$K_1 = 10K_2$$

  5. Compute the yield displacement:

$$D_y = \frac{F_{max} - K_2 D_D}{K_1 - K_2}$$

  6. Compute the yield force of the isolated structure:

$$F_y = K_1 D_D$$

  7. Compute the energy dissipation:

$$E_D = 4(D_D - D_y)(K_2 D_y - F_y)$$

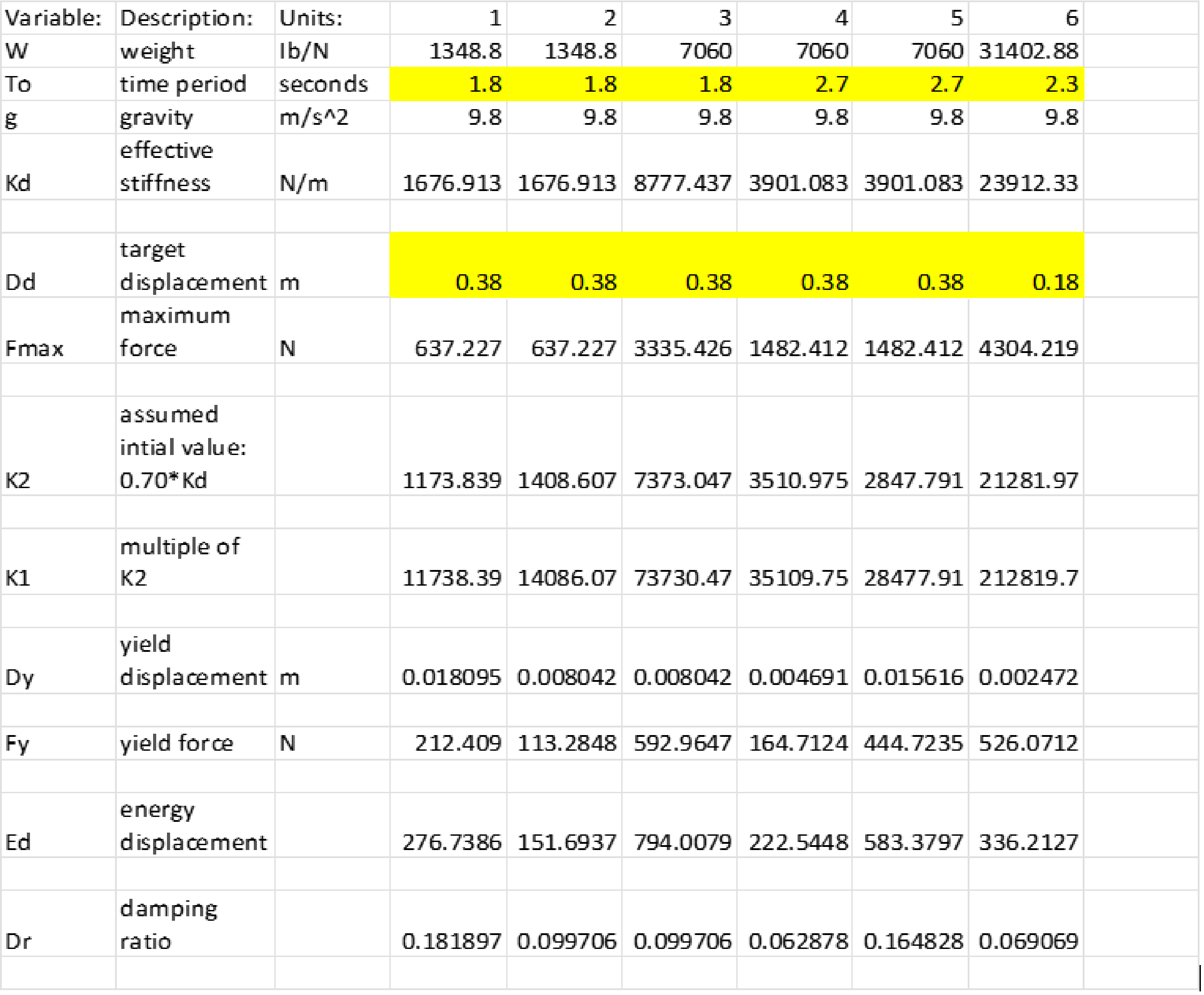
  8. Compute the new damping ratio:

$$\xi^{BI\prime} = \frac{E_D}{2\pi K_D D_D^2}$$

If $\xi^{BI\prime}$ is approximately equal to ξ^{BI} (say, with less than 1% difference), then you are done. Otherwise, adjust K_2 and repeat steps 4 – 8 until $\xi^{BI\prime} \approx \xi^{BI}$. Goal Seek in Excel or built-in optimization functions in Matlab will help here.

