Shakes and Quakes: K-12 Outreach Program

Linking **E**n**G**ineers t**O** Student**S**

in the Ultimate Classroom **K'Nex**ction

Sponsored by:

National Science Foundation: Scientists and Engineers in the Schools Program

Earthquake Engineering Research Institute: University of Notre Dame Student Chapter

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University of Notre Dame

Shakes and Quakes:
An Engineer's View

Recent earthquakes in the United States, Japan, Turkey, Taiwan, and India have underscored the tremendous importance of understanding the way in which civil engineering structures (e.g., buildings and bridges) respond during such dynamic events. The magnitude 6.7 1994 Northridge Earthquake death toll was 57, and more than 9,000 people were injured. About 1,600 structures were "red-tagged" as unsafe to enter, 7,300 were "yellow-tagged" for limited entry, and many thousands of other structures incurred at least minor damage, leaving 20,000 people temporarily homeless. Collapses and other severe damage forced closure of portions of 11 major roads to downtown Los Angeles. An estimated $20 billion in losses were claimed. On the first anniversary of the Northridge Earthquake, Kobe, Japan was struck by an magnitude 6.9 earthquake. Nearly 5,500 deaths were confirmed, with the number of injured people reaching around 36,896. Approximately 200,000 buildings were badly damaged or destroyed, and officials estimate that more than 310,000 people were left homeless by the earthquake. Over $147 billion in losses were attributed to this disaster. More recently, a magnitude 7.2 earthquake struck Turkey on November 12, 1999; its epicenter located in the town of Duzce (population 200,000), 115 miles east of Istanbul. Preliminary reports indicate that more than 100 buildings were destroyed, 400 confirmed dead and over 800 injured. This event follows the magnitude 7.4 August 17 Izmit earthquake which was the largest and most destructive tremor to occur in Turkey since the 1939 Erzincan earthquake. More than 17,000 people were confirmed dead and over 50,000 were injured. One of the main tasks of earthquake engineers is to develop the next generation of earthquake-resistant structures so as to reduce these human and financial losses.

Your Task

To better understand the way in which civil engineering structures respond to severe earthquakes, you will investigate the seismic behavior of two classes of buildings, those made from masonry and those made from steel. You form small companies that will design and construct model buildings. These buildings will be experimentally tested by subjecting them to simulated earthquakes.

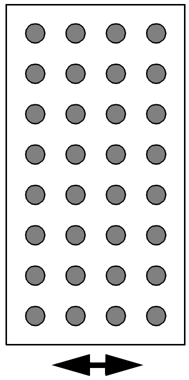
Masonry Structures

First, we will consider masonry-type structures using Legos. Your class should form into small companies consisting of several partners (3 to 5 students). There should be a maximum of 8 companies. Each company is required to construct a building from the provided Legos.

Each partner in the company should assume one or more of the following jobs:

- *Building Owner(s)*: the goal of building owner is to have a building that can rent for the most money.
- *Architect(s)*: the architect wants to make sure that the building is beautiful.
- *Engineer(s)*: the engineer seeks to have the building survive the largest earthquake.
- *Builder(s)*: the builder has the difficult task of constructing a building that makes the owner, the architect and the engineer happy.

Your Tasks:



Direction of Shaking

1.) Meet with your group, decide on a name for your company, and agree upon your respective jobs.

2.) Discuss with your group the type of building you would like to construct (good planning is one of the most important parts!).

3.) Sketch your ideas for the building on paper. Come to agreement on how your building project will proceed *before* starting construction. The *builder* should never allow construction to get ahead of the *architect's* and *engineer's* design.

The Design:

1. The base of the building must be no bigger than 4 by 8 Lego dots (see figure above).

Example Building

2. The building must be at least 30 floors high (one block equals one floor). Because the space on higher floors can be rented for more money, you may wish to design your building to have more than 30 floors.

3. The more space on each floor (i.e. more usable floor dots), the more rent that can be charged. Legos represent walls, so entire floors should not filled. Buildings will be hollow in the center. Upper stories rent for more than lower stories.

4. Space in the building can be rented for a higher price if the space is near a window. Windows are when there is no lego present. Therefore, your building should have as many "windows" as possible without sacrificing structural integrity.

The rent per floor is given by:

$$\$1000 \text{ x } \sqrt{(\textit{floor number})x(\textit{usable floor dots})x(\textit{window dots})}$$

See Appendix I for example calculations of rental income. Calculate your rent from the floor dot diagrams. A piece of Lego floor-plan layout-paper is included. More copies will be needed.

