Abstract

eCYBERMISSION Team Name	Quake Safe
Team Grade	6th
Project Start Date	08/04/2013
Project Finish Date	03/02/2014

Describe your project and explain how you used STEM (Science, Technology, Engineering and Mathematics) to improve your community (250 words or less)

In 2010, a massive earthquake in Haiti killed over 200,000 people and damaged or destroyed almost 300,000 homes. Through our research, we learned that "earthquakes don't kill people; buildings do." Existing solutions such as base isolation systems and vibration control devices are simply too expensive for Haiti. Our project solves the problem of structural failure of houses during earthquakes. Our solution is a hyperboloid-shaped structure made of bamboo. We tested small scale prototypes on vibration tables at Battelle Labs and compared them to concrete models used as controls. The result was that the concrete models cracked or collapsed, while our hyperboloid house did not fail under any circumstances. Furthermore, after an extensive cost analysis, we found that our Quake Safe House would be very affordable and only 10% of the cost of a comparable concrete building. We used Science to develop our solution, Technology to collect our data, Engineering to create our design, and Mathematics to analyze our data. Next, we plan on building a full-scale model and adding features to make this house a livable home, such as windows and doors. We also plan to reach out to organizations like Architecture for Humanity, US Army Corp of Engineers and FEMA for professional and financial support to help make our idea a reality in Haiti and other countries. We believe our Quake Safe House could save thousands of lives in an earthquake and prevent millions of dollars in damage in Haiti and other developing countries that experience earthquakes!

Tips for writing your abstract:
- Do not go into too much detail about one certain area - be brief!
- Include a problem statement and/or your hypothesis
- Summarize procedures and the important steps you took to solve your problem
- Briefly discuss your observations and results
- Summarize conclusions and/or next steps
- Do not go over 250 words!

*Please e-mail completed abstracts to swhitsett@ecybermission.com or fax to 703-243-7177 by April 15.

State
Ohio
Grade
6th
Mission Challenge
Environment
Method
Engineering Design Process
Students

Papaya (Submitted on: 3/4/2014 2:10:54 PM)
Tangerine (Submitted on: 3/4/2014 2:09:49 PM)
Pineapple (Submitted on: 3/4/2014 2:10:29 PM)

Team Collaboration

(1) Describe the plan your team used to complete your Mission Folder. Be sure to explain the role of each team member and how you shared and assigned responsibilities. Describe your team's process to ensure that assignments were completed on time and deadlines were met.

Our team has 3 members: Papaya, Tangerine and Pineapple. We have met about 4 hours a week since August 2013 in order to make sure that we had enough time to design, test and analyze our idea. In order to complete our Mission Folder, we divided the work evenly, but we did have specific areas of focus based on our strengths:

1. Pineapple led our research in books, websites and journal articles. He analyzed the data that we collected from our experiments. Pineapple also coordinated our visits to Battelle to test our designs on their shake table.

2. Tangerine led the experiments on the shake table at Battelle. He created our private team website to facilitate communication between team members. He was also in charge of maintaining our bibliography and designing our prototype models.

3. Papaya was in charge of putting together our concrete models for testing. She also led our interviews with experts. She coordinated all of the written documentation and was the main editor of our Mission Folder.

To ensure that project tasks were completed on time and deadlines were met, we posted the assignments and deadlines on a private team website, and we used Google Docs to collaborate on our Mission Folder outside of our meetings. We set fun goals to encourage each other to stay on track. We also shared what each member did during the week to make sure that every team member was aware of the project's progress (see attached Task Schedule). After working together to create and test our solution, we divided up the questions to complete each part of the Mission Folder.

Uploaded Files:

- [**View**] **Task Schedule** (By: Tangerine, 03/04/2014, .pdf)

Team's schedule of tasks to complete the Mission Folder.

Engineering Design

Problem Statement

(1) What problem in your community did your team try to solve? Why is this problem important to your community?

On January 12, 2010, a 7.0 magnitude earthquake hit the country of Haiti, killing 221,000 people, injuring 350,000 and leaving over 1.5 million people homeless. The disaster cost a staggering $7.8 billion, including 188,000 homes damaged and 105,000 homes destroyed (Figure 1). For our team, the earthquake in Haiti was more personal. A few months before the earthquake, one of our team members met a team of visiting students from Haiti. After the earthquake, we worried about how they were affected. Fortunately the students' hometown was far enough from the epicenter to be safe, but this motivated us to learn more about earthquakes and the problem of how to keep people safe during an earthquake in a poor country like Haiti.

The U.S. Geological Survey predicts that another big earthquake will likely hit Haiti in the next 20 years, so if this problem is not solved, many more people could be killed. Some assume that an earthquake of this large magnitude would be equally destructive in any part of the world, but our research suggests that this is not the case. We learned that the damage in Haiti was severe because of the lack of proper building materials and construction techniques. Buildings in Haiti are often built with unreinforced or cheap concrete, and walls are not built to withstand the lateral forces that occur in an earthquake. Haitians live on an average of only $2 per day, so most earthquake resistant solutions that are common in wealthier countries are simply too expensive.

Because of the problems of buildings in Haiti, we brainstormed possible housing structures that could withstand earthquakes but still be affordable. We came up with an innovative hyperboloid shaped house made of high strength bamboo connected by flexible joints. By testing our design on a vibration table at Battelle Labs, we found that our Quake Safe building was much better than standard concrete buildings and nearly impossible to break. We therefore believe that our Quake Safe hyperboloid house provides an affordable solution to protect people from earthquakes, not only in Haiti but also other developing countries.

