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Garbage Beam

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SANTA CLARA UNIVERSITY

Department of Civil Engineering

I hereby recommend that the
SENIOR DESIGN PROJECT REPORT
Prepared under my supervision by

PAULA BACK
&
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entitled

GARBAGE BEAM

be accepted in partial fulfillment of the requirements for
the degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

Tonya Nilsson ______________________ 6/13/17
Advisor Date

______________________ 6/9/17
Chairman of Department Date

Garbage Beam

By
Paula Back
Mariela Murillo

SENIOR DESIGN PROJECT REPORT

Submitted to
The Department of Civil Engineering
of
SANTA CLARA UNIVERSITY

In partial fulfillment of the requirements for the degree of
Bachelor of Science in Civil Engineering

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Spring 2017

Paula Back
Mariela Murillo

Department of Civil Engineering
Santa Clara University
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ABSTRACT

Located in a hot desert climate area prone to strong winds, Egypt is made up of many homes with little to no roofing leaving civilians exposed to the harsh elements. The overarching goal of this project is to provide these homes with efficient and affordable roofing using concrete with common garbage materials as reinforcement. Through preliminary testing and tensile testing it was possible to narrow the focus down to two reinforcement materials: fish netting and plastic grocery bags. From there final beam testing and pull out testing successfully demonstrated the promise of these materials. With this, however, it is still important to continue research on the materials and improve on the design in order to eventually create a one-way slab roof and pass that design over to an NGO that can successfully implement it.

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I. Background

Marginalized citizens of Egypt often have homes with little to no roofing while living in a hot desert climate area prone to strong winds. Civilians are often left exposed to the harsh elements. Construction with concrete in Egypt is very common, however, roofing systems made of concrete require steel reinforcement that is expensive and usually inaccessible to the impoverished. The residents often end up turning to quick fixes like plywood, pieces of sheet metal or tarp as seen in Figure 1[1].

Figure 1: Residents in a home in Egypt utilizing tarp as protection.

The overarching goal of this project was to provide these homes with efficient and affordable roofing by designing for a one-way slab that an NGO or organization could successfully implement. Initially the project was focused on using bamboo as the prime material. After further research, it was discovered that all of the time, cost and energy saved in using bamboo would be used toward the transportation of the material from a different country or

[1] "Housing Poverty in Egypt," https://www.habitatforhumanity.org.uk/what-we-do/where-we-work/europe-middle-east-and-africa/egypt

continent. The focus of the project, therefore, shifted to replacing the existing steel reinforcement found in concrete with something more accessible: garbage.

Given that approximately 24 percent of the Egyptian population lives in substandard housing conditions, one of the main constraints throughout design is cost[2]. It is crucial that all materials selected are easily found in a local dumpster or landfill and will not require any sort of transportation from an outside provider. The concrete beams reinforced with the product also must be effective in protecting residents from the harsh conditions while remaining intact.

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2 "Housing Poverty in Egypt," https://www.habitatforhumanity.org.uk/what-we-do/where-we-work/europe-middle-east-and-africa/egypt

II. Materials Used

Initially the project was focused on designing connections between the bamboo roofing system and the existing house made of either concrete masonry unit (CMU) blocks or cob. These roofing systems would look similar to that found in Figure 2[3]. Working with bamboo would come with both advantages and disadvantages as can be seen in Table 1.

Figure 2: Initial roofing design possibility using bamboo.

Table 1: Advantages and disadvantages of using bamboo[4].

Bamboo	
Advantages	*Disadvantages*
• Low cost of production • Compares in strength to concrete and steel • Lightweight • Handles shear very well • Fast growth	• Flammable • Difficult to connect separate pieces • Not local to Egypt • Requires an expensive treatment process to avoid rotting

[3] "Good Home Design" http://cdn.goodshomedesign.com/wp-content/uploads/2015/05/Bamboo-Roof-5.jpg

[4] Roach, Mary, "The Bamboo Solution," http://discovermagazine.com/1996/jun/thebamboosolutio784 (June 1, 1996).

While bamboo is an exceptional material in terms of physical properties, the application of it to this specific project was not optimal. Bamboo is a material that requires extensive knowledge and experience in order to use it effectively and safely[5]. It is not guaranteed that these requirements will be met during construction in the marginalized areas of focus, especially considering that resources such as an inspector are not widely available.

One of the most important pieces of this entire project was affordability. The closest known supplier of bamboo is a farm in Nairobi, Kenya[6]. That transportation process would not only be expensive but would also leave a negative environmental impact.

The next option was to improve the existing design using concrete but since the high costing steel reinforcement was the most inaccessible piece of the design, it was key to try to replace that aspect with a material much more affordable and easy to find. In Cairo, the largest city in Egypt, more than 15,000 tons of solid waste are produced every day and that number continues to grow[7]. With this fact came the idea to incorporate that garbage into the concrete as the tensile reinforcement.

