Shakes and Quakes: K-12 Outreach Activities in Earthquake Engineering

A PROJECT DEVELOPED FOR THE
NSF UNIVERSITY CONSORTIUM ON INSTRUCTIONAL SHAKE TABLES

http://ucist.cive.wustl.edu/

Objective: To stimulate young minds and allow them to better understand the way in which civil engineering structures respond to severe earthquakes, students investigated the seismic behavior of masonry structures. Two classroom visits were conducted. The first was a single 45-minute period that laid out the parameters of the project. Small companies consisting of 4 students were formed that design and construct model buildings from Legos according to predefined criteria. During the second class visit (2 periods), each student company gave an oral report and had their structure tested on the bench-scale shaking table. Final reports are due after the classroom testing.

Materials Required: 1. Quanser Shaking table and pendant controller; 2. Legos to be distributed to each student company (~$4 per group).

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Introduction

Recent earthquakes in the United States and Japan 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 1,500 people were seriously injured. About 12,500 structures were moderately to severely damaged, leaving thousands of 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 35,000. Approximately 180,000 buildings were badly damaged or destroyed, and officials estimate that more than 300,000 people were left homeless by the earthquake. Over $147 billion in losses were attributed to this disaster. 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.

The Task

To better understand the way in which civil engineering structures respond to severe earthquakes, you will investigate the seismic behavior of buildings made from masonry. You will form a small company that will design and construct a model building according to specific requirements. Each structure will be experimentally tested by subjecting them to simulated earthquakes.

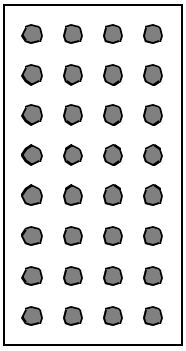
We will consider masonry-type structures in this project using Legos. Your class should form into small companies consisting of 4 students. Each company will be required to construct a building from the provided Legos. Each student in the company should select one of the following jobs:

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

Your *first* task is to meet with your group, decide on a name for your company, and agree upon who assumes each job. Then, discuss with your group the type of building you would like to construct. Sketch your ideas for the building on paper. Come to agreement on how your building

project will proceed *before* starting construction. Note that the builder should not allow construction to get ahead of the architects and engineer's design.

Please consider the following points in designing and constructing your building:



direction of shaking

1. The base of the building must be no bigger than 4 by 8 Lego dots (see figure at right).
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, the more rent that can be charged. Upper stories rent for more than lower stories.

Example Building

4. Space in the building can be rented for a higher price if the space is near a window. Therefore, your building should have as many "windows" as possible without sacrificing structural integrity. The rent per floor is given by:

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

   See Appendix I for example calculations of rental income. A piece of Lego floor plan layout paper is also included.

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.

The Critical Moment

On the day of testing, each group will be asked to give a 3 minute presentation on the whats/whys/hows of their building. How you give your presentation should be decided either by the group or by your teacher. After the presentations, your buildings will be tested on an earthquake simulator.

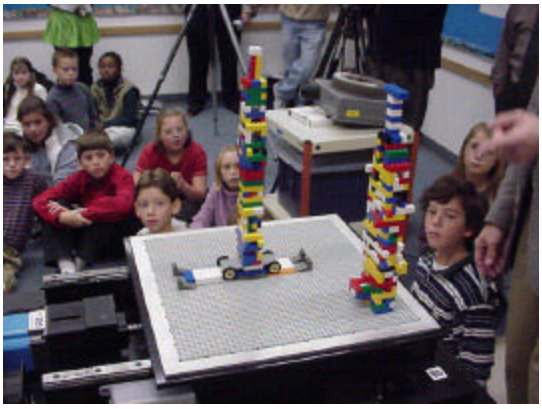
Before testing the model buildings, your teachers will select (i) the most attractive building, (ii) the building that would provide the most total rental income, and (iii) the tallest building. Then, we will see how each of your buildings survive different earthquakes.

