A Thesis

entitled

Investigation of the Seismic Capacity of a School Built with Recycled Materials

by

Joel A. Kozlesky

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Civil Engineering

Dr. Douglas K. Nims, Committee Chair

Dr. Mark A. Pickett, Committee Member

Dr. Andrew G. Heydinger, Committee Member

Dr. Patricia R. Komuniecki,
Dean College of Graduate Studies

The University of Toledo

May 2012
An Abstract of

Investigation of the Seismic Capacity of a School Built with Recycled Materials

by

Joel A. Kozlesky

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Civil Engineering

The University of Toledo
May 2012

In Guatemala, small one story school buildings are being constructed with concrete frames infilled with recycled plastic bottles. There are several benefits, such as being environmental friendly, ease of construction, and cheapness of construction. However, Guatemala is a seismically active area and the seismic capacity of this type of construction has not been examined. This combined experimental and analytical study addresses structural issues, the seismicity of Guatemala, the stiffness of the infill, the strength of the concrete used, and the ductility of the concrete frame. In this study a recycled plastic bottle building in Guatemala will be analyzed. The study will estimate the ability for this type of building, which is made out of concrete and the plastic bottle infill, to withstand an earthquake in Guatemala, based on the current construction. Thus the seismicity information data of the area will be determined along with the structural properties of the building. The importance of this study is the beneficial cost savings in new construction and saving lives of the children that will be attending school in these types of buildings in Guatemala.
For my loving parents, Charlie and Debbie Kozlesky. For their constant patience and
guidance through the course of my academic career.
Acknowledgements

The author would like to thank his Advisory Committee, Dr. Douglas K. Nims, Dr. Mark A. Pickett, and Dr. Andrew G. Heydinger. The author would also like to specially thank and express appreciation for the efforts of his Advisor Dr. Douglas K. Nims for suggesting the problem and for his beneficial guidance. Also thanks goes to Mr. Stan Radabaugh of Kuhlman Corporation for his expertise, advice, and recommendations about concrete. Also thanks goes to Mr. Jon DeWitt for his assistance in performing the experiments. Lastly special thanks goes to Mr. Chris Berry and Mr. Zach Balle of the Hug It Forward program in Guatemala for their coordination of information on the school buildings.
Table of Contents

Abstract ........................................................................................................................................ iii
Acknowledgements .................................................................................................................. v
Table of Contents ......................................................................................................................... vi
List of Tables ................................................................................................................................................ viii
List of Figures ................................................................................................................................................ ix
List of Abbreviations ......................................................................................................................... xii
List of Symbols .......................................................................................................................................... xiii

1 Introduction/Background ......................................................................................................................... 1
  1.1 Guatemala Seismicity ......................................................................................................................... 2
  1.2 Benefits of School Building ............................................................................................................. 3
  1.3 Challenges of the Study ..................................................................................................................... 4
  1.4 Construction Procedure and Quality ............................................................................................... 4
  1.5 Goals .................................................................................................................................................. 7

2 Testing and Analysis Procedures .................................................................................................................. 8
  2.1 Determination of Seismicity and Soil Properties ............................................................................. 9
  2.2 Concrete Strength .............................................................................................................................. 11
List of Tables

2.1 Concrete Mix Designs ......................................................................................... 12

2.2 Trial Concrete Mix Design ................................................................................... 13

3.1 Concrete Compression Test Results .................................................................... 21

3.2 Maximum Displacement of Various Loads on the Frame Model ....................... 28

3.3 Maximum Displacements of Full Building Model ............................................. 31

3.4 Capacity of Columns and Beams ........................................................................ 32

4.1 Recommended Concrete Mix Proportions ......................................................... 35

A.1 School Locations in Guatemala ......................................................................... 40

A.2 Test Locations in Puerto Rico ........................................................................... 40

A.3 ELF Results for Puerto Rico ............................................................................... 41
List of Figures

1-1 Tectonic Plates near Guatemala ................................................................. 3

1-2 Plastic Bottles and Chicken Wire ................................................................. 6

2-1 Frame Set-up for Push-over Test ................................................................. 14

3-1 Partial Response Spectra for Palmarejo, PR ...................................................... 18

3-2 Full Response Spectra for Palmarejo, PR ...................................................... 18

3-3 Partial Response Spectra for Guatemala ........................................................ 19

3-4 Full Response Spectra for Guatemala ............................................................ 20

3-5 Concrete Compression Strength over 28-Days ................................................. 21

3-6 Preliminary Model Set-Up .............................................................................. 25

3-7 Frame Model Set-Up ..................................................................................... 27

3-8 Maximum Horizontal Displacement of Frame Model ....................................... 28

3-9 Building Model Set-Up ................................................................................ 30

3-10 Deflected Shape of Building Model Due to the Response Spectra in the X-Direction and the Dead Load .............................................................. 31
B-1 Peak Ground Acceleration Map of Central America and Caribbean................. 42
B-2 School Location Map.................................................................................. 43
B-3 Roof System used in ELF ........................................................................... 44
B-4 Provided Drawing of School Building (Berry, 2011).................................. 45
B-5 Provided Drawing of School Building (Berry, 2011).................................. 46
B-6 Provided Drawing of School Building (Berry, 2011).................................. 47
B-7 Provided Drawing of School Building (Berry, 2011).................................. 48
B-8 Provided Drawing of School Building (Berry, 2011).................................. 49
B-9 Provided Drawing of School Building (Berry, 2011).................................. 50
B-10 Test 2 – 2 LVDTs, Force and Displacement over Time Lapse of Test ......... 51
B-11 Test 2 – 2 LVDTs, Force over Top LVDT Displacement............................ 51
B-12 Test 2 – Sting Pot, Force and Displacement over Time Lapse of Test......... 52
B-13 Test 2 – Sting Pot, Force over Displacement............................................. 52
B-14 Test 3 – 2 LVDTs, Force and Displacement over Time Lapse of Test ......... 53
B-15 Test 3 – 2 LVDTs, Force over Top LVDT Displacement............................ 53
B-16 Test 3 – Sting Pot, Force and Displacement over Time Lapse of Test......... 54
B-17 Test 3 – Sting Pot, Force over Displacement............................................. 54
B-18 Set-Up of Two LVDT Test .......................................................... 55

B-19 Location of Load Application ....................................................... 56