In some cases, plastic has been incorporated into concrete as a replacement to aggregate. In one specific test it was found that there was a significant decrease in strength but also a significant decrease in bulk density. One advantage of using the plastic as aggregate in this case, was that the plastic did not absorb any water, reducing excess water[8]. While the results of this test were not ideal with respect to the strength of the concrete, they did offer promise in how the

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[5] Myers, Evan, “Structural Design of Bamboo in East Africa”, http://www.academia.edu/5108420/Structural_Design_of_Bamboo_in_East_Africa (2013).
[6] Fielder Zack, et. al., “Bamboo Roofing System for Egyptian Houses” (2016), page 22
[7] Zafar, Salman, “Garbage Woes in Cairo,” http://www.ecomena.org/tag/waste-management-in-egypt/ (November 2, 2016).
[8] Maqbool Sadiq, Muhammad and Rafique Khattak, Muhammad, “Literature Review on Different Plastic Waste Materials Used in Concrete,” http://www.jetir.org/papers/JETIR1506020.pdf (June 2015).

plastic positively reacts to the concrete. Plastic is workable with concrete while still offering some strength. More research simply needs to be done with respect to how much more plastic is needed and how best this material should be incorporated into the concrete.

Along with plastic based materials, rubber from old tires was a viable alternative. Recycled rubber tires have also been tested for their strength as an aggregate but not for their tensile reinforcing strength. Similar to that of the plastic aggregate previously mentioned, the strength of the concrete decreased. One published test noted losses of up to 85% in compressive strength and up to 50% of the tensile strength. These cylinders, however, did not experience brittle failure but instead a gradual failure[9]. This fact offered promising data in that using the material in its entirety could possibly help hold the concrete together for a longer time period.

Another material that is commonly found in everyday garbage are throwing nets for fishing. It is estimated that approximately 10% of all marine debris is made up of "ghost nets" or nets that are lost at sea[10]. These nets are a material that can withstand the weight of hundreds of fish at a time in some cases. It was therefore determined that this material could successfully exhibit some sort of tensile strength.

As a result of these findings, the materials selected to test as tensile reinforcement were plastic grocery bags, plastic soda bottles, plastic soda can rings, fish netting and rubber tires, as can be seen below in Figure 3.

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[9] Eldin, Niel N., Senouci, Ahmed B., "Rubber-Tire Particles as Concrete Aggregate," http://ascelibrary.org/doi/pdf/10.1061/(ASCE)0899-1561(1993)5:4(478) (1993).
[10] "What are Ghost Nets?" http://www.marinemammalcenter.org/Get-Involved/events/ghost-below/ghost-nets.html?referrer=https://www.google.com/

Figure 3: Materials selected for testing.

III. Design Criteria and Standards

When designing the concrete beam, certain criteria and standards needed to be met before final design and testing were complete. Five different types of materials were initially investigated and tested but only two types were chosen for the final designs. Certain tests and calculations were done in order to narrow down the selection.

A. *Preliminary Testing*

The first type of testing done was preliminary testing of a simple reinforced concrete beam in order to better understand constructability, how the material would react with concrete, and what kinds of peak loads each material would have. As seen in Figure 4 below, the molds used were pre-fabricated with dimensions of 4"x4"x24". The materials were placed in the beam and held in place using dobies, which are tiny blocks of concrete with wiring.

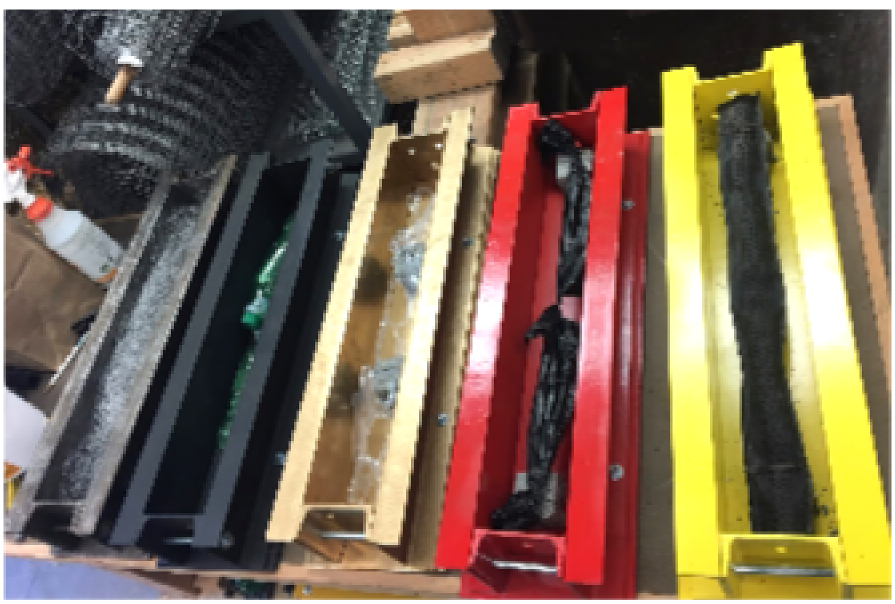

Figure 4: Pre-fabricated molds using in preliminary testing.

