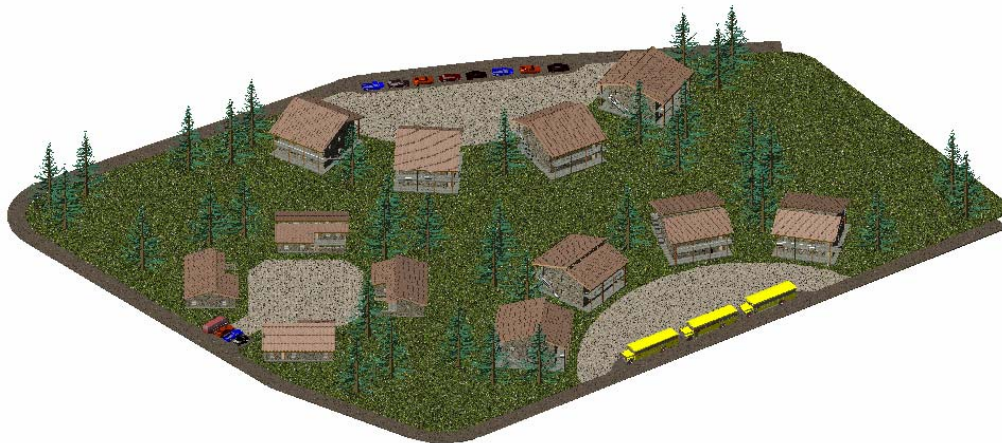


**FINAL REPORT:**  
**CAMPAMENTO SHALOM**  
**MAY 13, 2005**  
**ENGINEERING 340**



**TEAM #14**

**TEAM MEMBERS:**

Lou Davenport  
Laura McWethy  
Rebecca Mejia  
Eric Timmer

# Table of Contents

<b>1. EXECUTIVE SUMMARY .....</b>	<b>3</b>
<b>2. INTRODUCTION .....</b>	<b>4</b>
2.1. Project Background.....	4
2.2. Project Description and Scope .....	5
<b>3. PROJECT CONSIDERATIONS .....</b>	<b>6</b>
3.1. Local Materials and Construction Techniques .....	6
3.2. Design Codes .....	8
3.3. Design Norms .....	8
3.4. Economics.....	9
<b>4. DESIGN APPROACH .....</b>	<b>10</b>
4.1. Trusses .....	10
4.1.1. <i>Method</i> .....	10
4.1.2. <i>Small Group Cabin Truss</i> .....	11
4.1.3. <i>Casita Long Truss</i> .....	13
4.1.4. <i>Casita Short Truss</i> .....	14
4.2. Vertical and Horizontal Wall Reinforcement .....	15
4.2.1. <i>Alternatives</i> .....	15
4.2.2. <i>Final Design</i> .....	16
4.3. Floor Slab and Beam Design for Second Story Small Group Cabin .....	17
4.3.1. <i>Alternatives</i> .....	17
4.3.2. <i>Final Design</i> .....	18
4.4. Foundation .....	18
4.4.1. <i>Alternatives</i> .....	18
4.4.2. <i>Final Design</i> .....	18
<b>5. COST ANALYSIS .....</b>	<b>19</b>
<b>6. SOLUTION DISCUSSION.....</b>	<b>21</b>
<b>7. CONCLUSIONS/SUMMARY.....</b>	<b>21</b>
<b>8. RECOMMENDATIONS.....</b>	<b>21</b>
<b>9. ACKNOWLEDGEMENTS .....</b>	<b>22</b>

## **1. EXECUTIVE SUMMARY**

Team 14, Campamento Shalom, performed the structural analysis and design of two buildings. Both buildings are part of a master plan for the expansion of a Christian camp in Tonicapan, Guatemala. One building is a dormitory capable of housing forty-four people (and is referred to as small group cabin) while the other is a family-style house which can hold six to eight people (referred to as casita). The design for each building included truss layout, foundation, and wall design. The final products of the project were a full set of construction documents for each building, a cost estimate for the structural design portion of the project, and a 3-D rendering and fly-through video of each building for fundraising purposes.

## 2. INTRODUCTION

### 2.1. Project Background

In the spring of 2004, Team 14 decided they wanted to use their skills to help those in the developing countries. With this goal in mind, they contacted Engineering Ministries International (eMi), a Christian, non-profit organization based in Colorado Springs, Colorado which utilizes volunteer professionals to aid those in developing nations. Their contact with eMi placed them in touch with Randy Larsen, the head of eMi in Guatemala, who then assigned them to a project in Tonicapan, Guatemala.

The total eMi project involved the development of a master plan for Campamento Shalom, a Christian camp, as shown in Figure 1 below, which would improve the currently limited facilities and double the capacity of the camp from 250 to 500 campers.