Project Presentations

Final Project Report

Testing of Model Buildings

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.



The Concept of Seismic Isolation

Notes

1. The teachers who supervised the project during the Spring of 1999 in South Bend were Mrs. Anne Crossen (a.crossen@scs.tcpbbs.net) and Mr. John Meiser (j.meiser@scs.tcpbbs.net), 3rd grade homeroom teachers, Stanley Clark School.

2. The teacher who supervised the project during the Fall of 1999 in South Bend was Mrs. Dru Wrasse (d.wrasse@scs.tcpbbs.net), 5th/6th grade science teacher, Stanley Clark School.

3. In both classes, the teachers assigned the groups. Before assigning groups, Mrs. Wrasse asked the students to complete a simple survey to identify their strengths and weaknesses (e.g. artistic, likes to build models, likes to write, etc.). She used the survey results in assigning the groups to make sure that the groups were balanced (i.e., to ensure that a group didn't have 4 engineering-types or 4 architect-types in it). Unfortunately, I don't have this survey at this time.

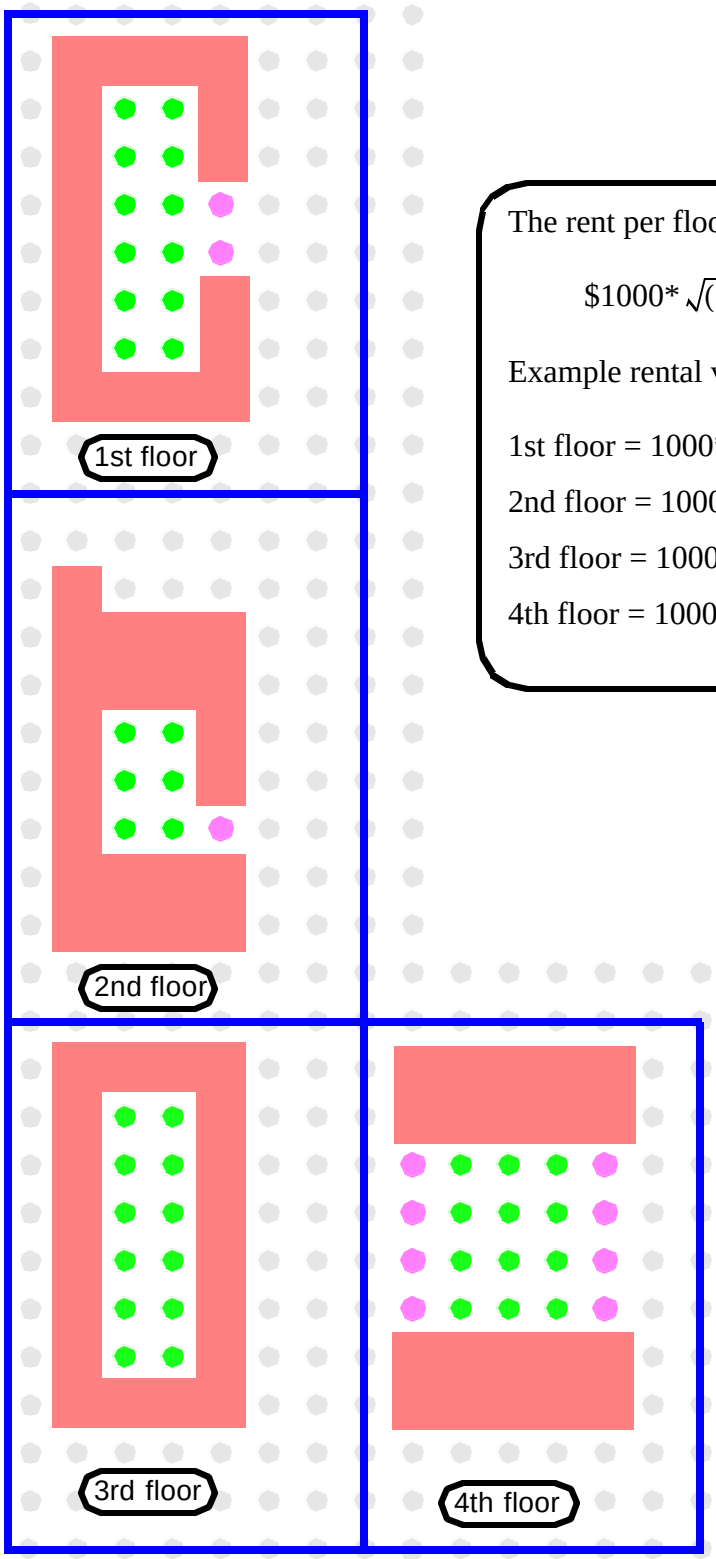
4. The University of Notre Dame issued a press release a few days before the testing in the Fall 1999 project. All three local TV stations sent out camera/reporter crews to cover the event. The story appeared on all three local networks that day during the noon, 5 pm and 10 pm news broadcasts.