(2) List at least 10 resources you used to complete your research (e.g., websites, professional journals, periodicals, subject matter experts).

1. Experts:

Anderson, Desiree, Chief Innovation Advisor, FEMA. "Natural Disasters." Telephone interview. July 2013.
Clay, John D., Battelle Special Programs. "Architecture Testing." Personal interview. September 2013.

Donovan, Darcey, CEO, Pakistan Straw Bale and Appropriate Building (PAKSBAB). "Earthquake Resistant Housing for Third World Countries." Personal interview. February 2014.

Esber, Patrick G., Battelle Test Engineer. "Architecture Testing." Telephone interview. November 2013.

Greene, David C., Professor of Geosciences, Denison University. "Third World Architecture." Personal interview. November 2013.

Nakamura, Yosio, Professor, Institute of Geophysics, University of Texas at Austin. "Seismology." Personal interview. August 2013.

O'Brien-Schroeder, Ursula, Independent Civil Engineer. "Building with Concrete." Personal interview. September 2013.
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2. Internet Searches:

"Concrete in Practice." NRMCA (n.d.): n. pag. Web. http://www.nrmca.org/aboutconcrete/cips/16p.pdf.

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Londono, Ximena. "Evaluation of Bamboo Resources in Latin America." International Network for Bamboo and Rattan (n.d.): n. pag. Web. http://www.inbar.int/wp-content/uploads/downloads/2012/09/inbar_working_paper_no35.pdf.

Mills, Russell S., Helmut Krawinkler, James M. Gere. “Model Tests on Earthquake Simulators - Development and Implementation of Experimental Procedures.” Stanford University, June 1979. https://blume.stanford.edu/sites/default/files/TR39_Mills.pdf.

Noy, Ilan. "The Enduring Economic Aftermath of Natural Catastrophes." Vox. VoxEU, n.d. Web. 27 June 2013. http://www.voxeu.org/article/economic-consequences-natural-catastrophes.

O'Connor, Maura. "Haitian Earthquake Death Toll." Columbia Journalism Review. N.p., n.d. Web. Aug.-Sept. 2013. http://www.cjr.org/behind_the_news/one_year_later_haitian_earthqu.php?page=all.

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"Straw Bale House Survives Violent Shaking At Earthquake Lab." ScienceDaily. ScienceDaily, 05 Apr. 2009. Web. Oct. 2013. http://www.sciencedaily.com/releases/2009/04/090403104229.htm.

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Grigorian, Mark and Grigborian, Carl, “An Introduction to the Methodology of Earthquake Resistant Structures of Uniform Response,” Buildings (2012), 107. Print.

Hough, Susan and Jones, Lucille. “Earthquakes Don't Kill People, Buildings Do.” San Francisco Chronicle, 4 Dec. 2002. Print.

Sakamoto, T., Yamaguchi, Y., Sasaki, T., Takafuji, K., Kanenawa, K., “Investigation into Crack Phenomena of Unreinforced Concrete Structures for Aseismic Evaluation of Concrete Dams,” NIST Special Publication 1057 (2006). Print.

4. Reference Books:

"Earthquake Simulator Testing of Metal Building Systems." Structures Congress 2011. American Society of Civil Engineers, p. 693-704. Print.

Salvadori, Mario. Why Buildings Stand Up. New York: W.W.Norton & Company, 2002. Print.

Reitherman, Robert. Earthquakes and Engineers: An International History. Reston: ZSCE Publications, 2012. Print.

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(3) Describe what you learned in your research.

When we began researching earthquakes, we learned that "Earthquakes don't kill people, buildings kill people." When an earthquake occurs in a city like San Francisco, there are usually few casualties. However, when that same magnitude earthquake happens in a third world country like Haiti, casualties are magnified and hundreds of thousands of people often die. This is because the buildings in Haiti are very poorly built compared to buildings in first world countries.

Constructing proper buildings in Haiti isn’t as easy as you may think, due to many limitations. First, there is no national building code and houses are built according to what can be afforded. Second, Haiti suffers from extreme poverty and is the poorest country in the western hemisphere. Most Haitians live on only $2 per day. We learned from geology and geophysics professors that the concrete used in Haiti, Guatemala and other developing countries is often not reinforced with steel rebar. Also, these countries often try to save money by reducing the amount of cement in the concrete mixture, which reduces its strength even further.

If mixed with the proper amount of cement, concrete does have a very high compressive strength (4,000 psi) which makes it good as a floor, road or sidewalk. However, concrete has a very low tensile strength (only 500 psi) which makes it weak when flexed or twisted. During an earthquake, large shear loads are created due to the lateral motion (Figure 2). Unreinforced concrete lacks the flexibility and strength required to withstand such strong horizontal forces, so buildings made only of concrete will easily come tumbling down as soon as an earthquake occurs.

There are many solutions that have been designed to make buildings withstand an earthquake. One common solution is to build with materials that have a very high tensile strength such as steel (Figure 3). Unfortunately, steel is not a good option for Haiti because its cost is too high. Another solution used in Japan and California is called base isolation. Base isolation systems separate the building's superstructure from its substructure in order to reduce the amount of vibration that is transmitted from the ground to the building. In addition, many other high tech solutions have been developed, such as lead rubber bearings, spring dampers and roller bearings. All of these solutions work very well to withstand earthquakes, but they are just too expensive to implement in Haiti and other developing countries.