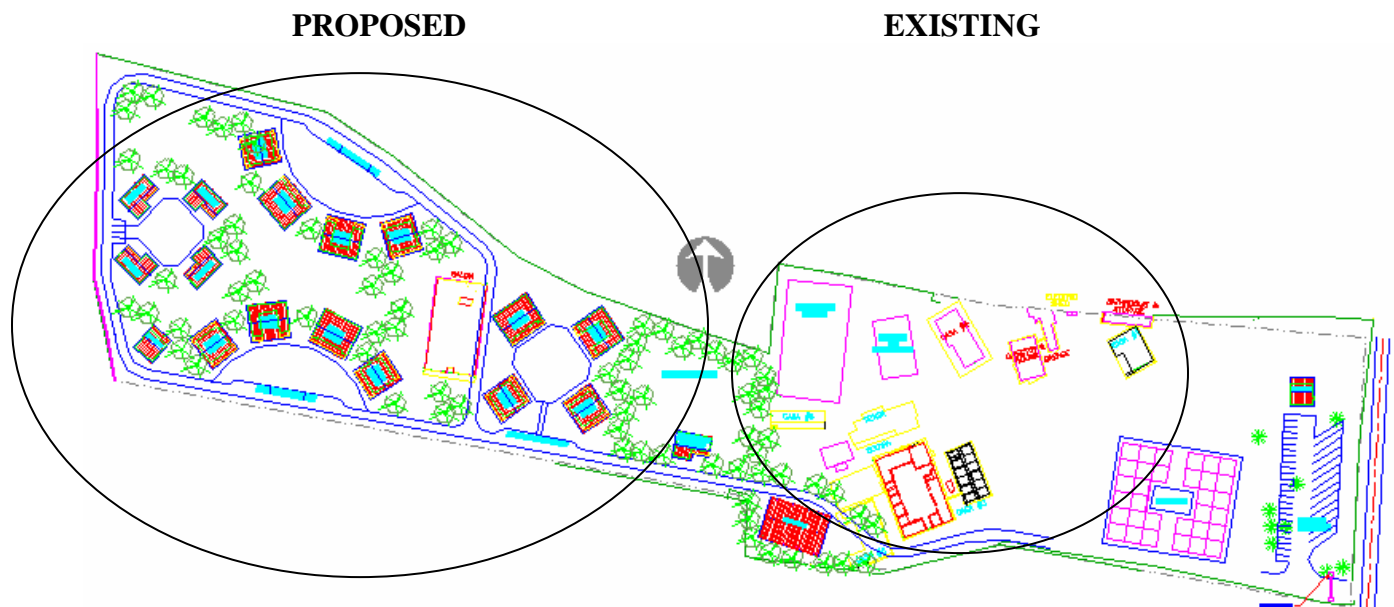


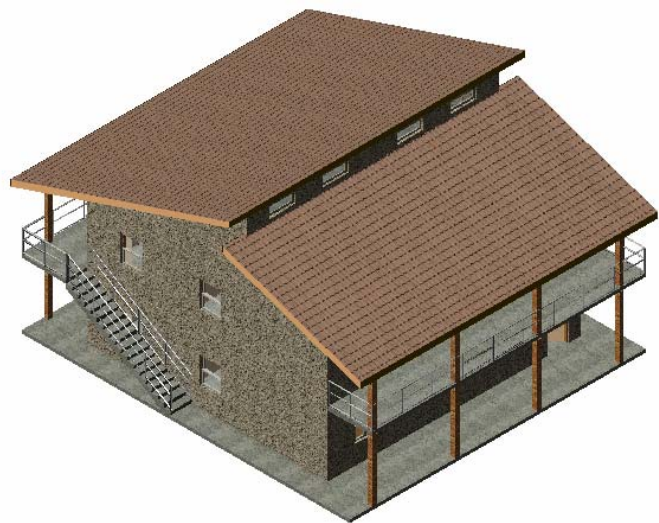
Figure 1: Campamento Shalom Master Plan

The portion of the project that Team 14 undertook was the structural design of two buildings, which would be replicated across the camp. The first building was a dormitory style building capable of housing 44 people (small group cabin) and the second was a family style house capable of housing 6 to 8 people (casita).

Eric Timmer and Lou Davenport were both able to visit the site in the summer of 2004, with a team of surveyors, architects and civil engineers volunteering with eMi. They stayed in Guatemala for one week and were able to photograph the site, take soil borings, and document different construction methods used in the area, as well as develop the master plan in conjunction with Randy Larsen and other members of the eMi staff.

## ***2.2. Project Description and Scope***

This project entailed the structural analysis and design of a 44-person dormitory and a 6-8 person family-style house, as shown in Figures 2 and 3. The elements included in the design were the trusses, slab, vertical and horizontal reinforcement, and foundation design. The final deliverables of the project included complete structural construction documents for each building, a detailed report outlining the design procedure, a preliminary cost estimate of the structural portion of the buildings, and three-dimensional renderings to be used for fundraising purposes.



