

RESONANCE OF STRUCTURES UNDER SINUSOIDAL SHAKING

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Abstract: *Resonance of structures*

Development of seismic resistant structures is one of the challenges civil engineers face. Quality of structures has progressed over time. Larger and stronger structures have been developed. However, many still seem to suffer severe damage and some collapse after an earthquake. There are many reasons why structures fail after an earthquake. One of these reasons, which may play a major role in a lot of these occasions, is the phenomenon of resonance effect, which occurs when the fundamental frequency of a structure is near the predominant frequency of an earthquake. It is important to understand the concept of resonance effect of structures in seismic design, and make an effort to avoid this effect to have more effective structural designs against earthquakes. In this project we observed and analyzed the resonance of different structures under sinusoidal shaking and compared their responses to show how a seemingly better designed structure may be at bigger risk of collapsing than another structure during certain circumstances.

Background: *Fundamental Period / Frequency*

Each structure has its own fundamental period and frequency. The fundamental period is relative to a structure's mass and stiffness as shown in Eq. 1. The stiffer the structure, the lower the fundamental period becomes since it will have smaller displacement amplitudes. Therefore, the structure would take less time to make one complete displacement cycle when undergoing vibration. A structure's fundamental frequency is closely associated with its fundamental period as shown in Eq. 2. The lower the fundamental period, the higher the fundamental frequency becomes.