B-20 Four Inch Displacement during String-Pot Test .......................... 57

B-21 Incorrect Stopping Point of Concrete Pour .................................. 58
List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACI</td>
<td>American Concrete Institute</td>
</tr>
<tr>
<td>ASCE</td>
<td>American Society of Civil Engineers</td>
</tr>
<tr>
<td>ELF</td>
<td>equivalent lateral force</td>
</tr>
<tr>
<td>FHA</td>
<td>Instituto de Fomento de Hipotecas</td>
</tr>
<tr>
<td>LVDT</td>
<td>linear variable differential transformers</td>
</tr>
<tr>
<td>PR</td>
<td>Puerto Rico</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
</tbody>
</table>
List of Symbols

§.......................... Denotes section of a specified code

Δ.......................... Deflection
Δ_E.......................... Experimental deflection
Δ_M.......................... Model deflection
φ.......................... Capacity reduction factor
Ω_0.......................... Over-strength factor

C_d.......................... Deflection amplification
C_S.......................... Seismic response coefficient
E.......................... Subscript noting an experimental value
F_a.......................... Short-period site coefficient
F_v.......................... Long-period site coefficient
K.......................... Stiffness of the chicken wire
K_E.......................... Experimental stiffness of the chicken wire
K_M.......................... Model stiffness of the chicken wire
k.......................... Height exponent
M.......................... Subscript noting a model value
M_n.......................... Nominal moment
M_u.......................... Ultimate moment
P.......................... Force load in pounds
R.......................... Response modification coefficient
S_a.......................... Site-specific spectral response acceleration parameter
S_DS.......................... Design, 5 percent damped, spectral response acceleration parameter at short periods
S_D1.......................... Design, 5 percent damped, spectral response acceleration parameter at a period of 1 second
S_MS.......................... 5 percent damped, spectral response acceleration parameter at short periods adjusted for site class effects
S_M1.......................... 5 percent damped, spectral response acceleration parameter at a period of 1 second adjusted for site class effects
S_S.......................... 5 percent damped, spectral response acceleration parameter at short periods
S_1.......................... 5 percent damped, spectral response acceleration parameter at a period of 1 second
T_L.......................... Long-period transition period
T_used.......................... Period used
t………………..Thickness of the plate element
\(t_M\)…………Model thickness of the plate element
\(t_{new}\)…………New model thickness of the plate element
\(U_2\)…………Deflection in the y-direction
\(V\)…………Total design later force or base shear
\(w/c\)…………..Water to cement ratio
Chapter 1

Introduction/Background

To create an environmentally friendly and economical one-room school building in Guatemala, a novel infilled reinforced concrete frame is being used. Recycled plastic bottles filled with clean inorganic trash are being used as the infill. The infill is confined by chicken wire and a thin layer of concrete to cover up the wire and bottles to create walls. This infilled panel is the primary load path for horizontal seismic forces. With Guatemala located in a high seismic zone, a frame with adequate seismic resistance is crucial to keeping the school building standing in an earthquake. Some of these structures have been built already, thus causing the great need for a seismic study to be completed.

Guatemala is a predominantly Spanish speaking country located in Central America. It has an area of approximately 42,000 square miles (Guatemala Land Statistics, 2011), with a population of about 13.8 million people (Guatemala Demographics Profile, 2011). A comparison of Guatemala’s population density, in the region of 330 people per square mile, with the population density of the United States, of approximately 80 people per square mile, the population density of Guatemala is more than four times as dense as that of the United States. Approximately 50 percent of the population of Guatemala is urbanized; therefore demonstrating that a seismic event in
Guatemala can easily affect a vast number of people. Furthermore, 38 percent of the population of Guatemala is under the age of 15 and Guatemalans spend on average 11 years in school. While the literacy rate is approximately 70 percent, the education expenditures of the government is 3.2 percent of the gross domestic product (Guatemala Demographics Profile, 2011). These numbers demonstrate both the importance of education to the country as well as the large segment of the population that is or will soon be school age. Finally these demographics make obvious the need as well as the importance of safe school buildings that will withstand a seismic event.

1.1 Guatemala Seismicity

Guatemala is a high to very high seismically active area as it is at the junction of four tectonic plates; these being the North American, Pacific, Cocos, and Caribbean (see Figure 1-1). This seismic activity increases the urgency of determining the seismic capacity of the building, thus in case of a major earthquake in the near future, the school building can be deemed safe. With all these tectonic plates in the area, earthquakes are so very common, that this area is considered to be one of the most seismically active areas in the world. At some point there will again be a major earthquake, thus it is of the utmost importance to have the school buildings be able to withstand that earthquake. Because some of these structures have been built, the need for an estimate of the seismic capacity is critical. The main goal of this study addresses that need. If the school building is safe, it will allow safe evacuation of all people inside.
1.2 Benefits of School Building

There are several benefits to using recycled material for the school building, for example being environmental friendly, easy to construct, and relatively inexpensive to construct. With the building located in a third-world country, such as Guatemala, all three of these conditions are very important. This concept of using recycled material allows for an immense educational purpose for Hug It Forward, the organization that builds the buildings. This organization uses children to collect plastic bottles around the communities in which the school buildings are built. The children also fill the bottles with inorganic trash. This allows the organization to teach the children the importance of cleaning up the community and the process of recycling. In the end, the children therefore can get a regular education in the school that they helped build.
1.3 Challenges of the Study

There are several challenges when working on a project in another country. The first is the language barrier. All the drawings and most of the documents are completed in Spanish. Thus to understand the documents the engineer must translate them. The second challenge is the distance, thus causing questions and answers to take longer than anticipated to be completed. The lack of availability of design data is also a challenge. The inability to get direct hands-on observation or actual access to the structures makes assessment and acquisition of information difficult. The quality of joints will depend on craftsmanship; this is difficult to capture. The design code in the area is not to a high level of detail. The code used in Guatemala is Instituto de Fomento de Hipotecas Aseguradas (FHA), translated as Development Agency of Insured Mortgages. Fortunately, in FHA Section 5.6, it states that reinforced concrete structures are to be designed according to the present regulation of the American Concrete Institute (ACI) code, along with some local specifications.

1.4 Construction Procedure and Quality

The school building is constructed using reinforced concrete with recycled plastic bottle infill. The plastic bottles are filled with inorganic trash and are kept in place by chicken wire that is attached to the reinforcement (see Figure 1-2). Then a thin layer of concrete is placed over the wire to cover up the bottles to create the walls. The roof is then attached. Several different materials have been used for the roof construction of different schools. These roofing materials include some of wood or metal beams with corrugated steel topping and one school with a thatched roof made out of eucalyptus trees.
and bamboos struts with a palm covering. After the completion of the walls and roof, the walls are painted and the school is ready for use.