**Figure 2: Small Group Cabin Rendering**



**Figure 3: Casita Rendering**

In addition, Team 14 also performed the analysis of two existing roof trusses to determine if they needed to be replaced and designed replacement wooden trusses. The report detailing analysis and design, along with all

calculations can be found in Appendix A.

### **3. PROJECT CONSIDERATIONS**

#### ***3.1. Local Materials and Construction Techniques***

Many considerations went into the definition of the problem to be solved by Team 14. One of the first defining characteristics was the locality of the project. To ensure a successful design, local materials and construction techniques had to be researched and taken into consideration. This had several ramifications for the project. First, steel had to be used only for the truss design since it is an expensive material in the area. Using double angled steel truss members is typical in Guatemala, even though steel is fairly expensive. The country outlawed the use of timber recently due to the country's diminishing tree supply. Before this law was set in place, most of the trusses were made out of timber. The cost of steel goes by the weight per linear foot so it is not always better to have the flanges be shorter while the thicknesses are larger.

Second, the majority of the buildings are made out of concrete and concrete (CMU) block, which is the case with most buildings in Guatemala. This block, however, is used predominantly for infill and has very little load bearing capacity.

Third, vertical and horizontal reinforcement is designed to go along doors and windows. Wall reinforcement is where the biggest differences occur between Guatemalan and American

construction techniques. In Guatemala it is typical to use a grid of vertical and horizontal wall reinforcement instead of typical American steel columns.

This can be seen in Figures 4 and 5. These wall reinforcements consist of a cage of rebar made up of usually four bigger bars running the full length, either vertically or horizontally, with ties every 6 to 12 inches. As the building goes up, concrete is poured around the cage to create, in effect, a rigid frame. The reinforcement is typically placed every 4 to 8 feet, for two reasons. First, their concrete masonry



**Figure 4: Vertical and Horizontal Reinforcing**



**Figure 5: Close-up of Rebar Cages of Vertical and Horizontal Reinforcing**

block does not have the load bearing capacity that is characteristic of American block as mentioned above. And secondly, this rigid frame resists earthquake shear forces by helping the building move as a single unit instead of each floor moving separately. In keeping with the culture, this method of construction was employed in the design of these buildings.

Finally, the foundation design used in Guatemala is similar to the U.S. but is constructed differently. In America, wood or metal panels are typically used to form the foundation. In Guatemala, it is typical to dig out the bottom width of the foundation and pour the concrete into this hole. The depth of the foundation is also not as great as in the U.S., as there is no need to be below the frost line.

### ***3.2. Design Codes***

In the U.S., structural engineers are required by law to use either Allowable Strength Design codes or Load and Resistance Factor Design codes, but there are no such requirements in Guatemala. To avoid inconsistency, Team 14 primarily followed the Universal Building Code (UBC) in their design, as that is the most common code used in Guatemala. Because of this, the buildings follow much more stringent requirements than in typical Guatemalan construction.

### ***3.3. Design Norms***

Another consideration which helped shape the project was the incorporation of design norms. While many are applicable, one of the most important to this project was cultural appropriateness, as discussed in the local construction techniques and building materials. Team 14 wished to honor the culture and maintain a design that fit into the infrastructure of the country. This affected the entire design of the buildings from material selection to erection specifications.

Transparency was another design norm that was incorporated in the final product, as the construction documents needed to be simple and easy to follow for the local workers. All of the plans were done in English and then translated to Spanish, which was also a consideration involving transparency.

In addition to these, trust is a design norm inherently important to structural engineering and consequently was to this project. With any project that has the potential of injuring many people in the case of failure, it is important that the design be trustworthy and have a factor of safety built into it. To ensure a trustworthy design, all calculations and construction documents were reviewed by two professional engineers. Furthermore, the design was done by following design codes, such as UBC.

### **3.4. *Economics***

As this project will be built completely on donated funds, economic considerations played a large role in design decisions. Team 14 had to ensure that the design was not only structurally sound, but also optimized to a low-cost solution. In most developed nations, construction techniques are continually being optimized in order to reduce the amount of labor involved. However, construction labor in Guatemala is very inexpensive when compared to the cost of materials. As a result, the design incorporated techniques that took advantage of this. An example was using steel only in the trusses.

## **4. DESIGN APPROACH**

### **4.1. Trusses**

#### **4.1.1. Method**

All trusses were designed using the computer program STAAD.Pro. Results from this program were verified with hand calculations, shown in Appendix B. The goal was to design each truss to be the most economically feasible (by minimizing the weight of steel) yet still capable of supporting the given load. Double-angle steel members were used for all trusses.

To begin, the general outline of each truss was taken from the architectural drawings provided by eMi. Using this, the outline of the truss was drawn in STAAD.Pro and internal members were added based on symmetry and placement of supports. Loads for each truss were originally calculated using ASCE 7 and can be found in Appendix B. The total dead, live, and wind load came to 39 psf for the small group cabin (44-person building) and to 44 psf for the casita (6-8 person building).