Fundamental Period

$$T = 2\pi\sqrt{m/k} \tag{Eq. 1}$$

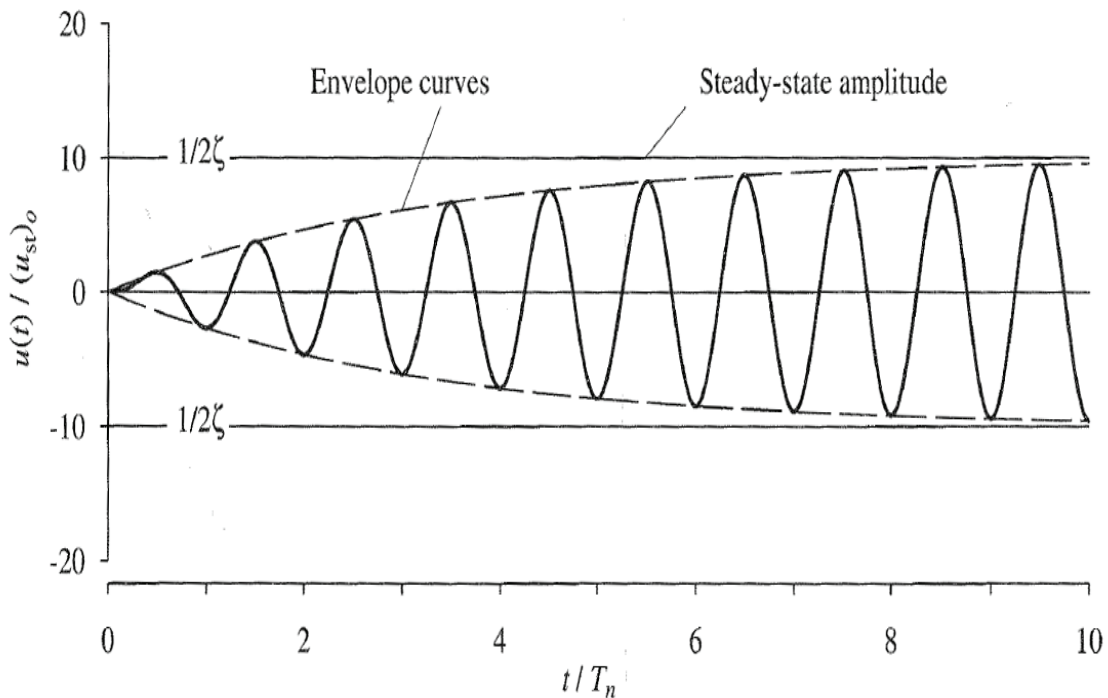
Fundamental Frequency

$$f = 1/T \tag{Eq. 2}$$

Resonance Effect: *The phenomenon*

Both the fundamental period and frequency affect the resonance of a structure. Resonance effect occurs when a structure is shook near its fundamental frequency and there is a large jump in the structure's response. Theoretically the amplitude of the resonance graph would continue to increase infinitely but due to the damping ratio in structures, it is bounded by a certain amplitude as shown in Fig. 1. The damping ratio of a structure is any effect which tends to reduce the amplitude of the response of a structure such as internal friction of the joints which dissipates the energy from an earthquake and transform it into heat energy.

Resonance Phenomenon



(Fig. I)

Objective / Approach: *Experimental & Analytical*

The objective of this project was to observe the resonance of different structures under sinusoidal shaking using analytical and experimental methods and show how resonance affects structures. The experimental approach was to construct two fifteen inch building models, one with braces and the other without, shake both under cyclic sinusoidal waves with different frequencies and compare their responses. The analytical approach was to use SAP2000 to make two simulation models with details from the experimental studies, run the same sinusoidal shaking test and compare the analytical with the experimental results. The purpose of the experimental aspect of this project was to verify that the analytical models are good representations of the actual structures. The final approach was to use SAP2000 to show resonance effect of each structure.

Construction of Models: *Testing & Calculations*

To begin the experimental approach the members were tested for their Young's Modulus which is important because it determines how much a material can deform without permanently affecting it which affects a structure's stiffness. Using a 0.2 pound weight over nineteen inch of one of the members and using Eq. 3 below and rearranging it to solve for the Young's Modulus (E), we obtain 1600 ksi.

Deformation Formula

$$\Delta = \frac{PL^3}{48EI} \tag{Eq. 3}$$

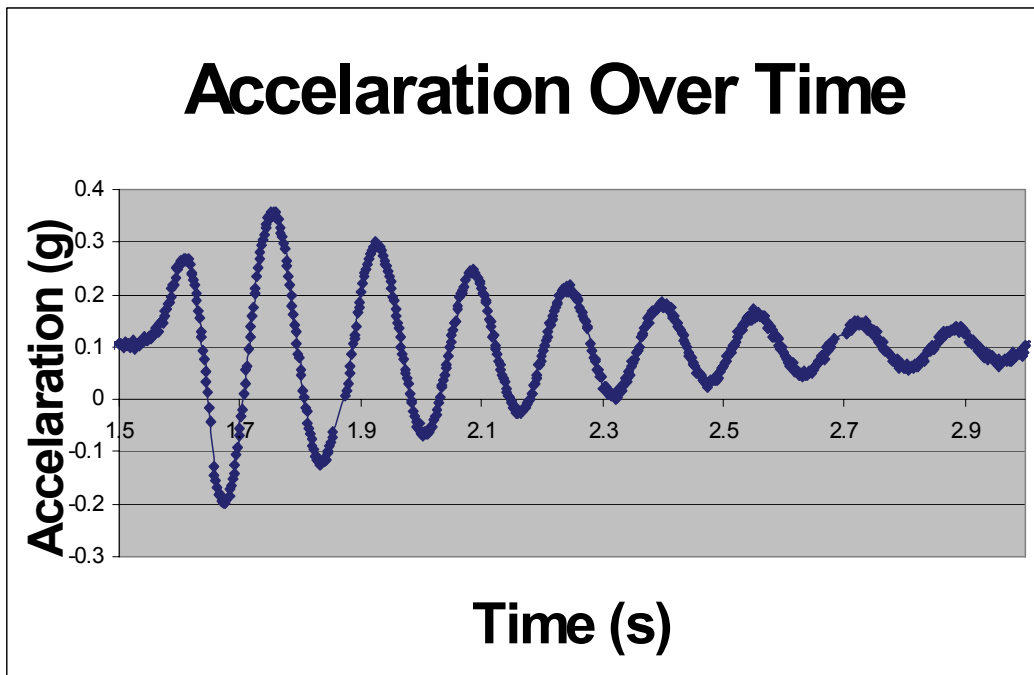
The structures were designed with four by four inch floor dimensions to allow them to fit spaced out on top of the shake table and five floors were separated three inches apart to make each model fifteen inches in height. The structures were constructed using 1/4 by 1/8 basal wood, the second with braces to increase its stiffness away from the first structure and both were attached to a wood base plate to be able to fix them to the shake table. Also, wood roof plates were attached to each structure to be able to attach twenty Newton disks on top of each structure. After the twenty Newton disks were attached, accelerometers which read acceleration over time were also attached on top of each structure and on the base plate. The acceleration over time of each structure was obtained by pushing and releasing each structure and allowing the accelerometers to transmit the data to a computer. Then using Eq. 4 and the acceleration over time Fig. 2, we obtained the fundamental period of each structure. Then the frequencies were identified to be 6.32 Hz for the first structure and 10.38 Hz for the second structure. Similarly, we used the acceleration over time Fig. 2 and Eq. 5 to obtain the damping ratio.