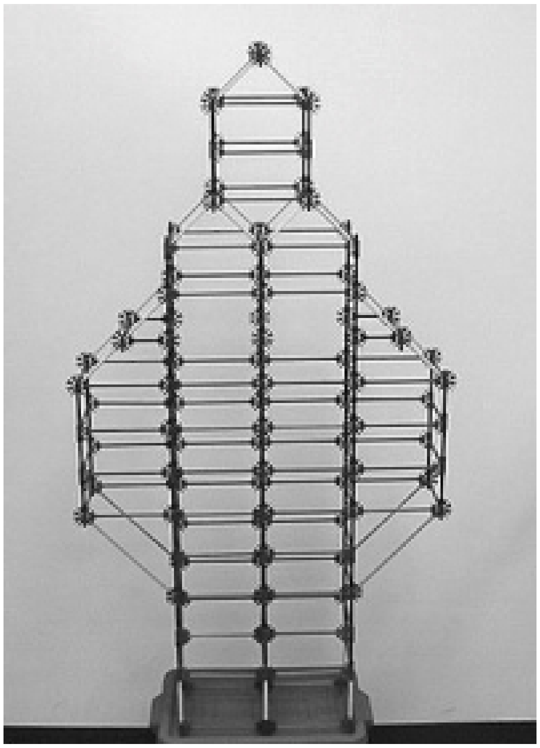
5. If you have ever been to Chicago, you will note the varied styles of the many tall buildings. Chicago has some of the most beautiful architecture in the world. As you design and construct your building, strive to make it as attractive as possible. For example, you may wish to add decorative spires to the top of the building.

6. Feel free to shake your various building designs to see what works and what doesn't.

Steel Structures

Steel structures behave much differently than masonry structures. They are flexible and, when properly designed, can withstand very large forces. Today, many of our skyscrapers, such as the Sears Tower in Chicago, are constructed from steel beams and columns. To construct a large building such as the Sears Tower often requires a consortium of design, engineering and construction firms. Therefore, your class should form two consortium firms to build a skyscraper from K'nex building toys.

Chicago's Sears Tower



The Design:

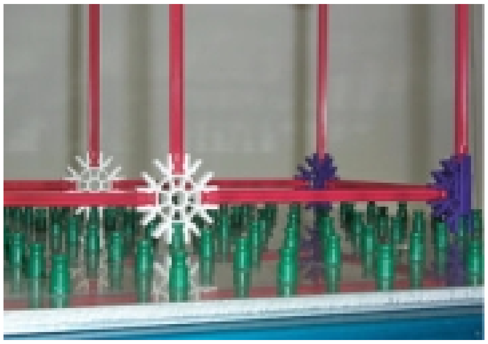
1. The base of the building must be no bigger than 15 cm x 30 cm (1 red x 2 red members).Your building must be able to connect to the pegs of a K'Nex board at in at least the four corners of the building, if not more places. (See Example below).
2. The building must be at least 2 m high, but may have as many floors as you like, as long as it doesn't touch the ceiling. The height of a usable floor must be at least 7.5 cm (i.e., one blue member).
3. The more space on each floor and the higher the ceilings on each floor, the more rent that can be charged. Upper stories rent for more than lower stories. Note that a floor slab must be supported on all four sides and at least at 15 cm (1 red member) intervals.

The rent per15 cm by 15 cm is:

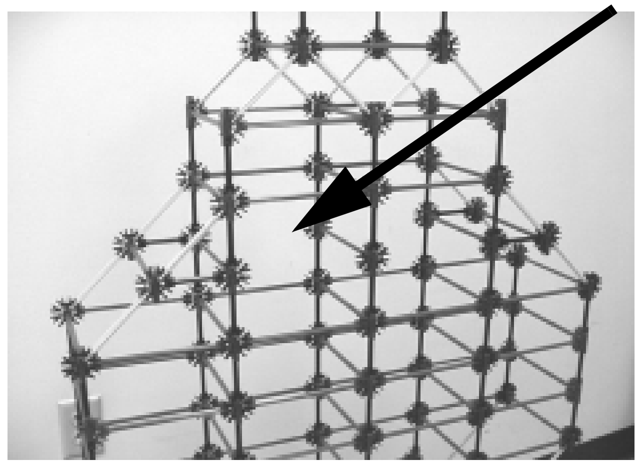
$$5000x\left[1 + \left(\frac{\textit{ceiling height (cm)}}{7.5}\right)x\left(1 + \frac{\textit{floor height from ground (cm)}}{7.5}\right)\right]$$

See Appendix II for example calculations of rental income.