In order to find a solution more appropriate for Haiti, we researched possible building designs that could be simple to construct and use locally available, low cost materials. Through interviewing an independent civil engineer, Ms. Ursula O'Brien, we learned that most rectangular shaped buildings fail at their corners because of the stresses that develop during an earthquake. We brainstormed alternate shapes such as pyramids like ancient Egypt (Figure 4) and spheres (Figure 5). However, each shape has its own limitations and drawbacks. Pyramids have limited head room, so there is a lot of wasted space. Spheres are difficult to build and tend to leak because of their many seams.

While thinking about alternate shapes, we came up with the idea of a hyperboloid (Figure 6). This shape is actually pretty familiar as the cooling tower in nuclear power plants. Besides its effect on airflow in the cooling tower, the hyperboloid shape provides a high strength with a low amount of material required. We learned that hyperboloids can be made very easily with a series of straight beams at two different angles, forming an "X" pattern.

We also investigated materials that could be inexpensive and either locally available or grown in a country like Haiti. In our internet searches, we found a type of bamboo called Guadua Angustifolia, which is incredibly strong and flexible (Figure 3), resistant to damage from UV light, and grows extremely fast. In fact, once you plant the initial crop, this type of bamboo will continue to reproduce every year without replanting. Guadua Angustifolia bamboo grows to a height of 20m in just 4-6 months!

Based on our research, we concluded that our simple and strong hyperboloid shape combined with a very efficient, locally grown bamboo might provide a breakthrough solution to withstand earthquakes in Haiti.

Experimental Design

(4) Develop a design statement. Be sure to describe what exactly your device should be able to do. Do not describe HOW it's going to do what it needs to do.

Our goal is to design a low cost, earthquake resistant house that effectively reduces building damage and eliminates the need for highly expensive materials or control devices, so that the house is affordable for all.

(5) Determine the criteria for a successful solution and identify constraints for your design. Discuss what the device must have in order to accomplish its job and the restrictions of the device (i.e. the size, the cost, the weight, etc.).

Our design must fulfill certain requirements in order to make a successful solution that is earthquake resistant, low cost and liveable. The most important criteria for our design is that the building must exhibit enough structural strength to withstand the lateral forces of a high magnitude earthquake. Next, it must be very low cost so that citizens in any country around the world can afford it. Lastly, the house must be appealing and provide a comfortable living space.

(6) Identify the relevant variables you will use to test your prototype or model and explain how you will measure your variables.

The variables to be tested include the building material (concrete vs. bamboo) and the building structure (cube with solid walls vs. cube with pillars vs. hyperboloid). We will test our variables by building scaled prototypes and testing them on a vibration table at Battelle labs using a standard earthquake test procedure.

<u>Build Prototype or Model</u>

(7) Develop a design and list the materials you used in your design. Include technologies you used (e.g., scientific equipment, internet resources, computer programs, multimedia, etc.).

We built three types of scale models in order to test how well our Quake Safe design could withstand the forces of an earthquake. We made at least two models of each type so that we could repeat the test and evaluate different conditions. We used the following materials in our scale models:

(1) Quake Safe Hyperboloid House:

- 32 Bamboo skewers (4mm diameter) to make 12” diameter x 10” tall hyperboloid
- 224 Connectors (¼” rubber bands)
- Roof made of cardboard and corrugated aluminum foil
- 12” wood embroidery hoop to attach and support the roof

(2) Concrete Pillar House:

- 12 Concrete pillars (?” x ?” and 10” high) made using QUIKRETE(R) Concrete Mix #1101
- ASTM E11 Mesh 8 sieve to remove large gravel pieces
- Vaseline(R) used as a mold release
- Mortar made using QUIKRETE Mortar Mix #1102 to connect the pillars to the roof
- Plywood base with wood frame supports to act as the foundation
- 12” x 12” x ?” roof made of concrete

(3) Concrete Solid Wall House:

- 4 Concrete walls (12” wide x 10” high x 0.3” thick) made using QUIKRETE Concrete Mix #1101
- ASTM E11 Mesh 8 sieve to remove large gravel pieces
- Vaseline used as a mold release
- Mortar made using QUIKRETE Mortar Mix #1102 to connect the walls to each other
- Plywood base with wood frame supports to act as the foundation
- Roof made of cardboard and corrugated aluminum foil

For the vibration testing, we went to Battelle labs where they have a shake table that is typically used to test how products withstand vibration during shipping. Dr. Patrick Esber at Battelle taught us about a standard test specification (ETSI EN 300 019-1-4 V2.1.2) used to measure how well objects could withstand earthquakes . We used this test method to find out how an earthquake would affect each of our house models and at what conditions (peak ground acceleration in g and frequency in Hz) each model failed.

(8) Explain how you built your prototype(s) or model(s)? Include each of the steps in your process.

For our testing, we made a total of five scale model concrete houses to use as controls and represent typical building designs in Haiti. Three of the houses were built with solid concrete walls and two with concrete pillars. In order to represent a 30 foot wide concrete house, we designed our model as a cube and scaled down the wall length to 1 foot so that we had a scale ratio of 1:30. We divided all dimensions of a real house by 30 to get the dimensions for our scale models. Similarly, we scaled the model walls to 0.3" thick in order to simulate a 9" thick concrete wall like in Haiti. To make the concrete houses, we used QUIKRETE Concrete Mix #1101 (4,000 psi compressive strength). We were concerned that the larger pieces of gravel in the mix would be too large for the 0.3" walls, so we sifted out all of the gravel larger than 3/32" diameter using an ASTM E11 Mesh 8 sieve before mixing and pouring the concrete into the molds (Figure 7). We also covered the wooden frame molds with a thin layer of Vaseline before pouring the concrete so that the finished concrete pieces would come out easily.