Questions

If you have any questions, please feel free to send e-mail to Prof. B.F. Spencer, Jr. at: *spencer@nd.edu*

Also see: *http://www.nd.edu/~eeriund/outreach_99.html*

Appendix I: Example of Lego Building Rental Value Calculations



The rent per floor is given by:

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

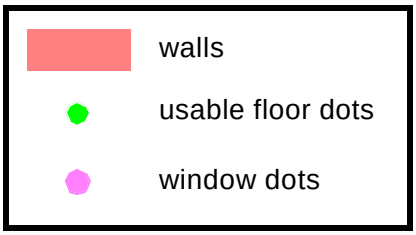
Example rental values for the floor plans at the left are:

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

2nd floor = $1000*\sqrt{2*6*1}$ = $3,461

3rd floor = $1000*\sqrt{3*12*0}$ = $0

4th floor = $1000*\sqrt{4*12*8}$ = $19,596



Appendix II: Lego Building Rental Value Calculation Worksheet

Earthquake Engineering Project

Company Name	
Building Owner	
Architect	
Engineer	
Builder	

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

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

Appendix III: Lego Floor Plan Layout Paper

Appendix IV: Comments from 3rd Grade Students after Spring 1999 Project

- I learned that a lot of earthquakes can happen easily. You have to build a building very strong. I enjoyed building the Lego project. It was fun to see the buildings on the earthquake machine. Our building was the first to collapse.
- I learned that the El Centro earthquake is too severe for Legos. The two buildings that were on the El Centro earthquake were thrown off quickly. If you have fear then I don't think you can face a earthquake.
- I learned a lot about earthquakes. I learned that people can put rubber under a building to protect it. The El Centro was a devastating earthquake. I also liked learning that it is hard to build an earthquake proof building.
- I enjoyed making the buildings. I learned how severe and important to make sure the building is safe. Now I've seen how buildings can fall on top of each other. I now know that sometimes they put rubber under the buildings. I think it was neat when you put the magnet in the liquid.
- My group worked to make a strong building. I learned that they put rubber underneath.
- My group and I started to make our own things. Then we put them together. I liked the way the machine works to make the buildings fall. I thought your slides were neat. I learned earthquakes are very dangerous. And I really think the man-made island is neat and scary and very dangerous. I couldn't believe how money the California earthquake cost, $15,000,000,000. I liked when you put the liquid in the cup then you put the magnet on and the liquid could not come out.
- I learned a lot about earthquakes today! If one tall building might collapse onto another. I enjoyed the earthquake simulator. Our building lasted all three earthquakes. Today was really fun!
- I learned all buildings are different, and some are made to go throughout certain things. There is a certain liquid that a magnet could attract. Scientists put rubber under some buildings.
- I thought it was a great experience to be able to do this. It was fun building it with my group. We all made the building together and shared all the jobs. I think it was very neat at the end because we tested all the buildings. Ours was the second to last to fall. We learned that if you make it thinner at the top, it makes it easier not to fall. In a Californian earthquake 1,500 people injured, and to fix everything it costs 15 billion dollars. A certain liquid can attract from a magnet. I learned that most buildings are different. I learned that most earthquakes are very severe. Since I know so much about earthquakes now, I don't think I want to live near ones.
- I learned that earthquakes can be very severe. My group and I built a building and tested it on an earthquake thing that made it seem like an earthquake. It was a great experience. Near the end Dr. Spencer put a liquid in a cup. He put a magnet on the cup. He poured it on Suva’s head. It wouldn't come out.
- I liked making the Lego buildings. I learned how to make a sturdy and good-looking building. My group tried to make an interesting and sturdy building. But obviously our plan didn't work because we were the first team to fail. I learned that it's hard to outsmart nature. I also learned about how severe earthquakes can be.