Fundamental Period 2

$$T = \text{cycles}/(t_2 - t_1) \tag{Eq. 4}$$

Damping Ratio

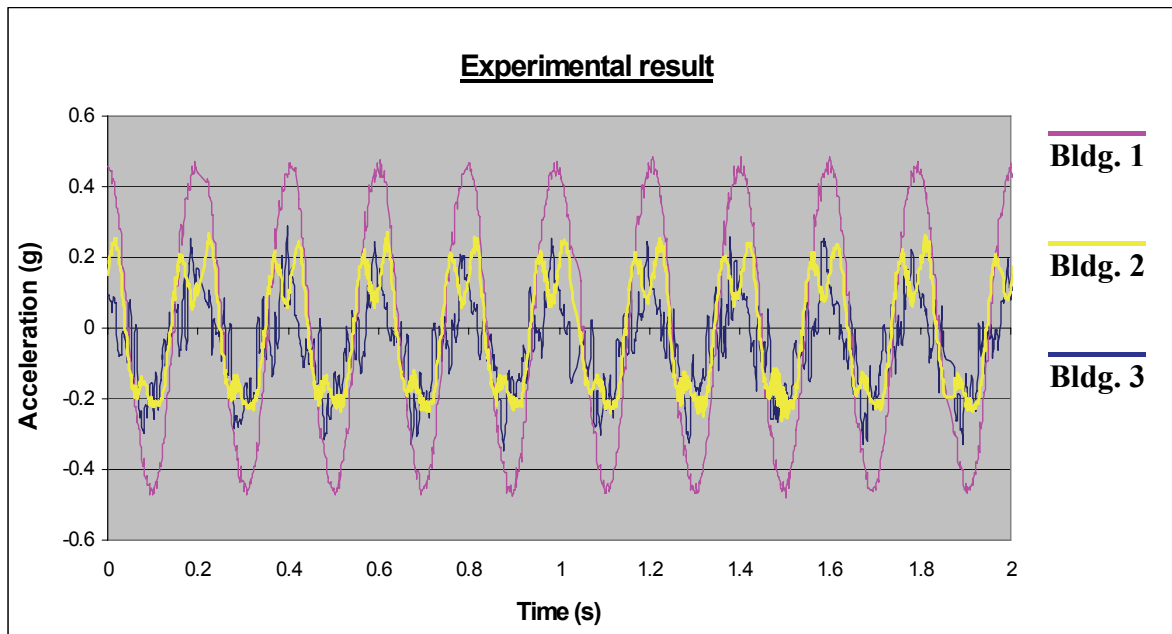
$$\zeta = \frac{1}{2\pi j} \ln \left(\frac{a_i}{a_{i+j}} \right) \tag{Eq. 5}$$



(Fig. II)

Shake Table Test: *Sinusoidal shaking*

After everything was set up, we used a quantum II shake table to shake our structures under a series of sinusoidal ground excitation with different frequencies, and recorded each structure's reaction. Subsequently, we plotted one of our experimental results which are shown in Fig. 3 below and compared the structures' responses.