Once we were done sifting, we added water and mixed the concrete. We then poured and spread the concrete mixture into twelve molds, each 12" wide x 10" high x 0.3" thick squares (Figure 8). To form the square houses, we connected the walls using QUIKRETE Mortar Mix #1102 (750 psi compressive strength) at the corners.

During our testing, we learned how important it was to carefully follow the directions for mixing the concrete. When we didn't use the correct amount of cement and water, the concrete pillars immediately broke when we removed them from their molds. However, when we tried again with the correct mixture, the pillars came out fine. Each of the pillars had a thickness of ?" x ?" and 10" high to model a real life building with 18" wide pillars (1:30 ratio). One house had twelve pillars and a solid concrete roof (0.3" thick). When we finished building the concrete houses, we glued each one to a wooden base for the vibration table testing.

For comparison, we made two scale model hyperboloid houses using the same scale as our concrete houses (1:30 ratio). The hyperboloids were made by weaving straight bamboo skewers, held together with ¼" rubber bands where they crossed. Each hyperboloid house was made of 32 bamboo skewers which were then glued to a wooden base. A roof was added to each house, made out of crimped aluminum foil with a wooden embroidery band around its edge for attachment and support. The roof was very lightweight and didn't add any structural strength to the house. After we were finished, the Safe Quake hyperboloid house with its bamboo frame and flexible joints seemed like it would be almost impossible to break.

Test Prototype

(9) Describe the data you collected and observed in your prototype testing (use of data tables, charts, and/or graphs are encouraged).

To test how well our Quake Safe design would survive an earthquake, we built scaled hyperboloid models using bamboo and we built models with solid concrete walls and with concrete pillars to use as controls. We tested all of the houses on a vibration table at Battelle labs to simulate an earthquake. Using a standard earthquake testing procedure (test specification ETSI EN 300 019-1-4 V2.1.2), we measured the peak ground acceleration and frequency at which each of the model houses fractured or failed.

The shake table at Battelle labs is normally used to test how products withstand vibration during shipping. Dr. Patrick Esber at Battelle taught us about a standard test method to measure how well objects would withstand earthquakes. We used this test method to find out how an earthquake would affect each of our house models and at what conditions (peak ground acceleration in g and frequency in Hz) each model failed.

The vibration tests showed that our hyperboloid Quake Safe house did not fail at any frequency or amplitude (Figure 9)! In contrast, we found that the concrete pillar houses failed completely at a peak ground acceleration of 2.5g and 9Hz. The houses made of solid concrete walls were an improvement, but they still failed at 2.5g and 12Hz, which is 33% higher than the failure frequency of the concrete pillar house. A short video of the testing results is attached in the next section (also available at http://youtu.be/L8Pb2WCnAkE).

In both types of concrete houses, the joints were the biggest point of failure, causing the houses to collapse. In our Quake Safe hyperboloid house, the flexible joints allowed the house to bend, but not break. As a result, the engineers at Battelle thought our bamboo hyperboloid house would be nearly impossible to break at any level of vibration on their table, and the testing results showed that our Quake Safe house could be a great solution for earthquake resistant housing in Haiti!

(10) Analyze the data you collected and observed in your prototype testing. Does your data support or refute your design statement? Do not answer with yes or no. Explain your answer using 'Our data supports/refutes the design statement because...'

Our data supports the design statement because it meets all of the design criteria for being earthquake resistant, inexpensive and comfortably livable. The data we collected and observed in our vibration table testing showed that both of the concrete houses failed under the earthquake test conditions, but our Quake Safe hyperboloid house did not fail under any test conditions. In fact, Battelle engineer Dr. Patrick Esber said that he did not think our hyperboloid house would fail under any seismic conditions. We also performed a cost analysis of our Quake Safe hyperboloid house and estimate that it would only cost about 10% of the cost of a comparable concrete house (Figure 10). Even though we didn't build a full scale Quake Safe house, we believe that the geometry of the hyperboloid would provide a spacious and comfortable living space.

(11) Explain any sources of error and how these could have affected your results

Our testing used scaled models that could have introduced sources of error. For example, we learned during our testing that the strength of the concrete depends on using an exact mixture of cement and water. When we didn't use the correct amount of cement and water, the concrete pillars immediately broke when we removed them from their molds. However, when we tried again with the correct mixture, the pillars came out fine. Therefore, one source of error is not using the exact same mixture of cement and water that is used to build concrete houses in Haiti. This difference could have strengthened or weakened the concrete model houses we tested.

Another source of error that could have affected our results was the size of the aggregates in the concrete mixture. Since we scaled our models with a 1:30 ratio, we had to sift the mixture to remove the larger sized rocks and pebbles. We could have possibly sifted too much and added too much cement and strength to the concrete, or we could have not sifted enough so that the concrete houses crumbled easier due to the larger rocks in the walls.

Lastly, the method of attaching the models to the wooden bases for testing could have made our models weaker or stronger. If they were attached too strongly to their bases, they might have transferred stronger vibrations to the models and made them break. On the other hand, if the houses were attached too loosely to their bases, they might have moved around during the vibration testing and made them more earthquake resistant. In both cases, the models might not have correctly represented full sized concrete or hyperboloid houses that were built on Haitian ground.