With the school building being in a third-world country, there can be a problem with construction quality. The joints and how the rebar is shaped in these areas can have an extreme effect on the strength of the building. In addition, the mixing of the concrete can be an issue. Currently the concrete is mixed by hand with shovels and hoes in a wheelbarrow; then it is poured into the frame with buckets. Therefore, there could be a major issue of the quality of the mix. Based on drawings of the school building provided by Hug It Forward and details on how the construction is completed, tests and analysis of the building can be completed. In this study a finite element model will be completed, as well as a test to determine the stiffness of the chicken wire, and a test of the concrete mix.
Figure 1-2: Plastic Bottles and Chicken Wire; (a) Photo of Plastic Bottles and Chicken Wire Infill (Berry, 2011), (b) Schematic of Plastic Bottle Wall Construction (Hug It Forward, 2011)
1.5 Goals

1.) The goal of this study is to make the recycled plastic bottle school safe for use.

2.) The overall solution must be consistent with the resources available in Guatemala. The affordability of the school must be preserved and the safety of the occupants must be assured.

3.) Another goal would be to propose construction standards to try to improve the buildings. These standards would include standards for mixing and placing the concrete; for the required amount of reinforcing steel; details on attachment of the chicken wire; placing the cover on the walls and in packing of the bottles; connection of concrete members; connection to foundations; and connection of roof.
Chapter 2

Testing and Analysis Procedures

This is a broad initial study and obtaining information is difficult. The objectives that are to be determined are as follows:

- The overall seismicity of the area needs to be obtained, as well as information about the soil conditions at the sites. The requirements and adequacy of the local codes need to be addressed.
- The concrete is hand mixed and hand placed, thus causing concerns about the mix design and curing.
- The provenance and dimensional consistency of the rebar need to be understood.
- The existing drawings give little detail about the stirrup placement and the development of the rebar in the joints.
- The quality of joints will depend on craftsmanship, and this is difficult to capture.
- The capacity of the chicken wire needs to be assessed and the anchorage details need to be evaluated.

It is possible that when a panel racks compressive forces that damage to the joints could be induced. It is possible that when the chicken wire is in tension, the anchorage
fails. It is also possible that given the light weight of the structure one relatively narrow shear wall on each side and adequate joint connectivity can make a robust structure.

Key aspects to take into consideration about the infill are the properties of the chicken wire and how they affect the building; also how the chicken wire is attached to the building. An assessment of the current design will be made based on the results of the finite element and the push-over test. Concrete behavior can be approximated with calculations and cylinder tests.

The key uncertainty is the behavior of the unique infill panel, so a test will be conducted to determine stiffness and capacity of chicken wire. This will give the basic information on the behavior of this new type of frame. This information will be used to define the stiffness properties of the frame in a finite element analyses. If the analysis shows the structure is seismically deficient, economical fixes will be proposed.

A conclusion will be made as to the safety of the school building during an earthquake. If the current design and construction procedure are not found to be adequate, then a new design will be made for new buildings and retrofit plans made for current buildings to make them safe for earthquakes. The overall solution must be consistent with the resources available in Guatemala. The affordability of the school must be preserved and the safety of occupants must be assured.

2.1 Determination of Seismicity and Soil Properties

With very little known about both the seismicity and the soil properties of the region, seismic design is challenging. The FHA code does not specify seismic design procedures. To use the ACI and American Society of Civil Engineers (ASCE)
procedures additional data had to be collected. The local construction manager of the school buildings stated that there are three main types of soil on which they are built; these being very clayish, volcanic rock, and heavy in limestone. With the soil classifications from ASCE 7-10 the volcanic rock and clay are soil classifications A and E respectively, the extremes. Thus these two scenarios will be studied.

The most difficult property to determine is how an earthquake will affect the school building in Guatemala, especially since it sits on four tectonic plates. Figure B-1, in the appendix, indicates that the peak ground acceleration for the country varies from 0.8 - 4.8 m/s\(^2\). However, this can not be directly used for determining the response spectrum that would affect the building. Figure B-1 also includes the peak ground acceleration for Puerto Rico, which is a territory of the United States. The United States Geological Survey (USGS) provides seismic hazard maps and data for all of the United States and its territories. An application on the USGS website provides a method of creating the response spectrum for a given location and soil location (i.e. a longitude and latitude with a soil classification).

Therefore, with this response spectrum for a location in Puerto Rico, a corresponding ratio of the peak ground accelerations of Guatemala and Puerto Rico can be applied. This will change the response spectrum in a proportional manner allowing for seismic design in Guatemala. As the locations of the school buildings vary greatly throughout the country (see Table A.1 and Figure B-2 in the appendix), the most critical scenario will be used for design.
2.2 Concrete Strength

One of the most important aspects to constructing a building out of reinforced concrete is the compressive strength of the concrete. Along with the strength another important aspect is the mix itself. Hug It Forward uses several different mixes for different static members of the school buildings. They have a different mix for the beams and columns, the foundation, and the several thin layers of concrete covering the chicken wire. The mixes are summarized in Table 2.1.

The strength of the concrete is stated to be 4500 psi in the design by Hug It Forward. However, it is very questionable if Hug It Forward is getting that strength since the organization has never tested any cylinders for compression and because of the procedures used to mix the concrete. The concrete is mixed by hand in wheelbarrows with shovels and hoes. This may not allow for consistent mixing. Also there is not a consistent amount of water that is put into the mix. The organization states that it only gets the mix wet enough that the mix looks like the concrete does that comes out of the back of the concrete truck in the United States. The static properties of the concrete being used are not known.
To try and capture the strength of the concrete mixes that Hug It Forward is using, a trial mix will be made. In determining the strength of the concrete mix an actual concrete mixer (Stow Manufacturing Company model number CM6) was used to mix the concrete. This will allow one to determine if the designed strength of 4500psi is being reached, since if the mix that used the mixer does not reach that strength, it would be unlikely that the hand mixed concrete would be greater than 4500psi. The trial mix will be based on the beam and column mix design provided by Hug It Forward, however, a predetermined water amount will be used to get a more consistent strength. The trial mix properties are shown in Table 2.2. After the mix was done a slump test was conducted along with a 7-day, 14-day, and 28-day compression test. These tests will determine if the concrete is workable and reaching the required strength.