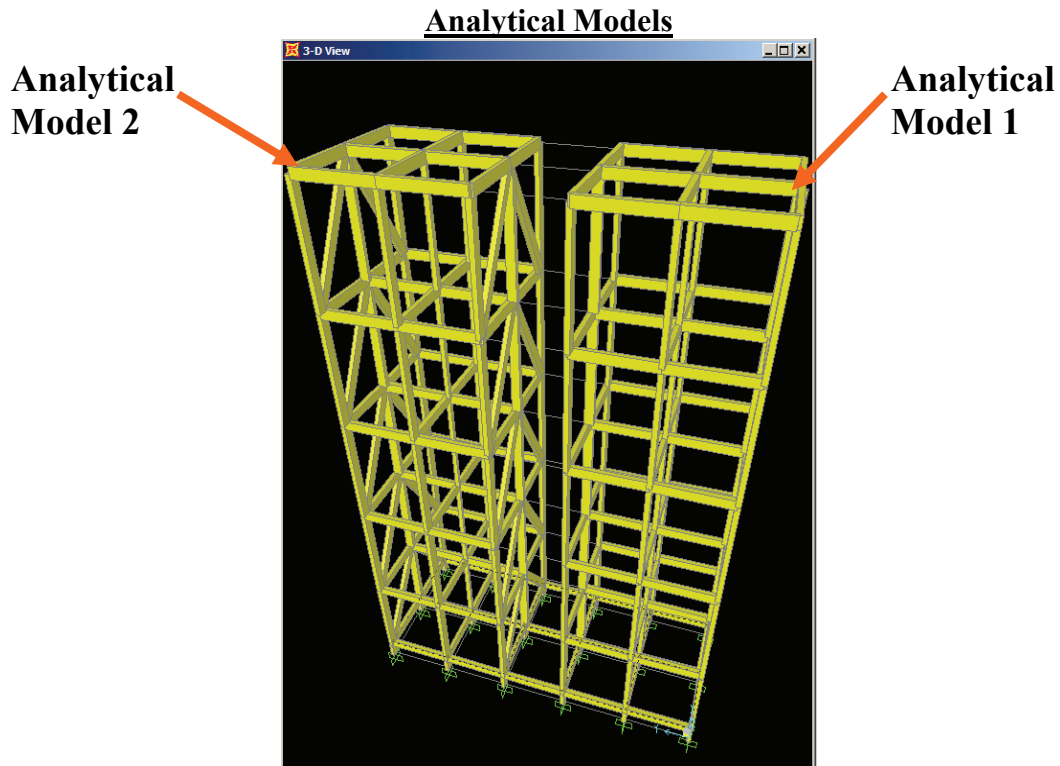


(Fig. III)

As you can see from the graph, building one has a much higher response than building two due to the fact that the frequency input on this graph was 5 Hz which is very close to the fundamental frequency of building one.