<u>Drawing Conclusions</u>

(12) Interpret and evaluate your results and write a conclusion statement that includes the following: Describe what you would do if you wanted to retest or further test your design. Evaluate the usefulness of your prototype or model. What changes would you make to your prototype or model for the future, if any?

Our shake table tests showed that our Quake Safe design (Figure 11) was far superior to the concrete houses used as controls. The concrete houses (both pillars and solid walls) showed catastrophic damage under the vibrational forces of the earthquake tests. They cracked and collapsed in a very short time. In contrast, our Quake Safe hyperboloid house was the only structure able to withstand the seismic forces of the shake table tests (see attached video or online at http://youtu.be/L8Pb2WCnAkE). There was absolutely no visible damage during or after the tests! Using the results of our testing, we concluded that Quake Safe has great potential for earthquake resistant housing.

We believe that our prototype was a realistic and useful test of the hyperboloid design concept. However, in the future we would like to further test our design by testing separately the hyperboloid geometry vs. the bamboo building material in order to determine their earthquake resistant properties. To do this, we would need to obtain additional shake table time so that we could conduct additional tests with other prototypes like a bamboo cube or a concrete hyperboloid, to ensure that our bamboo hyperboloid is truly the best choice.

We would also like to test a larger scale model and eventually a full scale house. In those tests, we would change our models to include realistic design features and test different foundations, doors, windows, walls, roofs and joints in order to measure the effect of those changes on earthquake resistance. With additional data, we believe that we would have a convincing and compelling story to make Quake Safe a reality in Haiti and other developing countries!

Uploaded Files:

- [**View**] **Figures** (By: Tangerine, 03/04/2014, .pdf)

  Figures for Mission Folder.

Community Benefit

(1) How could your design help solve your problem and benefit your community? Describe next steps for further research/design and how you have or how you could implement your solution in the future.

We believe that our Quake Safe hyperboloid house could save thousands of lives and prevent millions of dollars in damage because of its superior flexibility and strength during an earthquake. Its simple design and low cost materials gives our Quake Safe house tremendous potential to provide affordable earthquake resistant housing for countries like Haiti. We shared our work with Ms. Darcey Donovan, who designed earthquake resistant straw bale houses for Pakistan and is the CEO of a nonprofit organization called the Pakistan Straw Bale and Appropriate Building (PAKSBAB). Ms. Donovan thinks our project is “amazing and worthwhile,” and she encouraged us to keep working on it. She also thought that many people and organizations would be interested in providing financial support for our Quake Safe hyperboloid house.

The hyperboloid is a visually appealing, modern house shape for a community. In addition to being earthquake resistant, another benefit of our hyperboloid geometry is that the Quake Safe structure could be easily prefabricated and then collapsed to a bundle that is only 15% of its original expanded diameter. The entire frame of several Quake Safe houses could be transported on a single truck and used for either temporary emergency shelters or permanent homes. These collapsed structures could then be expanded like an umbrella to construct each house on-site. This ease of installation would save lots of time and money for the people of Haiti. Since all of the beams used are the same length, the Quake Safe house would be very easy to mass produce.

To further develop our solution, the first step would be to talk to architects and civil engineers to get advice on designing and constructing a large-scale model of our hyperboloid house that has windows, doors and everything to make it a livable home in Haiti. We would then test it on a full sized earthquake simulation table such as the one at University of Nevada.

We have several ideas for the walls and roof of our Quake Safe hyperboloid house. The outside material would depend on how the house is used. For temporary housing, the sides could be quickly and easily wrapped in a nylon or glass fabric. For permanent housing, the “wattle and daub” technique could be used to fill our bamboo structure with a mixture of clay, straw and sand. Other ideas for the outside wall include overlapping bamboo strips, vinyl siding or even stucco. The advantage of stucco is that it would provide resistance against fire.

For the roof, we think it should be a simple, lightweight sloped roof so that rainwater can be collected below. The roof could be constructed using cross beams made of bamboo which would be covered with corrugated steel, since this material is commonly available in Haiti. We also considered a roof made in the shape of an inverted cone (like a funnel), so that rainwater could be stored on the top of the house. The water on the top of the house could provide a simple, low cost solution for providing pressurized indoor plumbing.

The next step for further research would be to learn how to use Autodesk(R) CAD modeling software, so that our team can refine and test different materials and structures without the need to build physical models and use vibration tables. Autodesk provides free student licenses that we could use to further develop our hyperboloid design.

Finally, we plan to reach out to organizations like Architecture for Humanity, the US Army Corp of Engineers and

FEMA for professional advice and financial support to help make our idea a reality in Haiti and other poor countries that experience earthquakes. We have already been sharing our work to the public at local school and science museum events. However, we also plan to promote our idea through media, social networks and conferences, so that people are educated about the importance of earthquake safe buildings and maybe even engineers might be inspired to think outside-the-box about their designs!