Table 2.1: Concrete Mix Designs (Berry, 2011)

<table>
<thead>
<tr>
<th></th>
<th>Cement (bags)</th>
<th>Sand (buckets*)</th>
<th>Gravel** (buckets*)</th>
<th>Lime (bags)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns and Beams</td>
<td>1</td>
<td>3.5</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Foundation</td>
<td>1.5</td>
<td>5</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Floor</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Plaster^ (1st and 2nd)</td>
<td>1</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Finishes^ (3rd layer for wall)</td>
<td>0.25</td>
<td>3</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

*5 gal bucket (common in Guatemala)
**Gravel has 1-1.5cm diameter
^Finer, sifted sand
Table 2.2: Trial Concrete Mix Design

<table>
<thead>
<tr>
<th>Contents</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>47 pounds</td>
</tr>
<tr>
<td>Sand</td>
<td>1.75 buckets$^1$</td>
</tr>
<tr>
<td>Aggregate$^2$</td>
<td>1 bucket$^1$</td>
</tr>
<tr>
<td>Water$^3$</td>
<td>18.8 pounds</td>
</tr>
</tbody>
</table>

$^1$5 gal bucket  
$^2$1-1.5cm diameter  
$^3$w/c = 0.45

2.3 Push-over Test: Stiffness of Infill

A critical unknown that cannot be estimated is the stiffness of the chicken wire panels. This test allows for one to see how a member or frame reacts to an applied horizontal load. It allows for a time history to be produced for the loading and unloading to the frame. Also it allows for the stiffness of the frame to be determined. Once the test is completed and the data collected, the results can be input into a model such as a finite element model to allow for analytical determination of seismic forces.

In this study a 2x4 wooden frame was used, connected at the corners by small door hinges. Chicken wire will then be placed on both sides; with number nine deformed wire interwoven along each side. This represents the steel rebar that is used in the full scale version in Guatemala. The chicken wire is 20-gauge with a one inch opening. Tie wire is then used to keep the chicken wire taunt; a close up of this detail can be seen in Figure B-19. This set up allows the building (seen in Figure 1-2) to be modeled and determine the stiffness properties of the chicken wire. These properties are needed to determine the capacity of the chicken wire when a seismic event happens. Hug It Forward normally uses 22-gauge wire, however, 20-gauge was readily available here in
the United States thus it was used since it would be more conservative since it is a smaller wire. A larger wire would have a larger capacity. The frame used in testing is displayed in Figure 2-1. Once the properties are obtained the results will be applied to validate the finite element models and do further testing by analysis. The concrete plaster and finishes listed in Table 2.1 were neglected due to that fact that it was assumed that they would crack at the first sign of a seismic load and would not carry any load.

![Figure 2-1: Frame Set-up for Push-over Test](image)

2.4 Finite Element Model: Linear Elastic Response Spectra

A finite element model will be used to estimate the overall building response. In this study two models will be completed. The first will be a model of the scaled frame that was used in the push-over test. This will allow for the properties determined by the push-over test to be turned into an analytical approach. The second model will be of the
entire school building. This model will then be used to evaluate how a seismic event will affect the school building. Once the seismic load is applied to the model the results will allow one to determine if the school building is adequate for the high seismic region of Guatemala. SAP-2000 will be used to create these models.
Chapter 3

Results

3.1 Seismicity and Soil Properties

In determining how the school buildings would react to the seismicity of the region, three steps were taken. These steps included first deciding on soil types, followed by finding the response spectrum for a given location in Puerto Rico, and lastly converting this response spectrum for Guatemala.

Prior to running any tests some key variables had to be determined. These variables consist of the dimensions of the building and the weights of the first floor and the roof. The most extreme case was used for this test comprising the corrugated roof with small steel beams (W4x13) as the roof support. A drawing of this roof system can be seen in Figure B-3. This roof system differs from the thatched roof system seen in Figures B-4 to B-9. A thatched roof would react in a completely different manner since it is not an effective diaphragm. Further testing would be required to determine if a plastic bottle school building with a thatched roof would be sufficient in a seismic event. These values will used in the equivalent lateral force (ELF) method to determine how the school building will react to an earthquake. The weight of the building is also used in the ELF
method. The weight is show in Table A.3 and the procedure to determine the weight is outlined in Appendix C.

By using the application on the USGS website, three locations in Puerto Rico with two different soil type categories were used to find the most extreme values for the country. These locations can be seen in Table A.2. The two categories used were A and E, hard rock and soft clay respectively. These represent the volcanic rock and clayish soils in Guatemala.

After running the application certain variables had to be taken from the ASCE 7-10 code. This code is used for seismic design for buildings. These variables came from ASCE 7-10 Tables 1.5-1, 1.5-2, 11.6-1, 11.6-2, 12.2-1, 12.6-1, 12.8-1, and 12.8-2. With these values, equations from the ASCE 7-10 code, and the results from the USGS application the ELF method could be completed. The results of the ELF method for all the locations and soil types are shown in Table A.3.

The most extreme case was determined by the greatest base shear. This was determined to be 17.30 kips that occurred in Palmarejo, Puerto Rico with soft clay soil, shown in brackets in Table A.3. The response spectra for this scenario are shown in Figures 3-1 and 3-2. Therefore, this shows several extremely important findings: (1) the load is very small, (2) the capacity is adequate, and (3) the deformation will be addressed through proper construction design.
Figure 3-1: Partial Response Spectra for Palmarejo, PR

Figure 3-2: Full Response Spectra for Palmarejo, PR
From Figure B-1 a ratio for how the ground acts in Guatemala to Puerto Rico could be determined. The highest possible peak ground acceleration for Guatemala was used while the lowest possible peak ground acceleration for Puerto Rico was used to produce the most extreme case. These values were 4.8 m/s\(^2\) and 1.6 m/s\(^2\) respectively, for a ratio of 3.0. This ratio was applied to Figures 4 and 5 to produce the response spectra for Guatemala shown in Figures 3-3 and 3-4.

Figure 3-3: Partial Response Spectra for Guatemala
Figure 3-4: Full Response Spectra for Guatemala

Applying the 3.0 ratio to the base shear from Palmarejo, PR, the base shear in Guatemala would be 51.9 kips. This data will be used to apply to the finite element model to produce the frequencies of the building.

According to §12.8.1.3 of ASCE 7-10, there is a max value for some of the variables under certain conditions. The building in this study falls into this category. Thus some of the variables could be reduced. Nevertheless, the values were unchanged. This would create a case that was over designed causing it to be conservative.

3.2 Concrete Strength

Six concrete cylinders were made out of a trial mix, shown in Table 2.2, and were tested over a 28 day period. Two cylinders were put though a compression test at 7 days, 14 days, and 28 days respectively. The averages of the two cylinders on each day are
shown in Table 3.1 and the compression strength curve shown in Figure 3-5. The slump test produced a value of three inches. This means that the concrete is workable.