Analytical Models: *SAP 2000*

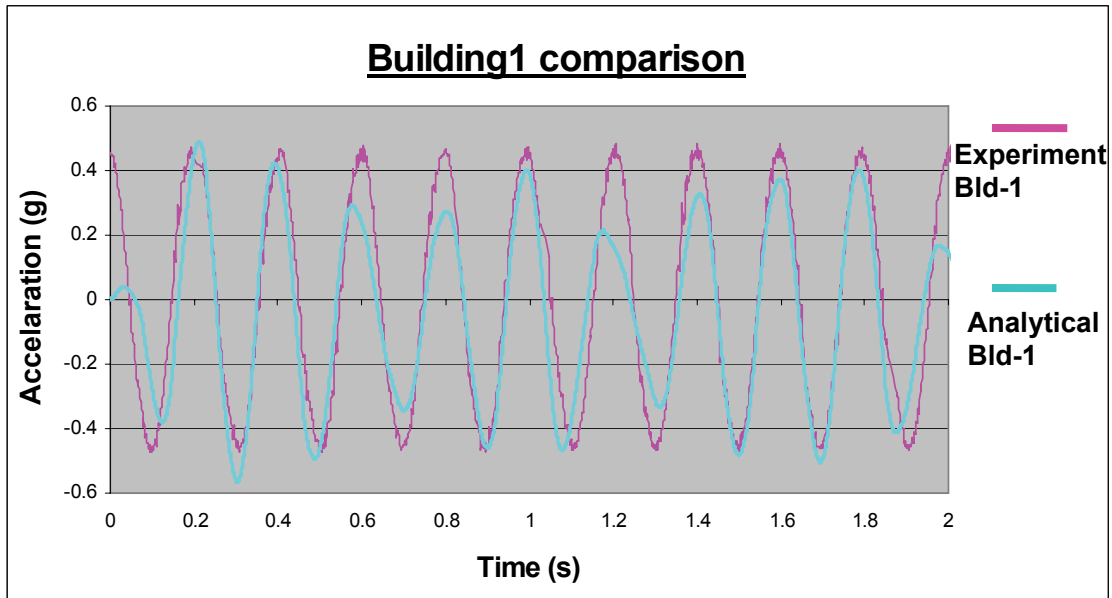
After completing our experimental studies we used SAP 2000 to create two simulation models using the same frame elements. We used the Young Modulus from our testing and the damping ratio which we calculated. We decided to use a spring support at the base to allow a small vertical displacement because during our testing we realized that the base of our structures was not completely restrained and our models were slightly uplifting during the shake table test. We also constrained the roof of each model to replicate a single unit roof movement similar to our structures. To conclude our analytical models we included 20 N plus 1.244 N loads to represent the disks and the accelerometers respectively. We then ran the analysis.



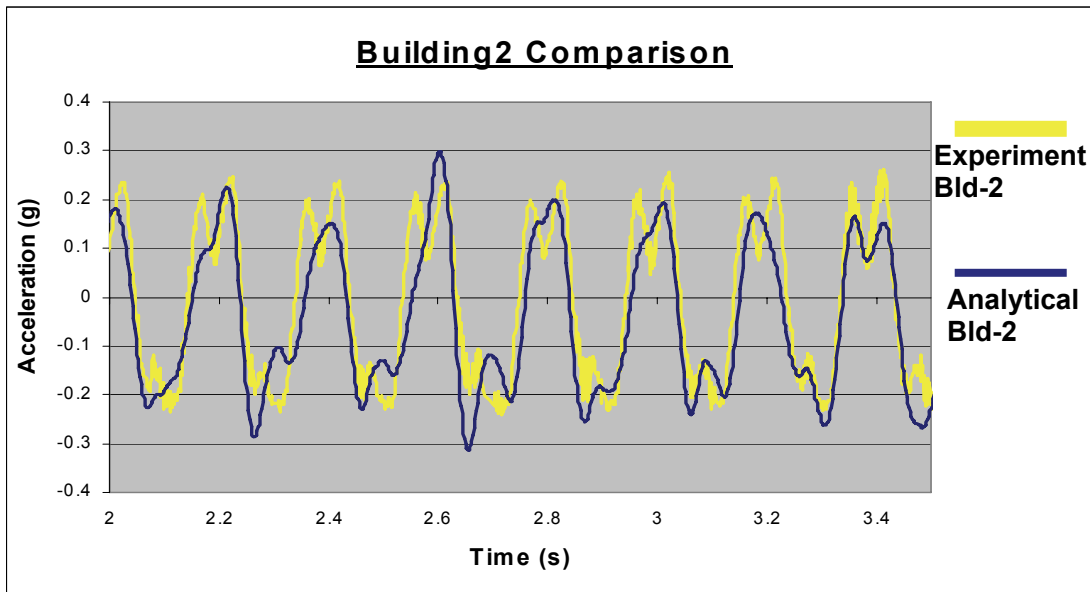
(Fig. IV)

Comparison: *Analytical VS. Experimental*

When we compared our analytical models to our experimental structures, the results were very similar. The frequencies in our experimental studies were 6.32 Hz for the first structure and 10.39 Hz for the second structure while the frequency of our analytical model one was 6.47 Hz and 10.30 Hz for our analytical model two. We then compared the responses between experimental and analytical building one and similarly for building two both shown in Fig. 5 and Fig. 6 below.