Report your final values of ξ^{BI}, T_0, K_D, D_y, F_y, K_1, and K_2 in a concise table [redacted]

There are a lot of variables that go into these calculations, so we organized the spreadsheet to calculate them quickly and keep them organized. We had to go through a couple different iterations before we found the number we were looking for, and adjust some of the numbers (weight, time period, etc.) to fit our model.



Variable:	Description:	Units:	1	2	3	4	5	6
W	weight	lb/N	1348.8	1348.8	7060	7060	7060	31402.88
To	time period	seconds	1.8	1.8	1.8	2.7	2.7	2.3
g	gravity	m/s^2	9.8	9.8	9.8	9.8	9.8	9.8
Kd	effective stiffness	N/m	1676.913	1676.913	8777.437	3901.083	3901.083	23912.33
Dd	target displacement	m	0.38	0.38	0.38	0.38	0.38	0.18
Fmax	maximum force	N	637.227	637.227	3335.426	1482.412	1482.412	4304.219
K2	assumed intial value: 0.70*Kd		1173.839	1408.607	7373.047	3510.975	2847.791	21281.97
K1	multiple of K2		11738.39	14086.07	73730.47	35109.75	28477.91	212819.7
Dy	yield displacement	m	0.018095	0.008042	0.008042	0.004691	0.015616	0.002472
Fy	yield force	N	212.409	113.2848	592.9647	164.7124	444.7235	526.0712
Ed	energy displacement		276.7386	151.6937	794.0079	222.5448	583.3797	336.2127
Dr	damping ratio		0.181897	0.099706	0.099706	0.062878	0.164828	0.069069

We had to set a target displacement (18 cm) and time period (2.3), and then adjust the K2 value until we had a damping ratio of around 7, shown in our last variation. Once we had gotten our damping ratio and determined our target displacement, we had to model it in the SAP2000 software. We created a simple 1 story building and added the weight on top.

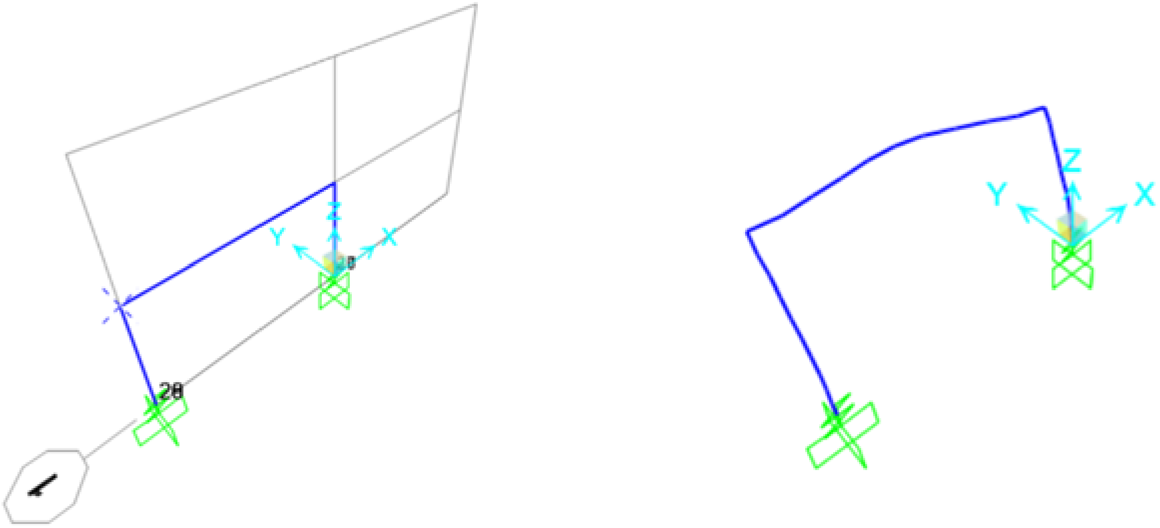


Figure 2. On the left is the 1 story building modeled in the SAP2000 software, with specific joints and loads applied, but without the ground motion. The right model is after being subjected to ground motion.

We then had to simulate it with ground motion, or an earthquake. We chose the El Centro earthquake and implemented the ground motion so that we could see the effects of the earthquake on a building that was not seismically isolated. We had to add in the lead-rubber bearings next, to see how the effects on the building would change when it was seismically isolated. What we found was that the bearings dissipate the energy induced by the earthquake and can make the building more flexible. This is the ideal outcome of seismic isolation; the bearings take most of the shock and allow the building to stay stable, making it safer for everyone in and around the building and saving more money in the long run.

References:

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