- I learned that earthquakes are very deadly. El Centro is one of my favorites. I really liked the slides. I learned that no two buildings are not synchronized. I don't know the name of the one that happened in the center of Kobe, Japan.
- I liked this project because I learned a lot of things. Our group built a tower that stood up good. We each kind of did a section and then put them together. I learned that when you put springs or rubber underneath so the building is stronger. I learned that the El Centro earthquake was huge. I saw a special liquid that when you put a magnet to it, it makes it tougher. I got to see a simulator when it was working. There is a special thing you put on top of a building so it will not shake very much.
- My group tried to make the most windows, but we only made about 10 windows. There was a building that was a thousand years old. There are some people who put rubber under the buildings.
- My group focused on the decorating on the top. Our fall wasn't very severe. Ours didn't even have any cracks. Some of the earthquake slides looked very severe. I liked the El Centro earthquake best. California had some bad earthquakes too. The rubber that's put on the bottom of the building, the rubber has a connection to the building, and the rubber helps the building survive. It can also be used with springs.
- I learned a lot about balance. It was really fun building with the Legos. It was exiting watching the buildings in the earthquake. It was fun watching the buildings improved. We tested our building a lot but we messed up at the end. The pictures of the earthquakes were neat. I bet if these were real big buildings it would have cost a lot of money in damage. I think it would be fun if we do that again next year. I am very glad we do not live near earthquakes. I wish I could build buildings like that every day. I learned that earthquakes can be very, very dangerous. It was a very good week for all of us. I guess it is really hard to outsmart nature. I thought the neatest slides were of the buildings that had lost a floor.
- I liked making the building. I also liked testing them. I learned that they put rubber under the building. Now I know how severe earthquakes can be. I'm happy he put a magnet on the bottle.
- I enjoyed making the Lego houses. I learned that people put rubber under a building to protect it. There is a certain liquid that a magnet attracts. The Lego houses on the earthquake simulator never would have survived the El Centro earthquake. Our group made the Lego house look like a person.
- I learned the El Centro earthquake in California was very severe. It was fun making buildings out of Legos. It is incredible how buildings can crack but not collapse. It was a great experience. The people in my group were Rebecca, Ben, and Max. I enjoyed the project.
- When I grow up I think want to be an architect. I learned to build, work in a team, to be an architect, and to secure the building. Another thing I learned is how earthquakes can do so much damage in about fifteen seconds! Those shock absorbers are really cool! The buildings are fun to watch shake back and forth. The one on the wheels I though it was going to lose. Thank you for coming.
- I really liked building the building the Legos. The earthquake simulator. The slides were interesting. I never new earthquakes were so short! It was fun learning about electro magnets. It

was cool when you showed the slides of the shock absorbers under the old city hall building. Learning about man-made islands was cool. I loved the project!