Randy Larsen reviewed the load calculations and stated that the loads could be decreased to 15 psf total for dead, live, and wind load along with the self weight of the truss itself, even though this did not meet US standards. While the 15 psf total load was smaller than what was calculated for dead, live and wind combined for each truss, Randy assured that the load would be safe and appropriate for the type of material being used and was a typical value for that area of Guatemala. This is partially due to the roofing material, which is made out of a lightweight corrugated aluminum material called lamina. In addition, the area is not susceptible to strong wind currents due to its geographic location.

The small group cabin required 4 trusses, all of which were identical to each other. The casita required six trusses. Of these, three trusses were shortened to allow for the porch area in the front of the building.

The required weld lengths were calculated according to LRFD specifications and can be found in Appendix B. Cross-bracing was also added to provide for lateral support between trusses. This was designed according to Randy Larsen’s specifications and runs underneath the roof lamina sheeting.

### 4.1.2. Small Group Cabin Truss

#### 4.1.2a. Alternative Designs

Figures 6 through 8 below show the three different truss designs that were originally developed.

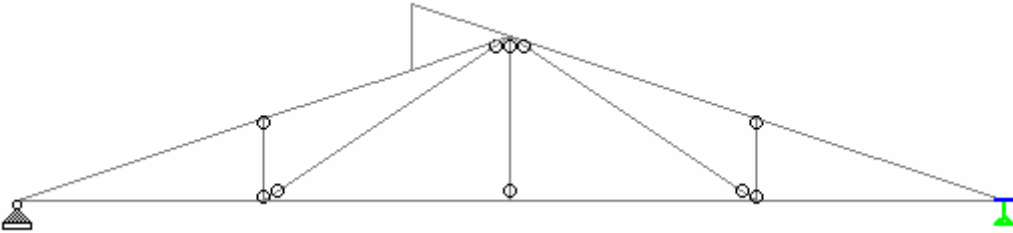


Figure 6. Truss 1 (Small Group Cabin)

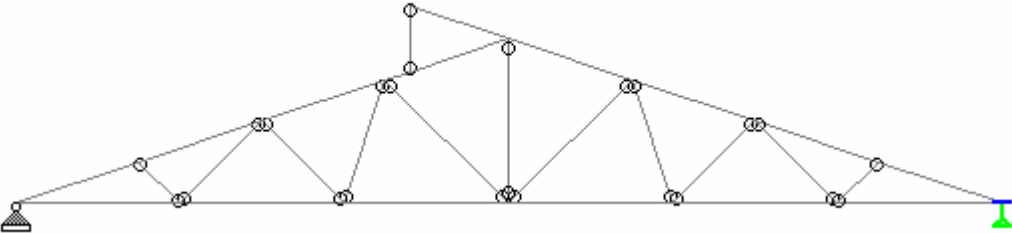
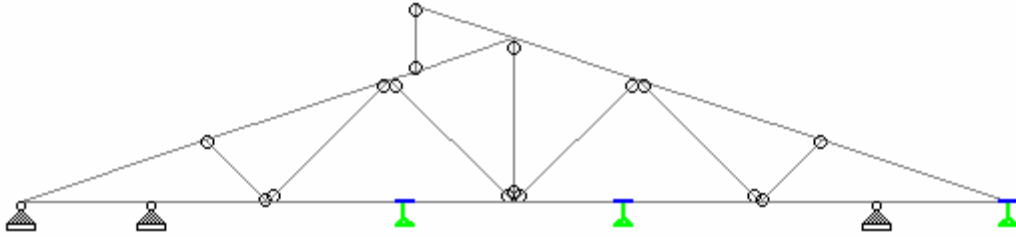


Figure 7. Truss 2 (Small Group Cabin)

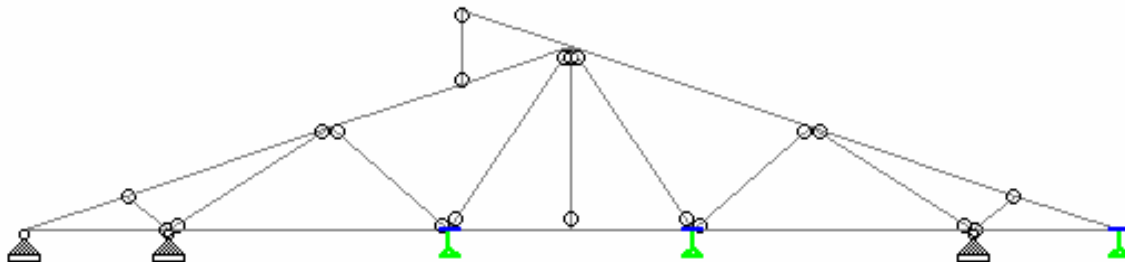


**Figure 8. Truss 3 (Small Group Cabin)**

The truss in Figure 6 was unable to support the calculated load, while the truss in Figure 7 was over designed. The truss in Figure 8 supported the calculated load according to output from STAAD.Pro. However, it did not have interior members at the supports. This was problematic because the truss had no vertical component to take the load at the support point, which would have resulted in bending along the bottom chord.