Table 3.1: Concrete Compression Test Results

<table>
<thead>
<tr>
<th></th>
<th>7-Day</th>
<th>14-Day</th>
<th>28-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (psi)</td>
<td>2149</td>
<td>2822</td>
<td>2232</td>
</tr>
</tbody>
</table>

Figure 3-5: Concrete Compression Strength over 28-Days

The most interesting thing that is shown in these results is the fact that the strength deceased from the 14-day test to the 28-day test. This should never be the case for a mix of concrete. Thus one of two conclusions could be drawn. The first being that the mix was not completely mixed or the second being that the machine testing the cylinders was not in balance. However, it can also be deduced that even if the strength would have continued to increase by the normal percentage amounts that concrete
normally does, it would have only been around 3000 psi. This is quite disconcerting since the design is to be for 4500 psi.

Several factors could have contributed to this rather low strength result. The first being the actual mix itself. The design of the mix might not be adequate; meaning that the proportions of cement, water, sand, and aggregate could be changed. The second would be the fact that the concrete was just poorly mixed. However, it still shows that even with a mixer, the concrete was not reaching the design value, thus making one wonder if mixing it by hand in wheelbarrows without even knowing how much water is going into the mix, can the concrete be reaching its full strength. In Chapter 4, recommendations on a new mix that will meet the design strength will be proposed.

3.3 Push-Over Test: Stiffness of Infill

The goal of the push-over test was to determine the stiffness of the infill. Since the plastic bottles making up the infill are non-load bearing, only the stiffness of the chicken wire was needed to be determined. This was accomplished by a series of different push-over tests on the frame pictured in Figure 2-1. Three two-part tests were completed. The first part of the test used two linear variable differential transformers (LVDTs) (Trans-Tek model number 0244). The LVDTs were attached at two different locations; one at the top, at the height the load was being applied, and the other at the halfway height. They were attached by a stiff wire that does not deform and remains straight. The wire was attached to a hood that was screwed into the frame. One hook was on each side of the frame to help keep the frame from twisting. Since the LVDTs only have a maximum range of two inches that can be measured, the second part of the test was necessary. The second part used an instrument called a string pot (Celesco
model number PT101-0010-211-1110). The string pot has a maximum range of 10 inches and was attached to the top of the frame. This allowed for a larger displacement to be applied to the frame. This was required since the frame did not yield under the smaller displacements. A load cell was attached to the end of the apparatus that applied the displacement to measure the load (pounds) that was required to create the displacement.

The LVDT test was conducted by first displacing the frame by one inch and returning it to zero. The frame was then displaced to two inches and returned to zero. This process was then repeated. The string pot test was also conducted by first displacing the frame by one inch and returning it to zero. The frame was then displaced to two inches and returned to zero. This process was continued to three inches and four inches.

In both tests the data from the LVDTs or string pot and the load cell was collected by a data acquisitioner and processed by a computer program. Once this data was compiled, data graphs were produced to determine the stiffness of the chicken wire. Test 1 was discarded as it was the first trial test and the data was faulty since the expected outcome was unknown. After knowing what to expect Tests 2 and 3 were completed to produce reliable data. The data was set into two types of graphs. The first type shows both the displacement and the force along two y-axes and the time length of the test along the x-axis. The second type of graph is a partial hysteresis loop. This is a plot of the force along the y-axis and the displacement along the x-axis. These graphs allow the stiffness of the chicken wire to be determined. Since the frame is only a one section piece and only one location of displacement, the stiffness matrix is only a 1x1 matrix. Thus the stiffness is just the slope of the line on the graphs. From averaging the slopes from both Tests 2 and 3 from different cycles of the load the stiffness was determined to
be approximately 17.5 lb/in. An approximate value is suitable since the quality of construction will be the determining factor on how the stiffness matrix would turn out, in consequence with how taunt the chicken wire is attached to the concrete frame. With difficulty in capturing the quality of construction without personal inspection an approximate value is acceptable. These graphs can be seen in the appendix in Figures A-10 to B-17, along with pictures of the test set ups and frame displacement in Figures B-18 to B-20.

3.4 Finite Element Model: Linear Elastic Response Spectra

The finite element models were used to analyze the structures in a variety of ways. Two main models were created along with a preliminary model.

This preliminary model was used to assist in converting the data provided from the stiffness test to be relevant in the finite element model. The preliminary model was a simple four member frame with a plate element representing the chicken wire with the default steel properties assigned. The four members each represented the two columns, Column C-1 and Column C-2, and the two beams, Intermediate Beam and Bottom Beam, designs respectively. The lower two nodes were pinned. This set up can be seen in Figure 3-6, while the design details of each member can be seen in the drawings provided by Hug It Forward in Figure B-6. The details for Column C-1, Column C-2, Intermediate Beam, and Bottom Beam are labeled on Figure B-6 in Spanish as Detalle Columna C-1, Detalle Columna C-2, Solera de Intermedia, and Solera de Humedad respectively. Note that to bypass the constraint in SAP2000 that a column must have four longitudinal bars. Since Column C-2 only has two longitudinal bars, the two bars in each row were placed
in the same location with half the diameter; thus this simulation only has two bars instead of the four required by SAP2000 and the ACI code.

A 1000 pound load was applied in the same plane as the frame along the intermediate beam. This resulted in a 0.025773 inch displacement of the top of the frame. The following equations were used to convert the data to a useful amount.

\[ K_E = \frac{P_E}{\Delta E} \]  
\[ K_M = \frac{P_M}{\Delta M} \]

Equation 1

Equation 2

Figure 3-6: Preliminary Model Set-Up
\[
\frac{K_E}{t_{\text{new}}} = \frac{K_M}{t_M} \quad \text{Equation 3}
\]

P and Δ are the load in pounds and the displacement in inches respectively, while E and M are the subscripts for experimental and model respectively. The thickness of the plate element that represents the chicken wire is denoted by \( t \), while K is the stiffness of the chicken wire. Equation 1 is the result from the push-over test. Thus as stated in section 3.3, above, the stiffness is equal to 17.5 lb/in (\( K_E \)). The 1000 pounds load was divided by the 0.025773 inch displacement in Equation 2 to produce a stiffness of the model equal to 38800 lb/in. These values were inserted into Equation 3 in addition to the default value of \( t_M \) of one inch that represents the membrane thickness of the chicken wire. This produced a new value of \( t \) to be equal to 0.000451 inches. The bending thickness of the chicken wire was set to equal zero since there is no bending occurring. The purpose of this process was to bypass the built in shell and plate theory of SAP2000. This allowed the chicken wire to be properly modeled in the final two finite element models, without a long series of tedious calculations. This new value of \( t \) is inserted into SAP2000 where the previous \( t_M \) was used.