- I like to build the Lego building, then I like to see the building fall down and see the other buildings, and I the pictures you brought in for us to see. I learned that liquid if you put the magnet on the cup it freezes. I really liked the shock absorber I really liked the building on wheels.
- I really liked the earthquake thing. My building was the one who tied with the building with the decks. I was the architect for my group. Those earthquake slides were interesting. That experiment with the water. Also that oil stuff you almost spilled on my head. I enjoyed building our building. It's cool that you get a chance to play with Legos. I learned that if you put shock absorber under that building, it would save a lot of money instead of paying for the building to get fixed. I learned a lot. Thank you for coming!
- I liked the earthquake simulation. I think we should do it again sometime. I also liked it because we all worked with our classmates. The drawings that we made look a lot different from the way we made them out of Legos.
- I really liked the earthquake machine. It was really fun watching the building fall down. I learned a lot about building buildings. I liked the slides. It was fun building. I learned if you put shock absorber it will last longer. The magnetic liquid was cool. It was really fun watching the video with the water. Our building looked very, very cool.
- I really liked the earthquake simulation. Ever since I heard about it. I thought it would be really fun and it was. But we lost and didn't win anything. It was still really fun. It took it a long time, but it was fun. I really liked the liquid that hardened when it was near a magnet. I learned that shock absorbers can stop a building from falling.
- I really liked the earthquake simulation. I liked watching the buildings and seeing how long each building stayed. I never knew about the Kobe earthquake. I think it is interesting that you can put shock absorbers on a building. It is also interesting to me about the apartment buildings and how they fell and stuff. It was fun and interesting!
- I really enjoyed your presentation. The earthquake simulator was very cool. I liked building the Lego buildings and that we had engineers and all that stuff. My grandpa told me to build from big to small. He also told me to build it the littlest we could, but then it broke so we couldn't use it. He was an engineer so that's why I picked engineer.
- I'm sorry I didn't get to come. I heard it was really cool! I wonder what building stood up. I bet the earthquake simulator was cool. Well I'm sorry I couldn't be there for everything.
- I really liked when we got to start building the building. I was the builder. That was fun being the builder, and I liked when Troy said, “My Grampa said that we've got to build the building little to big.” So we did. Then Mary tested it, and it broke so Troy said, “Ok so maybe Grampa doesn't know what he's talking about.”
- I really enjoyed your presentation. What happened with our buildings was we all made buildings, and then we tested them and we saw which ones survived. After, there were two champions. So we whacked one and then we built another. Then we tested the other new building against the other building and found out that the new model was stronger. Ours didn't win any judging contests, but we did win for the strongest. I really liked the black liquid also.

- I liked the earthquake simulator. It was fun building the building. It was nice of you to come. I really liked when you put a magnet on the liquid and it wouldn't come out.
- I really liked the earthquake. I saw one in Chicago. I learned teamwork. I was the building owner. We made our building really strong. But our building fell down quick. You taught me a lot about earthquakes. I thought it was neat how you put that liquid in the shock thing and you put that magnet on. I liked playing with the Legos. I saw the pictures you gave us.
- I really liked the earthquake simulation because I liked building the buildings, even though our building took a long time, and someone broke it after we had spent a long time on it. It would be neat to put in a shock absorber. And I also liked the liquid magnet.
- I really liked the earthquake simulator. I also liked the building Legos. I also liked testing it. Our building looked nothing like the thing we drew Because we tried it, but it didn't work. I liked the electromagnet that got hard when the magnet was on it and soft when it wasn't on it.
- I really learned a lot. I learned how to build a perfect structure a learned where to put the right beams. I learned just the right amount of windows and floor space, and ours was one of the winning buildings. I learned a lot about how to build the perfect building. I really like that competition. I thought the different kinds of earthquakes. I learned that you have to have plans and keep on rebuilding it. We rebuilt our building over five times before we found the winning structure. Building beams and other safety materials was fun. I also learned about shock absorbers and what you have to do to keep a building in shape.
- I really like the earthquake simulator; it was a blast watching the buildings go down. But one thing I'm glad about, I wasn't in it when it was going down.
- I thought the earthquake simulator was really cool. My building was not the strongest, but it didn't really matter. It was one of the coolest projects I've ever done. Thank you so much for coming.