4. Because the beauty of a city attracts business and tourism, the city where your structure is to be built is having a contest. Whichever consortium can build a landmark structure (the most beautiful building) will earn the architectural design award.



Example of connection to K'Nex board pegs



Example of a High-Ceiling Floor

The Critical Moment

On the day of testing, Quake Day, companies will be expected to give a 3 minute presentation on the whats/whys/hows of their building before it is placed on the shake table. Each group member is expected to participate, and groups should address problems they encountered with their respective jobs, structural considerations, changes in design, and the highest calculated rent, as well as any other pertinent information.

Testing Day

Before testing the model masonry buildings, your teacher(s) will select (i) the most attractive building, (ii) the building that would provide the most total rental income, and (iii) the tallest building. Then, we will see how each of your model masonry buildings survive different earthquakes.

After the model masonry structures are tested, the steel structures (K'Nex) that each consortium of companies built will be tested under various loading conditions. Your teacher will have (i) selected the landmark structure, and (ii) determined the structure with the most rental income.

Final Project Report

Each group should submit a final project report (at least two-pages in length) to your teacher (the company's CEO) documenting your experiences in designing and constructing your Lego building. Describe in detail the process your group went through to arrive at the final design. Indicate how your final building differed from the one initially conceived. What lessons did you learn during this process? How did your building fail? What design changes would you make if you had to rebuild the structure? What was the most difficult part of the process? Include any necessary drawings/pictures of your building. You may wish to take notes and photographs during the design and construction process that can be used to help write your final report. Additionally, please compare and contrast the way masonry structures and steel structures fail.