#### **4.1.2b. Final Design**

In the end, Truss 4 in Figure 9 was chosen as the final design.



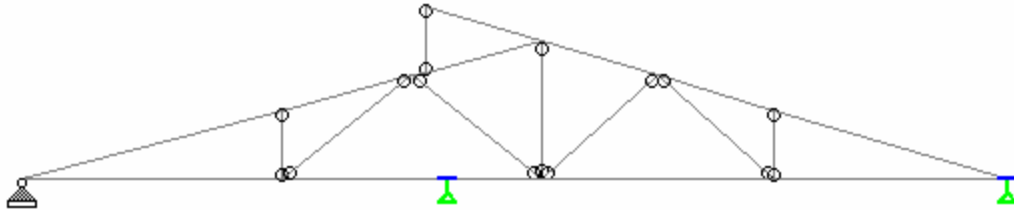
**Figure 9. Truss 4 (Small Group Cabin)**

This truss has been modified to include internal members at the supports. In addition, the truss can sustain the calculated load and is also economically feasible. Calculations verifying that this truss functions appropriately are shown in Appendix B. The top and bottom chords are 3 in. x 3 in. x  $\frac{1}{4}$  in. double angle members and the interior members are 2 in. x 2 in. x  $\frac{1}{8}$  in. double angles.

### 4.1.3. Casita Long Truss

#### 4.1.3a. Alternative Design

Truss 5, as seen in Figure 10, was the original design for the long truss on this building.

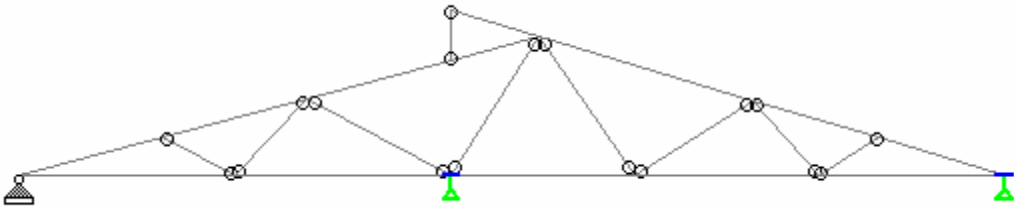


**Figure 10. Truss 5 (Casita)**

This truss, though, had no members at the internal support, which would have caused bending in the bottom chord. In addition, it did not line up with the wall appropriately, which resulted in an incorrect slope along the top chords.

#### 4.1.3b. Final Design

Truss 6 on Figure 11 was chosen as the final design.



**Figure 11. Truss 6: Final Design (Casita)**

This truss does have members at the internal support and is capable of withstanding the calculated load. Results and calculations for this truss analysis are shown in Appendix B. The top and bottom chords are 2 in. x 2 in. x  $\frac{1}{4}$  in. double angle members and the interior members are 2 in. x 2 in. x  $\frac{1}{8}$  in. double angles.

#### 4.1.4. Casita Short Truss

##### 4.1.4a. Alternative Design

Truss 7 on Figure 12 was originally designed to be the short truss for this building. This truss, though, had an incorrect slope and needed to be re-designed.

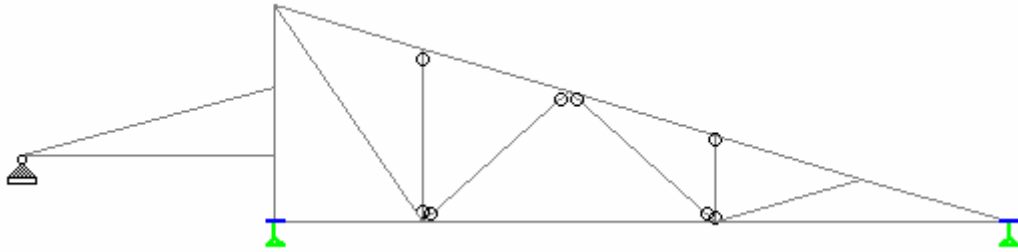


Figure 12. Truss 7 (Casita)

##### 4.1.4b. Final Design

Truss 8 on Figure 13 was chosen as the final design.