The first main model completed in SAP2000 was one to replicate the frame from the push-over test with a slight addition. This frame was based on a whole single bay of the building to scale. This can be seen in Figure 3-7 and replicated from the drawings from Hug It Forward in Figure B-5. In addition to the prior Spanish translations the Top Beam is noted in Figure B-5 by Solera de Corona.
In this finite element model series of loads were applied to the model. These loads were 1, 5, 10, and 50 kips applied along the top beam. The maximum displacements occurred along the top beam and are summarized in Table 3.2. To correctly model the chicken wire, the new value of t was used. The restraints were taken to be fixed due to the foundations under the columns as seen in Figure B-5.

Figure 3-7: Frame Model Set-Up
Table 3.2: Maximum Displacement of Various Loads on the Frame Model

<table>
<thead>
<tr>
<th>Load (kips)</th>
<th>Maximum Horizontal Displacement (inches)</th>
<th>Maximum Vertical Displacement (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.065585</td>
<td>-0.00937</td>
</tr>
<tr>
<td>5</td>
<td>0.327927</td>
<td>-0.004687</td>
</tr>
<tr>
<td>10</td>
<td>0.655854</td>
<td>-0.009373</td>
</tr>
<tr>
<td>50</td>
<td>3.279272</td>
<td>-0.046866</td>
</tr>
</tbody>
</table>

A graph of the horizontal displacements is shown in Figure 3-8. This depicts that the frame is also relatively linear as the experiment model from the push-over test was seen to have been. Thus, concluding that the stiffness is correctly incorporated into SAP2000.

Figure 3-8: Maximum Horizontal Displacement of Frame Model
The second and final main model was one of the entire plastic bottle school building. The load applied to the building was the response spectrum for Guatemala produced by the procedure in section 3.1 and displayed in Figures 3-3 and 3-4. The same applications from the preliminary model to the frame model are applied in this model as well. The unique aspect to this model is that the roof is modeled as a rigid member so that it acts as one member instead of separate beams to simulate the roof acting like a diaphragm. A modal limitation was set for the model with a minimum of one mode and a maximum of 5 modes. The response spectrum was applied along both sets of walls (the x- and y-axis). This allows for the building to be analyzed for any direction from which the waves of the earthquake might approach the building. The set-up for the building is depicted in Figure 3-9 with all three sets of beams, both types of columns, the chicken wire in every bay that is not a door or window, and the rigid roof above with the two triangle sections made of solid concrete. The details for the building are shown in Figures B-4 to B-9; the only difference is the modeled building uses the steel beam and corrugated metal roof instead of the thatched as depicted in Figures B-4 to B-9. Another unique characteristic is that the dampening is assumed to 5% constant dampening because of the friction in the building. Lastly the roof is connected to the walls by pins, while the base of the columns modeled as fixed joints due to the foundations.
Once the load of the response spectrum was applied the building could be analyzed. The spectrum was applied in the x-direction only then in the y-direction only. The deflected shape of the building due to response spectra is shown in Figure 3-10. All the maximum displacements occurred along the top beam as expected. The results are summarized in Table 3.3. The model was run for both the designed 4500psi concrete and the 3000psi concrete strength estimate that the concrete mix is actually reaching.
Figure 3-10: Deflected Shape of Building Model Due to the Response Spectra in the X-Direction and the Dead Load

Table 3.3: Maximum Displacements of Full Building Model

<table>
<thead>
<tr>
<th>Max Deflection – psi</th>
<th>Along X-Axis Direction</th>
<th>Along Y-Axis Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4500psi</td>
<td>0.2102 inches</td>
<td>0.3453 inches</td>
</tr>
<tr>
<td>3000psi</td>
<td>0.2676 inches</td>
<td>0.4439 inches</td>
</tr>
</tbody>
</table>
It can be seen that the stronger concrete strength produces a smaller deflection due to a seismic event. Also these deflections are very small and as seen in the push-over test the chicken wire can withstand these deflections easily. Thus the concrete columns and beams would be the limiting factor. Based on the dimensions and steel reinforcement the design properties of the columns and beams for moment were determined and compared to the values produced in the finite element model. These results are compared in Table 3.4 below; only the most extreme cases are shown. The values are for the designed 4500psi compressive strength concrete.

Table 3.4: Capacity of Columns and Beams

<table>
<thead>
<tr>
<th></th>
<th>Design φMₙ (kip-in)</th>
<th>Mᵤ from Finite Element Model (kip-in)</th>
<th>Case from which it came</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column C-1</td>
<td>67.96</td>
<td>71.161</td>
<td>Dead Load + Response Spectra in x-direction</td>
</tr>
<tr>
<td>Column C-2</td>
<td>57.66</td>
<td>60.571</td>
<td>Dead Load + Response Spectra in x-direction</td>
</tr>
<tr>
<td>Intermediate Beam</td>
<td>47.52</td>
<td>86.443</td>
<td>Dead Load + Response Spectra in y-direction</td>
</tr>
</tbody>
</table>

As it can clearly be seen the moment provided by the design in each case is not sufficient to meet the required amount to support the building in a seismic event. These three values are for the max case for each type of element. The top beam and intermediate beam have the same dimensions thus the higher required moment was used for analysis. The majority of the elements do, however, have enough strength to meet the needs for the building to withstand a seismic event. Recommendations for how to increase the strength of these elements can be seen in section 4.2.
Chapter 4

Conclusion and Recommendation

4.1 Conclusion

It can be concluded that the plastic bottle school building does not meet the required conditions to withstand a seismic event. This is due first to the beam and column elements not being large enough or containing enough steel reinforcement; moreover second for the reason that the concrete mix is not achieving the design strength. Nevertheless, the strength of the chicken wire is satisfactory. The following conditions should be met to achieve a sound building in a seismic event:

- The concrete meets the designed strength.
- The construction quality of the beam-column joints is sound.
- The connections of the roof to the walls are pinned so that the roof and top beam move as one.
- Metal roof connected in such a way that it behaves as a shear diaphragm
- The chicken wire is correctly connected to the concrete frame in a taunt manner.
- Connection to the foundation is adequate
When a seismic event occurs, the first aspect of the building that will fail is the concrete due to cracking. The chicken wire will withstand a much greater deflection than what the concrete could. Thus leading to the conclusion, a recycled plastic bottle school building will withstand a seismic event in Guatemala if and only if the concrete frame of the building meets the requirements of the ACI code.

4.2 Recommendation for Improvements

Several recommendations are put forth for Hug It Forward. These recommendations all deal with construction quality since that is the limiting factor to the design of the plastic bottle school building.