Uploaded Files:

- [**View**] **Vibration Tests Video** (By: Tangerine, 03/04/2014, .swf)

  Video of vibration table tests at Battelle. This video is also available online: http://youtu.be/L8Pb2WCnAkE

eCyberMission Task Schedule
Quake Safe

Week beginning	Task	Team Member
8/4/2013	Review eCyberMission website.	Everyone
8/11/2013	Brainstorm problems and solutions. Identify problem of earthquake deaths.	Everyone
	Research causes of earthquake deaths.	
	Search for experts to interview.	
8/18/2013	Research Haiti 2010 earthquake.	
	Research building methods in third world.	Everyone
	Compile earthquake statistics in Google Docs.	
8/25/2013	Study low cost and green materials.	
	Construct hyperboloid sample.	
	Learn about 3D shapes for unusual buildings.	
9/1/2013	Summarize material properties for all options.	
	Filter, mix, and pour concrete to make solid wall houses.	Everyone
9/8/2013	Make additional hyperboloid models.	
9/15/2013	Interview civil engineer Ursula O'Brien-Schroeder. Research modern techniques to prevent earthquake damage. Investigate mortar to connect concrete walls.	Everyone
9/22/2013	Interview Jeff Walker of the International Association of Emergency Managers.	
	Research Haiti builing codes.	
9/29/2013	Make corregated roofs for concrete and hyperboloid models.	
	Visit building site to see traditional US building methods.	
10/6/2013	Research properties of all building types.	Everyone
10/13/2013	Build bases for all scale models.	
10/20/2013	Research vibration testing for earthquakes.	Everyone
10/27/2013	Visit Battelle and vibration lab. Interview Patrick Esber at Battelle.	Everyone
11/3/2013	Meet with David Green at Denison University.	Everyone
11/10/2013	Visit Logan Round House	
11/17/2013	Made concrete pillar houses and concrete roofs.	Everyone
	Repeat concrete pillar houses since first batch cracked.	Everyone
11/24/2013	Prepare hyperboloid model with solide walls.	

eCyberMission Task Schedule
Quake Safe

12/1/2013	Researched windows and doors for Quake Safe design.	
	Study types of siding for design.	Everyone
12/8/2013	Test concrete and hyperboloid prototypes at Battelle	Everyone
12/15/2013	Review videos and test results.	Everyone
12/22/2013	Write Mission Folder (divide up sections).	Everyone
12/29/2013	Write Mission Folder	Everyone
1/5/2014	Write Mission Folder	Everyone
1/12/2014	Work on figures for Mission Folder.	Everyone
1/19/2014	Review sections together.	Everyone
	Work on bibliography.	
1/26/2014	Revise figures section.	Everyone
2/2/2014	Contact Darcie Donovan to investigate full scale test.	
2/9/2014	Edit Mission Folder entries.	Everyone
2/16/2014	Edit Mission Folder entries.	Everyone
2/23/2014	Present concept at Stemfest at The Works Museum.	Everyone
3/2/2014	Wrap up everything and submit!	Everyone

Figure 1 Buildings destroyed in 2010 earthquake in Haiti.

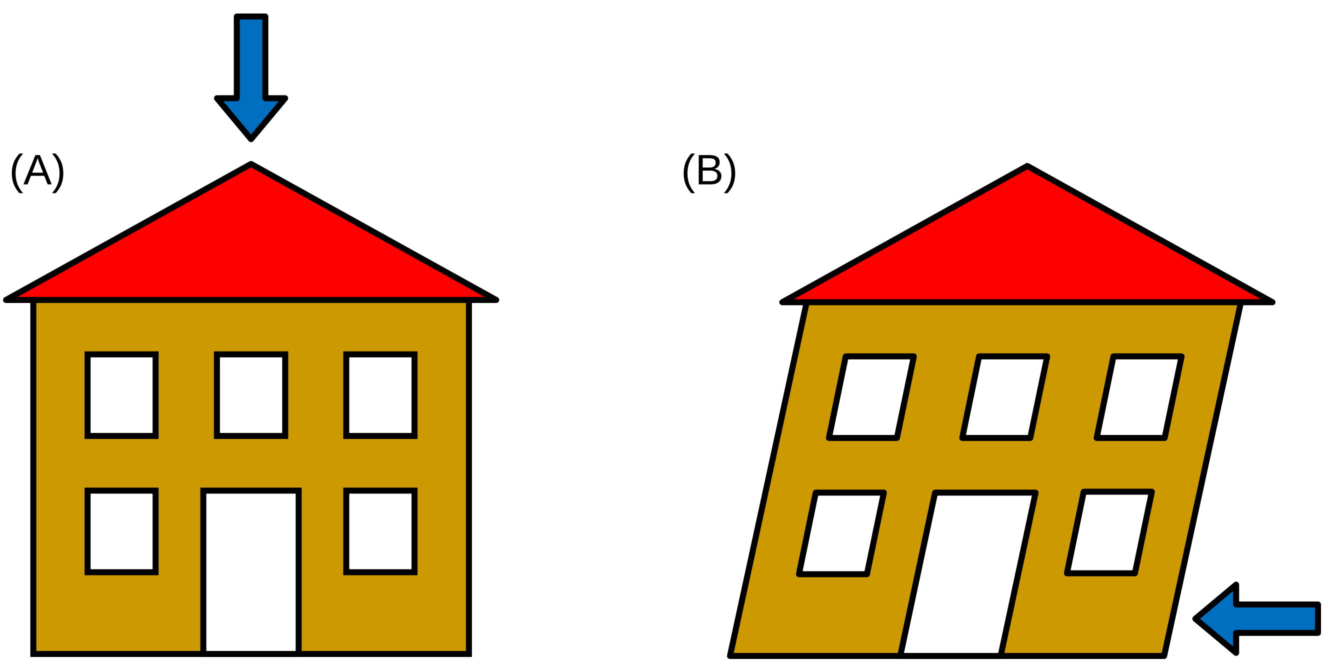

Figure 2 (A) Normal force of gravity. (B) Lateral forces of earthquake.