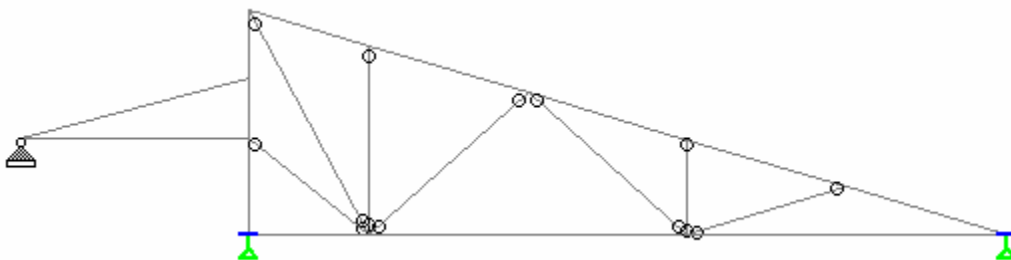


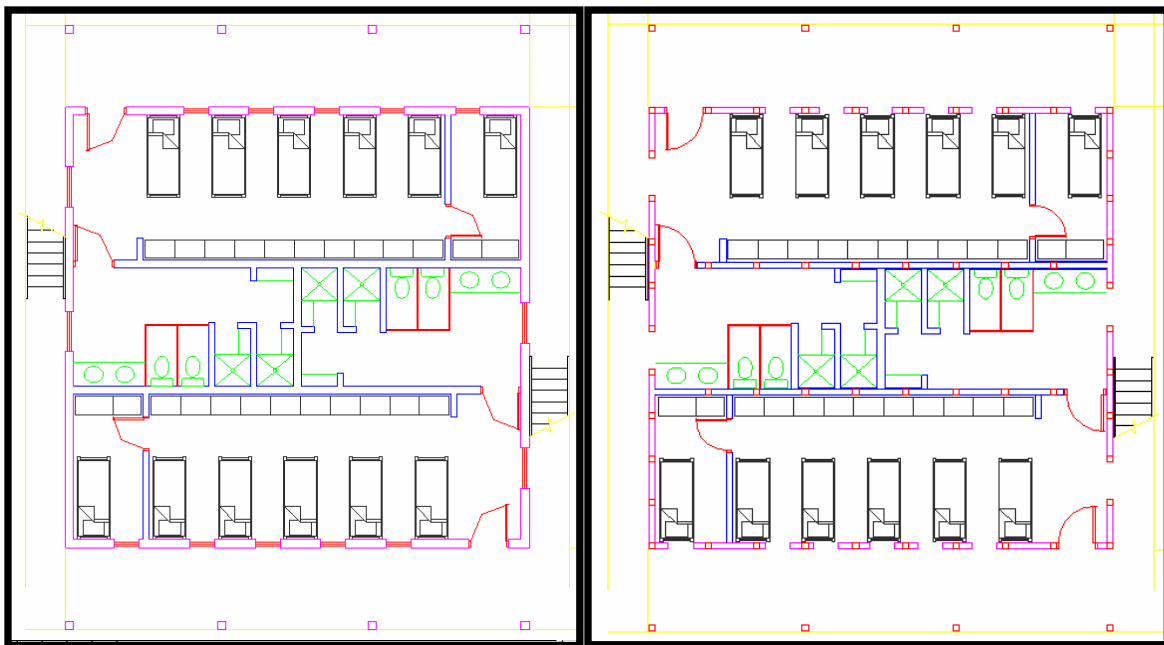
Figure 13. Truss 8: Final Design (Casita)

This truss has the correct slope and lines up appropriately with the two exterior walls. Calculations justifying this truss design can be seen in Appendix B. The top and bottom chords are 2 in. x 2 in. x  $\frac{1}{4}$  in. double angle members and the interior members are 2 in. x 2 in. x  $\frac{1}{8}$  in. double angles. These members were also designed to match the members on the long truss.