The first recommendation is for Hug It Forward to make several concrete cylinders with the next batch of concrete that is produced. This will allow for the most accurate values of the concrete strength for their mixes to be determined. These cylinders can be sent to the most convenient location that can complete a concrete compression test on the cylinders.

The second recommendation is for the mixes to be modified. This recommendation is based on the results discussed in section 3.2. Since the concrete is not reaching 3000 psi, when it was designed for 4500 psi, additional strength is required. The main way of adding strength is to have stronger aggregate by using a proper mix of two aggregate sizes. Table 4.1 displays a recommendation for a stronger mix for the beams and columns, correlating to the trial mix in Table 2.2, which should meet the designed strength of 4500 psi. However, further testing of this concrete mix should be completed to confirm that it meets the designed strength.
Table 4.1: Recommended Concrete Mix Proportions

<table>
<thead>
<tr>
<th>Contents</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>47 pounds</td>
</tr>
<tr>
<td>Sand</td>
<td>1 bucket$^1$</td>
</tr>
<tr>
<td>Total Aggregate</td>
<td>1.75 buckets$^1$</td>
</tr>
<tr>
<td>0.4-0.6 inch diameter</td>
<td>0.875 buckets$^1$</td>
</tr>
<tr>
<td>1-1.5 inch diameter</td>
<td>0.875 buckets$^1$</td>
</tr>
<tr>
<td>Water$^2$</td>
<td>18.8 pounds</td>
</tr>
</tbody>
</table>

$^1$5 gal bucket  
$^2$w/c = 0.45

The switch in the sand and aggregate amounts is due to the fact that too much sand will cause the concrete to lose strength. Also having larger aggregate will cause the concrete to gain strength. The water used for making the concrete should be checked. If the water is contaminated at all, that can also result in the concrete to lose strength. The water amount should be predetermined in the design of the concrete as seen in the recommended mix, not just added at will. It is also recommended that at least a small portable concrete mixer be purchased. A concrete mixer will allow for complete mixing of all the elements making up the concrete, which can not be guaranteed by the current hand mixing techniques. A mixing procedure is outlined in Appendix C for using a concrete mixer. Also a concrete cold pour should not stop in the middle of a joint as seen in Figure B-21, but rather at the mid-height of the column. This will then not allow a discontinuity to form in the joint.

The third recommendation deals with the roof system. The heaviest system was tested and checks out. Therefore, the other lighter systems will also work. Nevertheless, the roof should always be securely connected to the walls of the building so they move as
one. Also the corrugated metal sheets should be overlapped and tacked down all along the roof; not just one sheet connected at each end. This method will allow the roof to not fail in shear.

The fourth recommendation is that when pouring concrete is finished for a section, the pour should not stop at a joint, as seen in Figure B-21, rather for it to stop at the mid height of a column. This will prevent discontinuities from forming in the joint, thus creating a stronger joint. Also the reinforcing studs used to hold the chicken wire should go all the way through the member, not just a short piece sticking out from each side.

This goes along with having good quality control. There should always be a knowledgeable construction manager on location that is inspecting all aspects of construction. The construction manager should be making sure that the chicken wire is taught, the reinforcement tied correctly, and the pouring of concrete ends in the correct locations.

Lastly for improvements to create stronger columns and beams, the following should be done:

- For Column C-1 the reinforcement bar sizes should be increased from 4-#3 to 4-#4. This will allow for there to be enough capacity to carry the required moments. Also there should be appropriate concrete cover for the reinforcement.

- For Column C-2 the reinforcement bar sizes should be increased from 2-#3 to 4-#3. This will allow for there to be enough capacity to carry the required moments and create better confinement. Also there should be appropriate concrete cover for the reinforcement.
• For the Intermediate Beam the reinforcement bar sizes should be increased from 4-#3 to 4-#4. This will allow for there to be enough capacity to carry the required moments. Also there should be appropriate concrete cover for the reinforcement.

• The Top and Bottom Beams have enough capacity as designed.

For the recycled plastic bottle school building to have the greatest opportunity to allow the occupants and the structure itself to survive a seismic event, a consistent set of construction standards should be adopted based on these recommendations and additional testing and analysis should be completed.

4.3 Recommendations for Further Studies

The following is a list of further studies that should be completed to further understand how a recycled plastic bottle school building will react to a seismic event:

• Site visit to determine the quality of construction. This would include investigating the roof connection, the concrete mix, the beam-column joints, and the chicken wire connections.

• Further investigation on the ground motion in Guatemala.

• Testing of new concrete mixes to make sure they meet the design strength.

• Testing of the chicken wire to failure.

• Conducting a full scale push-over test.

• Completing an inelastic analysis of the building.
References

http://geology.about.com/library/bl/maps/blcentralamerica.htm


Guatemala Demographics Profile. (2011, July 12). Retrieved December 2011, from indexmundi.com:
http://www.indexmundi.com/guatemala/demographics_profile.html


Appendix A

Tables

Table A.1: School Locations in Guatemala

<table>
<thead>
<tr>
<th>City</th>
<th>Approximate Latitude</th>
<th>Approximate Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilasco</td>
<td>15.12</td>
<td>-90.12</td>
</tr>
<tr>
<td>Chipocolaj</td>
<td>15.78</td>
<td>-90.23</td>
</tr>
<tr>
<td>Granados</td>
<td>14.63</td>
<td>-91.67</td>
</tr>
<tr>
<td>La Cereza</td>
<td>15.78</td>
<td>-90.23</td>
</tr>
<tr>
<td>La Gloria</td>
<td>15.56</td>
<td>-90.83</td>
</tr>
<tr>
<td>Las Mananitas</td>
<td>13.85</td>
<td>-90.38</td>
</tr>
<tr>
<td>Las Promesas</td>
<td>14.65</td>
<td>-90.51</td>
</tr>
<tr>
<td>Nueva Reforma</td>
<td>14.93</td>
<td>-91.91</td>
</tr>
<tr>
<td>Nuevo Paraiso</td>
<td>14.93</td>
<td>-91.91</td>
</tr>
<tr>
<td>San Francisco El Rio</td>
<td>19.84</td>
<td>-90.54</td>
</tr>
<tr>
<td>San Juan La Laguna</td>
<td>14.69</td>
<td>-91.29</td>
</tr>
<tr>
<td>Sepulau</td>
<td>15.78</td>
<td>-90.23</td>
</tr>
<tr>
<td>Todos Santos</td>
<td>15.50</td>
<td>-91.60</td>
</tr>
<tr>
<td>Tzibal</td>
<td>15.78</td>
<td>-90.23</td>
</tr>
</tbody>
</table>