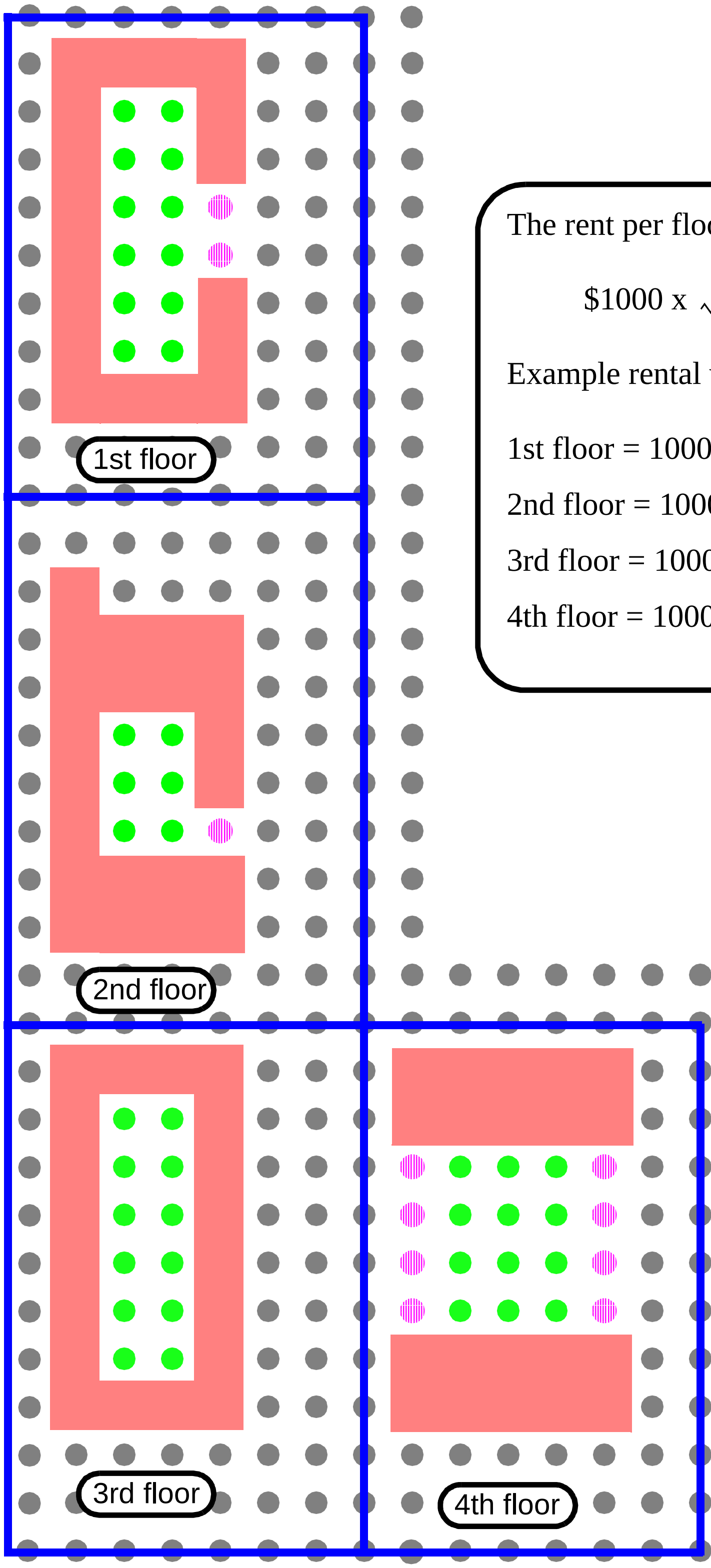
Questions

If you have any questions, please feel free to send e-mail to:

the Notre Dame EERI Chapter at: *eeriund@nd.edu* or

to our chapter faculty advisor Dr. Kurama at: *ykurama@nd.edu*

Appendix I: Example of Lego Building Rental Value Calculations



The rent per floor is given by:

$$\$1000 \text{ x } \sqrt{(floor\ number)x(usable\ floor\ dots)x(window\ dots)}$$

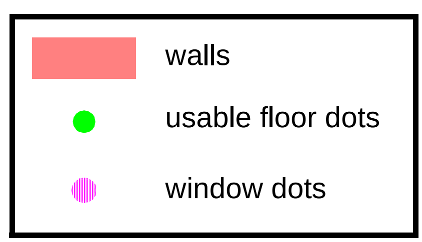
Example rental values for the floor plans at the left are:

1st floor = 1000 x $\sqrt{1 \text{ x} 12 \text{ x } 2}$ = \$4,899

2nd floor = 1000 x $\sqrt{2x6 \text{ x } 1}$ = \$3,461

3rd floor = 1000 x $\sqrt{3x12 \text{ x } 0}$ = \$0

4th floor = 1000 x $\sqrt{4x12 \text{ x } 8}$ = \$19,596



Lego Floor Plan Layout Paper

Original

Revised

Appendix II: Lego Building Rental Value Calculation Worksheet

Earthquake Engineering Project

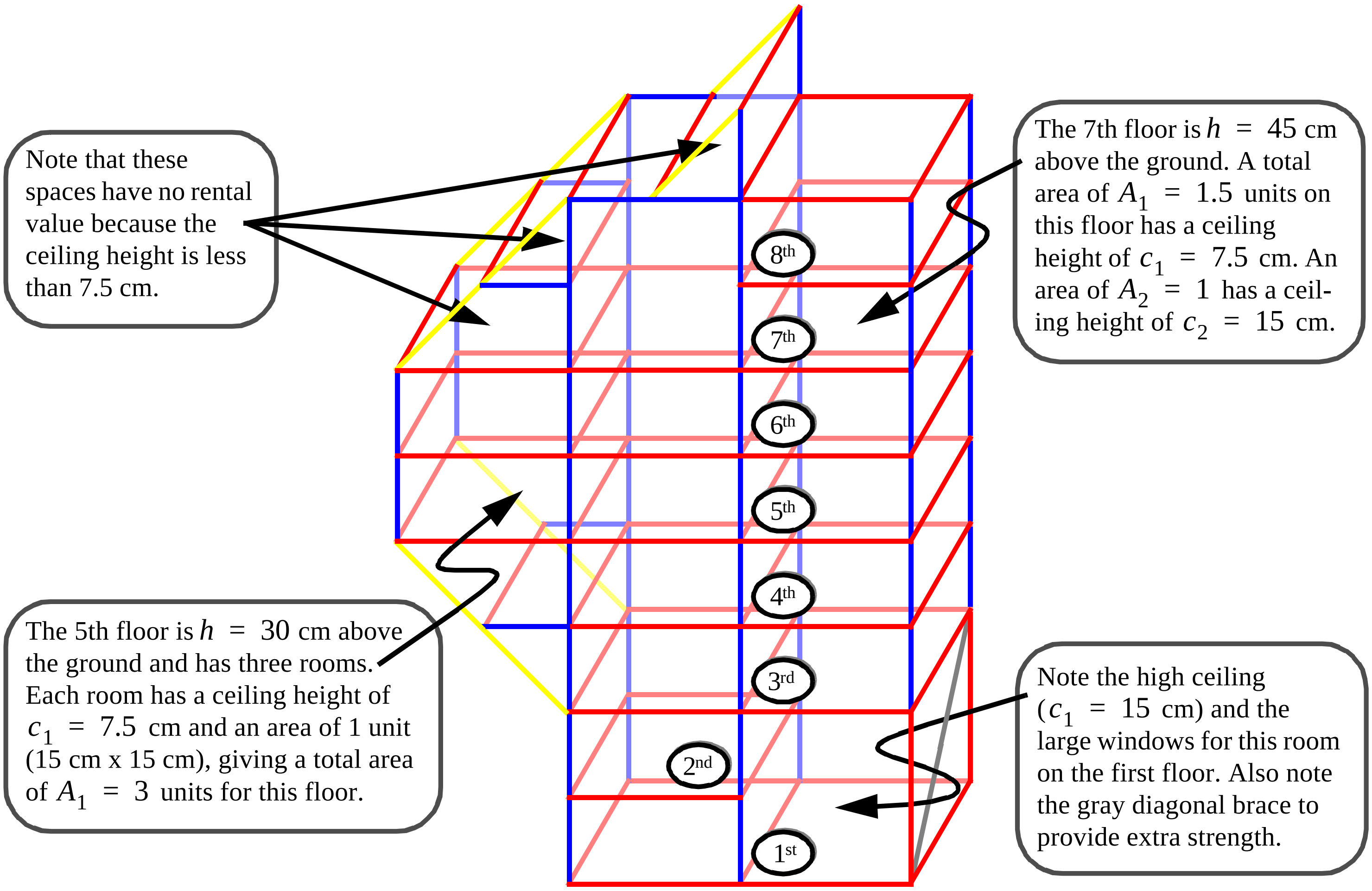
Company Name	
Building Owner(s)	
Architect(s)	
Engineer(s)	
Builder(s)	