Material	Tensile Strength
Structural Steel	36,000 psi
Unreinforced Concrete	500 psi
Reinforced Concrete	2,000 psi
Bamboo (Guadua Angustifolia)	14,000 psi

Figure 3 Comparison of material properties.

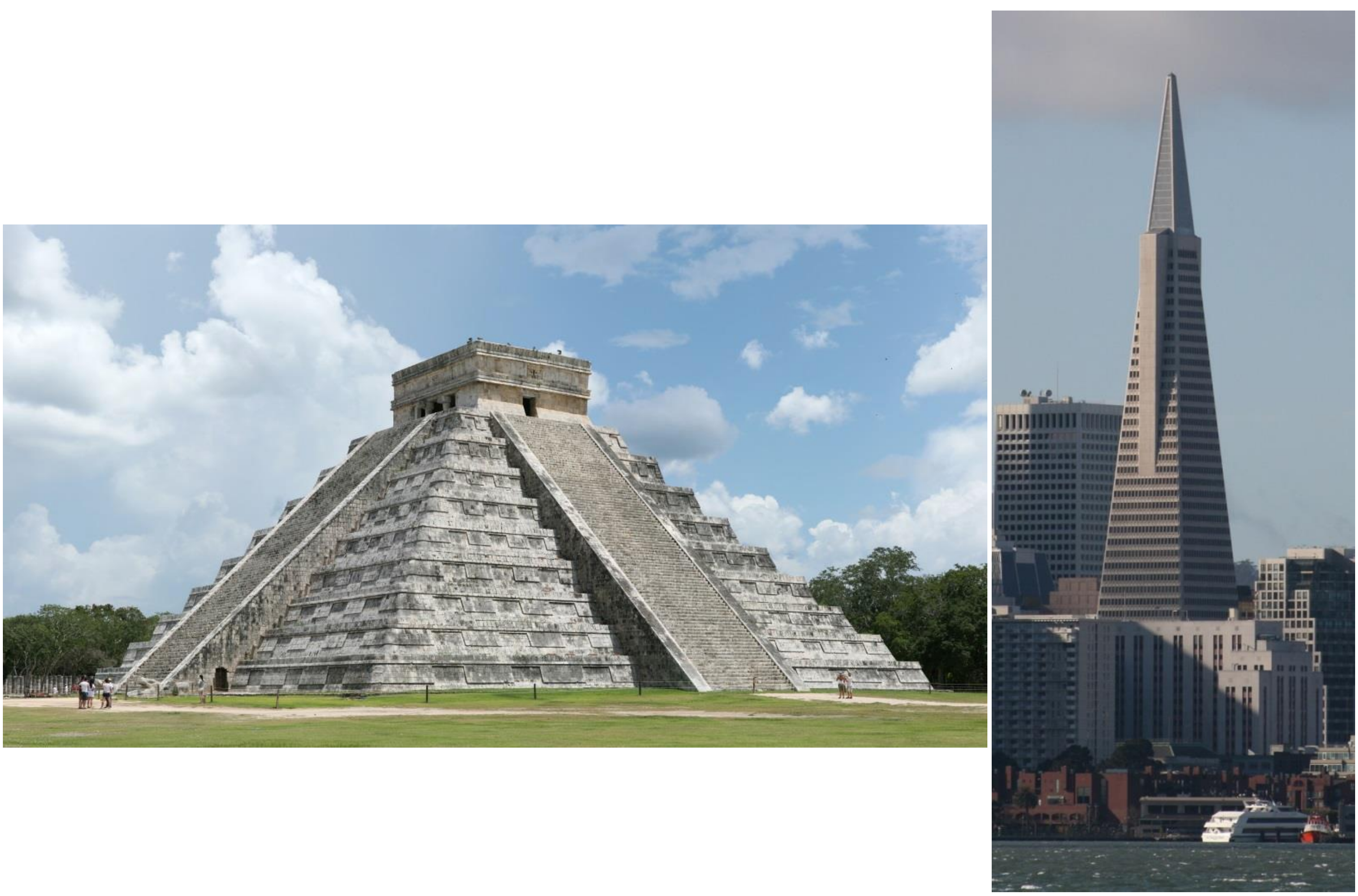

Figure 4 Pyramid shaped buildings.

Figure 5 Spherical shaped buildings.

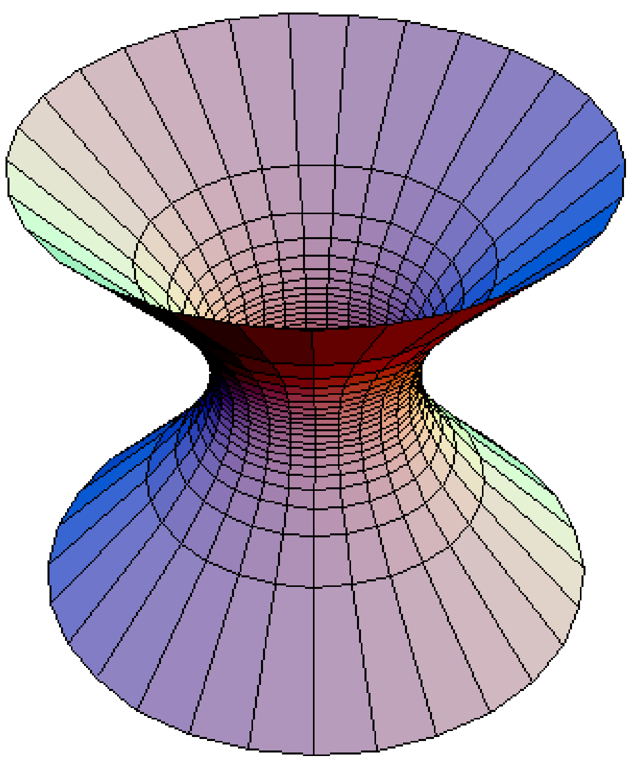

Figure 6 Hyperboloid shape.