(Fig. V)

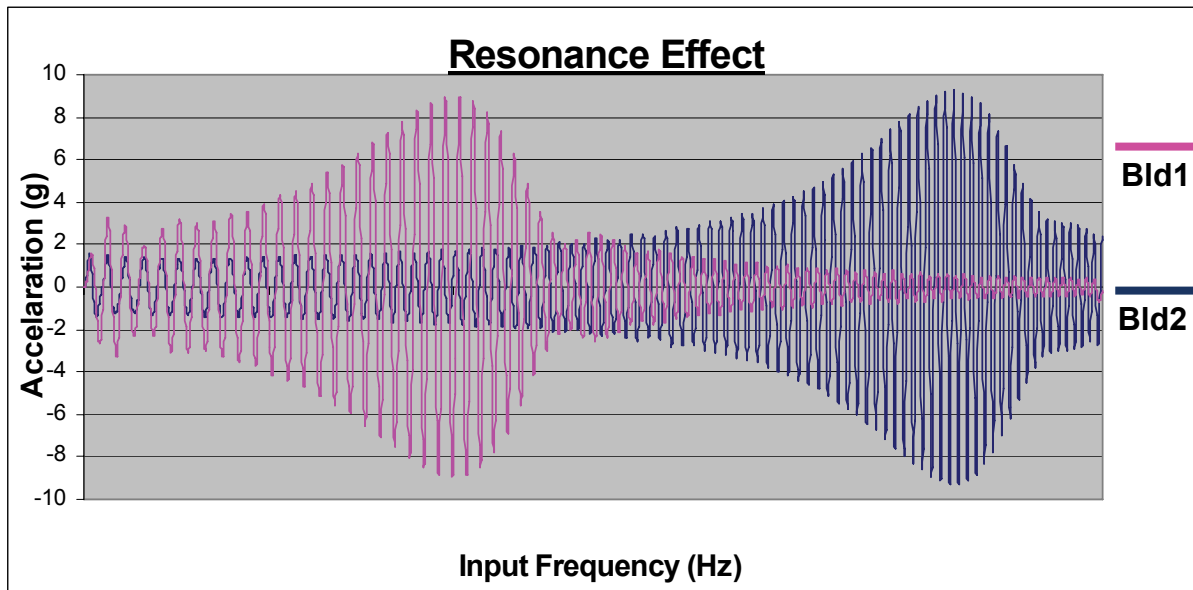


(Fig. VI)

As you can see the results from our analytical models are very similar to our experimental results. Both building one and two comparisons have similar shapes, acceleration amplitudes and fundamental periods. Therefore, since the frequency and response comparisons were very accurate, we can confidently say that our analytical models are good representations of the actual structures.

Analytical Test: Resonance Effect

Having concluded that our analytical models are good representations of our actual structures, we used SAP 2000 to run a sinusoidal shaking test covering the frequency of both models to show the resonance effect of structures. As you can see from Fig. 7 below, building one reacts more when shook near 6 Hz which is near its fundamental frequency and building two reacts more when shook near 10 Hz which is also near its fundamental frequency.



(Fig. VII)

Conclusion: Understanding

We concluded that it is important to understand and recognize the effect resonance has on structures and take into account that designing structures with a fundamental frequency away from the predicted predominant frequency of an earthquake is a good idea in seismic design and should not be over looked. As you can in Fig. 7, if the predominant frequency of a predicted earthquake is 10 Hz, it may be in our best interest to design a structure like building one since building two has a significantly higher response or make the frequency of building two away from 10 Hz using installation of dampers or base isolators.

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