$1000 x $\sqrt{(floor\ number)x(usable\ floor\ dots)x(window\ dots)}$

Floor #	**Floor Dots**	**Window Dots**	$\sqrt{\quad \cdot \quad}$ **($)**	**Cumulative Rent ($)**

Floor #	Floor Dots	Window Dots	$\sqrt{\quad\cdot\quad}$ ($)	Cumulative Rent ($)

Appendix II: Example of K'Nex Building Rental Value Calculations



Floor #	h^*	$A_1{}^\dagger$	$c_1{}^\ddagger$	Value \$ $5000A_1\left[1+\left(\frac{c_1}{7.5}\right)\left(1+\frac{h}{7.5}\right)\right]$	A_2	c_2	Value \$ $5000A_2\left[1+\left(\frac{c_2}{7.5}\right)\left(1+\frac{h}{7.5}\right)\right]$
1	0	1	7.5	10,000	1	15	15,000
2	7.5	1	7.5	15,000			
3	15	2	7.5	40,000			
4	22.5	2.5	7.5	62,500			
5	30	3	7.5	90,000			
6	37.5	3	7.5	105,000			
7	45	1.5	7.5	60,000	1	15	75,000
8	52.5	1	7.5	45,000			
			Subtotal	427,500		Subtotal	90,000
						Grand Total	\$517,500

$^*h$ is the height of each floor from the ground.
$^\dagger A_i$ is area of each room in area units (1 area unit = 15 cm x 15 cm).
$^\ddagger c_i$ is the height of the ceiling for each room on the floor.

Appendix IV: K'Nex Building Rental Value Calculation Worksheet

Earthquake Engineering Consortium Project

Consortium Name	

Floor #	h^*	A_1 †	c_1 ‡	Value \$ $5000A_1\left[1+\left(\frac{c_1}{7.5}\right)\left(1+\frac{h}{7.5}\right)\right]$	A_2	c_2	Value \$ $5000A_2\left[1+\left(\frac{c_2}{7.5}\right)\left(1+\frac{h}{7.5}\right)\right]$

Floor #	h[*]	A_1[†]	c_1[‡]	Value \$ $5000A_1\left[1+\left(\frac{c_1}{7.5}\right)\left(1+\frac{h}{7.5}\right)\right]$	A_2	c_2	Value \$ $5000A_2\left[1+\left(\frac{c_2}{7.5}\right)\left(1+\frac{h}{7.5}\right)\right]$
			Subtotal			Subtotal	
						Grand Total	

[*] h is the height of each floor from the ground.
[†] A_i is area of each room in area units (1 area unit = 15 cm x 15 cm).
[‡] c_i is the height of the ceiling for each room on the floor.