Figure 7 Sifting out the larger gravel.

Figure 8 Casting concrete walls for scale models.

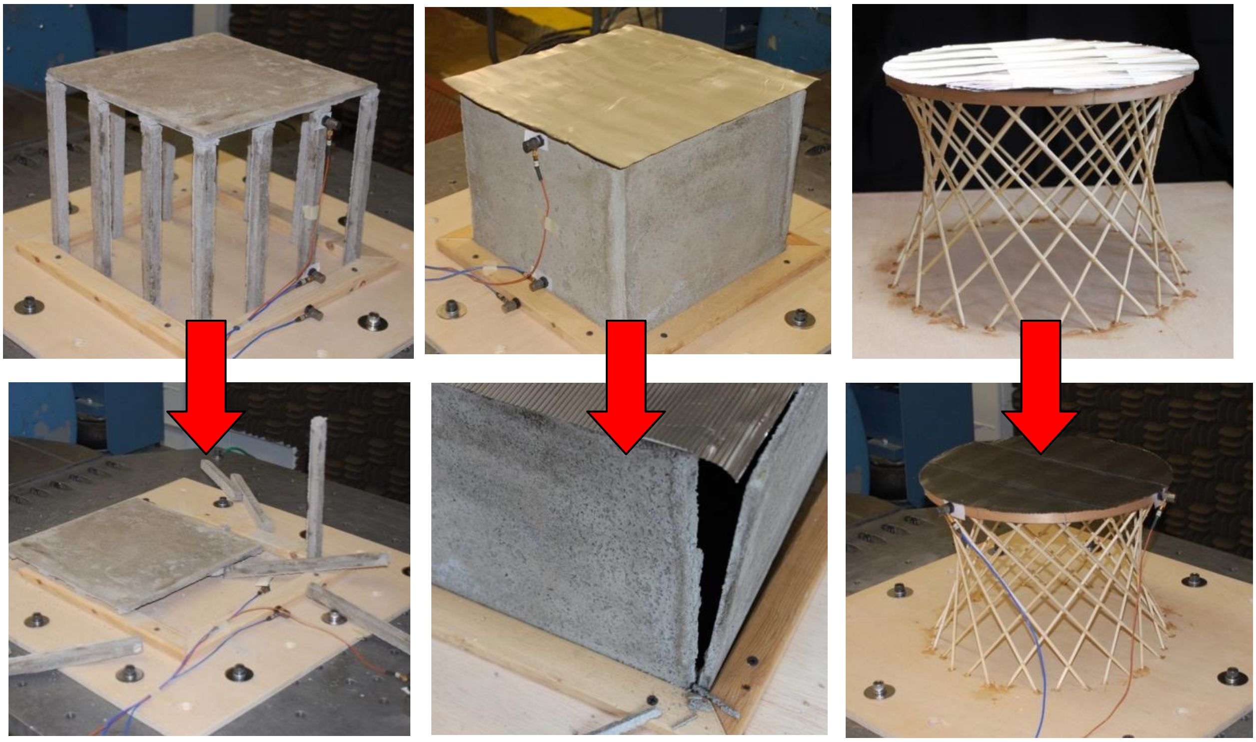

Figure 9 Results of vibration testing on concrete model houses versus bamboo hyperboloid.

Components[1]	**Traditional Concrete**	**Quake Safe House**
Raw Materials		
Structural frame	$ 3,000[2]	$ 100[3]
Walls	$ 2,800	$ 150-300[4]
Roof	$ 200	$ 200[5]
Transport to site	$ 500	$ 50
Labor[6]	$ 1,500	$ 300
Total	$ 8,000	$ 800-950

Assumptions:
[1]Area of house 20ft x 20ft.
[2]Concrete and block $15 per square foot.
[3]Guadua Angutifolia bamboo 32 beams @ $2.50 each. Connecting wire $20.
[4]Nylon fabric, bamboo stips, or stucco.
[5]Sloped corrugated metal roof, but could also be shaped to hold water.
[6]Average labor rate $0.50/hour.

Figure 10 Cost Analysis for building Quake Safe house in Haiti.

Figure 11 Model of our Quake Safe house.

Photo Credits

Figure 1 Haiti Earthquake: American Red Cross/Marko Kokic
https://www.flickr.com/photos/americanredcross/

Figure 4 Chichen Itza: Wikipedia
http://upload.wikimedia.org/wikipedia/commons/5/51/Chichen_Itza_3.jpg

Figure 4 Transamerica Building: Wikipedia
http://upload.wikimedia.org/wikipedia/commons/5/5f/TransamericaPyramidFromTI.jpg

Figure 5 Dome House: Scott Amus
http://farm3.staticflickr.com/2711/4326437580_d58d69fbe0_o.jpg

Figure 6 Hyperboloid: Wikipedia
http://upload.wikimedia.org/wikipedia/commons/7/7f/HyperboloidOfOneSheet.png

https://www.ecybermission.com/Advisor/ViewFile/11121