## 4.2. Vertical and Horizontal Wall Reinforcement

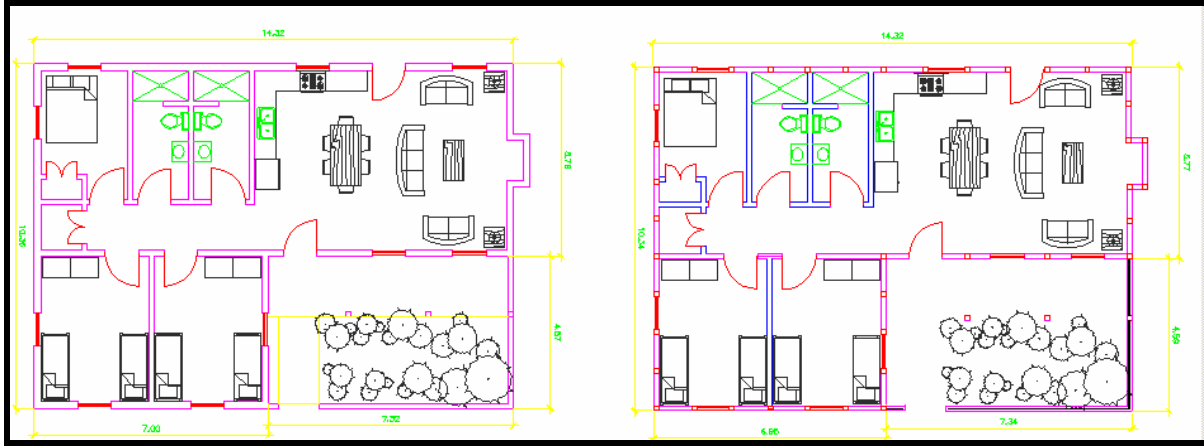
### 4.2.1. Alternatives

During a phone conversation with project manager Randy Larsen, he stated that reinforcement was placed every four feet in walls to provide resistance against shear forces generated during earthquakes. For this reason, vertical reinforcement was placed approximately every four feet horizontally and vertically throughout the exterior walls of the building. This reinforcement was designed to be 15 cm by 15 cm, as shown in Appendix C. With this design, the floor layout of the small group cabin had to be rearranged to keep columns from being interrupted by the windows. This new layout can be seen in Figure 14 below.



**Figure 14. Existing and Proposed Layout for Small Group Cabin**

Placing columns approximately every 4 feet also affected the layout of the casita, which was adjusted as seen in Figure 15.



**Figure 15. Existing and Proposed Layout for Casita**

#### **4.2.2. Final Design**

After submitting the original design to Randy Larsen, he stated that the reinforcement could be placed either at four feet or at a greater distance. During the original phone conversation, his remark about reinforcement was interpreted as a stringent maximum requirement. However, Randy Larsen later clarified that four feet was a general guideline for the Guatemalan area. He also stated that it would be more economical to only place vertical and horizontal reinforcement along windows and doors. In the end, we chose this latter arrangement as part of our design. This also kept the original floor layout design for the small group cabin valid. Having square 15 cm by 15 cm horizontal and vertical reinforcement still worked with this new design since the reinforcement had been slightly oversized originally. Consequently, 15 cm by 15 cm vertical and horizontal reinforcement were placed along the windows and doors of both buildings.

### ***4.3. Floor Slab and Beam Design for Second Story Small Group Cabin***

#### **4.3.1. Alternatives**

Originally, the design incorporated 6 inch by 12 inch concrete floor beams that ran approximately every 4 ft. (on top of the original columns). These beams spanned parallel with the trusses between the exterior walls of the building but were also supported by the two interior walls, making the maximum span 3.8 m. They had 2 - #6 bars spaced equally at the bottom and 9 - #3 stirrups every 5 inches on center, starting 10 inches away from the face of the support. The floor slab for these beams was designed as a 4 inch thick, one-way slab with #4 bars every 7 inches on center. Calculations supporting this design are shown in Appendix D.

However, this design was rejected by Randy Larsen because of the large amounts of forming that would have to take place for all the beams. Furthermore, the columns every four feet were not necessary. Consequently, he suggested designing a two-way slab and using a crown or spandrel beam along the top of bearing walls. After consulting with Professor De Rooy, the CRSI handbook was used to design a one-way slab that required no floor beams. This slab was 5.5 inches thick with #6 rebar every 8 inches at the bottom, #4 rebar every 8 inches at the top, and #3 temperature steel rebar every 15 inches. This slab had a cover of 0.625 inches instead of the typical 0.75 inches to keep the concrete costs low (and prevent the slab from becoming thicker). In addition, a crown beam 6 inches by 12 inches was designed to run along the top of all bearing first floor walls. Calculations supporting this design are shown in Appendix D.

### **4.3.2. Final Design**

After submitting the latter design to Randy Larsen (a 5.5 inches one-way slab), he determined that it would cost 30% more than the original design, even with all the formwork because of the large amount of steel rebar. To obtain the most cost effective option the two original designs were merged. The final design included a 6 inch by 12 inch crown beam on top of all bearing walls as well as 6 inch by 12 inch floor beams placed approximately every 4 feet. The floor slab remained 4 inches thick with #4 bars every 7 inches on center. In addition, the floor slab had #5 rebar every 10 inches on center to tie into the crown beam.

## **4.4. Foundation**

### **4.4.1. Alternatives**

The foundation design was started by sizing the running spread footings that would be placed under all walls on both buildings. Calculations resulted in a running footing 40 cm wide, as shown in Appendix E. Column footings were then sized and found to be 80 cm wide. Since the columns were originally placed every 4 feet, only a 1 foot gap remained between each column footing. For ease of forming and pouring, the design was changed to include an 80 cm spread footing under all bearing walls. This design also worked for the casita. Calculations supporting this are shown in Appendix E.

### **4.4.2. Final Design**

Once the columns were no longer placed every 4 feet, the 40 cm running footing was kept everywhere except at column line crossings, where 80 cm square column footings were placed. This design remained consistent for both buildings.

The ground floor slab for both buildings was 10 cm thick on grade. This slab had a 6 inch by 6 inch light welded wire fabric placed 1 inch from the bottom of the slab. This was implemented based on guidelines provided by Randy Larsen.