Table A.2: Test Locations in Puerto Rico

<table>
<thead>
<tr>
<th>City</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carolina</td>
<td>18.38</td>
<td>-65.96</td>
</tr>
<tr>
<td>Palmarejo</td>
<td>18.04</td>
<td>-67.08</td>
</tr>
<tr>
<td>San Sebastian</td>
<td>18.33</td>
<td>-66.99</td>
</tr>
</tbody>
</table>
### Table A.3: ELF Results for Puerto Rico

<table>
<thead>
<tr>
<th>Location</th>
<th>Palmarejo, PR</th>
<th>San Sebastian, PR</th>
<th>Carolina, PR</th>
<th>[Palmarejo, PR]</th>
<th>San Sebastian, PR</th>
<th>Carolina, PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Class</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>[E]</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Ss (g)</td>
<td>1.295</td>
<td>1.173</td>
<td>0.966</td>
<td>[1.295]</td>
<td>1.173</td>
<td>0.966</td>
</tr>
<tr>
<td>S1 (g)</td>
<td>0.504</td>
<td>0.447</td>
<td>0.377</td>
<td>[0.504]</td>
<td>0.447</td>
<td>0.377</td>
</tr>
<tr>
<td>Tl (sec)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>[12]</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Fa</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>[0.9]</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Fv</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>[2.4]</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>SMs (g)</td>
<td>1.036</td>
<td>0.938</td>
<td>0.773</td>
<td>[1.166]</td>
<td>1.056</td>
<td>0.909</td>
</tr>
<tr>
<td>SM1 (g)</td>
<td>0.404</td>
<td>0.357</td>
<td>0.302</td>
<td>[1.211]</td>
<td>1.072</td>
<td>0.94</td>
</tr>
<tr>
<td>SDs (g)</td>
<td>0.691</td>
<td>0.626</td>
<td>0.515</td>
<td>[0.777]</td>
<td>0.704</td>
<td>0.606</td>
</tr>
<tr>
<td>SD1 (g)</td>
<td>0.269</td>
<td>0.238</td>
<td>0.201</td>
<td>[0.807]</td>
<td>0.715</td>
<td>0.627</td>
</tr>
<tr>
<td>Occupancy Category</td>
<td>III</td>
<td>III</td>
<td>III</td>
<td>[III]</td>
<td>III</td>
<td>III</td>
</tr>
<tr>
<td>Importance Factor</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
<td>[1.25]</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Seismic Design Category</td>
<td>Based on: SDs</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>[D]</td>
<td>D</td>
</tr>
<tr>
<td>Based on: SD1</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>[D]</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Based on: More severe</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>[E]</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Response Modification, R</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>[1]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Over-strength factor, Ω0</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>[2.5]</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Deflection Amplification, C_d</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>[2]</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Height Limit</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>[None]</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>T&lt;sub&gt;used&lt;/sub&gt; (sec)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>[None]</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Sa (g) @ T&lt;sub&gt;used&lt;/sub&gt;</td>
<td>0.691</td>
<td>0.626</td>
<td>0.698</td>
<td>[0.76]</td>
<td>0.698</td>
<td>0.594</td>
</tr>
<tr>
<td>Base Shear, V (kips)</td>
<td>15.38</td>
<td>13.93</td>
<td>11.47</td>
<td>[17.3]</td>
<td>15.67</td>
<td>12.9</td>
</tr>
<tr>
<td>k height exponent</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>[1]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Level</td>
<td>Story height (feet)</td>
<td>Story weight (kips)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 roof</td>
<td>2.3</td>
<td>5.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7.87</td>
<td>11.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>10.17</td>
<td>17.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The values in this table come from equations and tables in the ASCE 7-10 code.

Brackets [...] indicate extreme scenario.

The procedure in determining the story weight is shown in Appendix C.
Appendix B

Figures

Figure B-1: Peak Ground Acceleration Map of Central America and Caribbean (About.com, 2011)
Figure B-2: School Location Map (Hug It Forward, 2011)
Figure B-3: Roof System used in ELF
Figure B-4: Provided Drawing of School Building (Berry, 2011)
Figure B-5: Provided Drawing of School Building (Berry, 2011)
Figure B-6: Provided Drawing of School Building (Berry, 2011)
Figure B-7: Provided Drawing of School Building (Berry, 2011)
Figure B-8: Provided Drawing of School Building (Berry, 2011)
Figure B-9: Provided Drawing of School Building (Berry, 2011)
Figure B-10: Test 2 – 2 LVDTs, Force and Displacement over Time Lapse of Test

Figure B-11: Test 2 – 2 LVDTs, Force over Top LVDT Displacement
Figure B-12: Test 2 – Sting Pot, Force and Displacement over Time Lapse of Test

Figure B-13: Test 2 – String Pot, Force over Displacement
Figure B-14: Test 3 – 2 LVDTs, Force and Displacement over Time Lapse of Test

Figure B-15: Test 3 – 2 LVDTs, Force over Top LVDT Displacement
Figure B-16: Test 3 – String Pot, Force and Displacement over Time Lapse of Test

Figure B-17: Test 3 – String Pot, Force over Displacement
Figure B-18: Set-Up of Two LVDT Test
Figure B-19: Location of Load Application
Figure B-20: Four Inch Displacement during String-Pot Test
Figure B-21: Incorrect Stopping Point of Concrete Pour
Appendix C

Procedures

Concrete Mixing Procedure – for a small portable mixer (Pickett, 2011)

1. Pre-wet the mixer and let water sit inside for at least 5 minutes.
2. Add in half on the fine and half of the coarse aggregate, and mix for 1 minute.
3. Then add half of water, and mix for 1 minute.
4. Pour in the remaining fine and coarse aggregate, and a quarter of the water, and mix for 2 minutes.
5. Add the remaining water and all of the cement, mix for 5 minutes.

This procedure allows for a very distributed mix of all of the elements making up the concrete mixture.
Determination of the Story Weights Procedure

1. The weight of the concrete was taken to be 150 lb/ft$^3$

2. The total area of the columns was determined and multiplied by the height of the building and the weight of concrete to get the total weight of the columns equal to 4005 lb.

3. The total area of the beams and length of the walls were added to the weight of the columns to get the total weight of the walls equal to 19.514 kips.

4. The amount used in determining the weight for the first story is half the wall weight increased by 15% to take into consideration the weight of the plastic bottles, chicken wire, and steel rebar; 11.22 kips.

5. The roof weight was determined by adding the weight of the corrugated metal sheets, the weight of the steel beams, and the weight of the 2 triangle concrete sections above the top beam; 5.978 kips.