## **5. COST ANALYSIS**

While the buildings were still in the architectural design phase, the project manager in Guatemala provided a preliminary cost estimate of \$65,000 for the 44 person dormitory. He indicated that it was a rough approximation based on square footage, and that it was very conservative. The \$65,000 was described as a total package estimate, including all materials and labor necessary to raise the building, as shown in Appendix F.

After the design was completed, a more accurate cost estimate was prepared for financial planning and fundraising purposes. This new estimate included only the structural elements of the buildings (e.g. concrete, block, rebar, doors/window, and trusses). When two members of the team traveled to the site during the summer of 2004, they were able to purchase a book containing basic labor and material costs for construction in Guatemala. The book served as an excellent reference and provided the necessary information to convert construction material quantities into a practical cost estimate. Tables 1 and 2 show a breakdown of the cost estimate for the structural elements of each building. A more detailed cost estimate breakdown can be found in Appendix F.

**Table 1: Small Group Cabin Cost Estimate**

Dormitory (44 person)				
Description	Quantity	Unit	Price per Unit	Price
<b>Concrete</b>	<b>56.8</b>	<b>CM</b>	<b>Q650.00</b>	<b>Q36,920</b>
<b>Rebar</b>			<b>Q25,399.03</b>	<b>Q25,399</b>
<b>Block</b>			<b>Q13,300.00</b>	<b>Q13,300</b>
<b>Trusses</b>			<b>Q23,499.00</b>	<b>Q23,499</b>
<b>Doors/Windows</b>			<b>Q21,456.50</b>	<b>Q21,457</b>
			Total Quetzales	Q120,575
			<b>Total Dollars</b>	<b>\$16,077</b>

**Table 2: Casita Cost Estimate**

Casita (6-8 person)				
Description	Quantity	Unit	Price per Unit	Price
<b>Concrete</b>	<b>22.8</b>	<b>CM</b>	<b>Q650.00</b>	<b>Q14,820</b>
<b>Rebar</b>			<b>Q1,426.62</b>	<b>Q1,427</b>
<b>Block</b>			<b>Q5,000.00</b>	<b>Q5,000</b>
<b>Trusses</b>			<b>Q17,305.40</b>	<b>Q17,305</b>
<b>Doors/Windows</b>			<b>Q14,328.50</b>	<b>Q14,329</b>
			Total Quetzales	Q52,881
			<b>Total Dollars</b>	<b>\$7,051</b>

The cost estimate was limited to the structural portion of the project because most of the final decisions for plumbing, electrical, furnishings, roofing materials, and finishes (interior and exterior) will be made at a later date. Both estimates made by Team 14 and Randy Larsen are conservative. Finally, it is important to note that the final cost will be affected by the use of volunteer labor and donated supplies.

## **6. SOLUTION DISCUSSION**

While the design was very thorough there is one thing that could perhaps be modified in the future. This involves the slab design for the second-story of the small group cabin, which was a bit over designed to ensure that it would be safe. Perhaps an engineer more familiar with the method of slab construction in Guatemala would be able to simplify this design.

## **7. CONCLUSIONS/SUMMARY**

The objectives of this project were to provide assistance to a team working with eMi to benefit Campamento Shalom and provide complete structural construction documents, calculations and fundraising materials. Team 14 was able to perform the design and analysis necessary to attain these objectives and be a benefit to eMi and the camp. This was done while maintaining local construction techniques and design standards, which were both important design considerations.

## **8. RECOMMENDATIONS**

There were many challenges associated with the design of buildings for a site that is several thousand miles away. However, by sending part of the team to visit Campamento Shalom, the task became considerably less daunting. Personally gathered site data combined

with a plethora of photographs turned out to be invaluable when visualizing and designing a building according to Guatemalan standards. Nevertheless, the scope of the project should have been defined earlier and a more detailed project timeline should have been constructed. Finally, in order to account for client changes, the deliverables should have been started earlier. The construction documents, report and 3-D renderings could have been already in progress as second semester began, allowing for sufficient time for review and correction.

## **9. ACKNOWLEDGEMENTS**

This project was completed with the help of several different people, and Team 14 would like to thank them for their assistance, knowledge, advice, and review of the design.

Guatemalan Project Manager: Randy Larsen, P.E., eMi

Structural Engineering Mentor: David Puskas, P.E., BSW

Advisor: Leonard De Rooy, P.E., Calvin College

Industrial Consultant: Roger Lamer, P.E.

## **TABLE OF APPENDICES**

***APPENDIX A – EXISTING TRUSS ANALYSIS AND REDESIGN***

***APPENDIX B – TRUSS CALCULATIONS AND STAAD.PRO OUTPUT***

***APPENDIX C – VERTICAL AND HORIZONTAL REINFORCING  
CALCULATIONS***

***APPENDIX D – FLOOR SLAB AND BEAM CALCULATIONS***

***APPENDIX E – FOUNDATION CALCULATIONS***

***APPENDIX F – COST ANALYSIS DATA***