Testing was done 14 days after the concrete was poured. Using the Tinius Olsen Hydraulic Universal Testing Machine in the SCU structure lab, the five material beams were tested, as well as a control beam using two No. 3 rebar. A three-point load test was used during this testing because the primary focus was to look at behavior of material, constructability and the peak load.

Figure 5 shows the embedment of the plastic soda can rings as reinforcing with concrete after failure. The material had no problem binding with the concrete and was very difficult to remove once testing was complete. This behavior was a good indicator of how the material could easily be used as a reinforcement without the worry that it would just "slip out."

Figure 5: The result of preliminary testing with the soda can rings.

Although soda bottles and soda can rings had some of the highest values in terms of peak loads, as can be seen in Table 2, both were eliminated as testing materials because of challenges with constructability. A great deal of caution was taken when dealing with the soda bottles and rings to avoid damaging the materials, but realistically, materials pulled out of a dumpster, landfill or off the streets will already be damaged in some way. For that reason, it was determined that these materials would not perform as initially expected.

Table 2: Results from preliminary testing.

Material Tested	Max Load (lbf)
Control (w/ (2) no. 3 rebar)	3430
Fish Net	1288
Soda Rings	983
Bottles + Rings	955
Grocery Bags	729
Tire	617

B. Tensile Testing

Tests on the tensile strength of the remaining three (3) materials (tire, fish netting and plastic grocery bags) were performed. This testing process entailed securing both ends of the material on the 10 Kip machine and pulling until failure. Values for Force vs. Deformation were recorded during the test. This data was converted to Stress vs. Strain and plotted as shown in Appendix A. The values for Modulus of Elasticity (E) from these plots can be found in Table 3.

Table 3: Values for Modulus of Elasticity and yield stresses found from tensile testing.

Plastic Grocery Bag

Avg. E Values (psi)
151,000
Avg. Yield Stress (psi)
25,000

Rubber Tire with Metal

Avg. E Values (psi)
5,000
Avg. Yield Stress (psi)
2,300

Fish Net

Avg. E Values (psi)
223,000
Avg. Yield Stress (psi)
56,000

Given the results of this test, rubber tire was eliminated from the list of materials tested. The Modulus of Elasticity was too small in comparison to that of concrete which is 2,850,000 psi. This meant that the rubber tires were too flexible, resulting in a mismatch of stiffnesses. The rubber tire would not even be engaged before the concrete failed. Following this test, the only materials remaining were fish netting and plastic grocery bags.

C. Design Specifications

Before beginning to calculate and design the final beams for testing, there were certain specifications that needed to be followed. The International Building Code (IBC) of 2015, is a set of code and standards that multiple countries use in order to design commercial, residential and other types of buildings. This code is used in both the United States and Egypt, our country of focus. The IBC was also recommended by a faculty member, Dr. Hisham Said, who is from Egypt. The IBC was used to find certain live loads were applied to the beam, which can be found in Appendix B.

Another standard used was the ACI 318-14, which contains the building code requirements for structural concrete. This report was used to calculate the moment capacity of each beam. Though the code moment capacity formulas are based on using steel reinforcement, it is a starting point because no equations or formulas currently exist for waste.

During testing, the ASTM four-point load test was used in order to find the maximum moment. The reason this test was used was because the maximum moment is constant over a larger area. This helps in identifying stress where the failure initiated. The test setup can be seen in Figure 6.

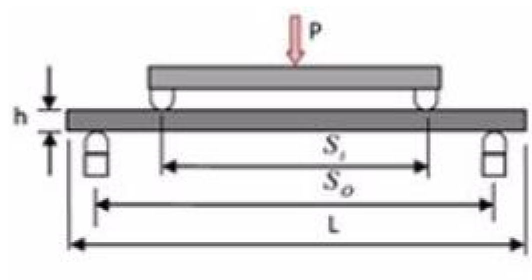

Figure 6: Diagram of a four-point load test.

D. Load Calculations

Before calculating how much material was needed for a concrete beam, the first step was to calculate how much load each beam needed to hold. Using the IBC of 2015 and the tables found in Appendix B, there were two types of live loads roofs were expected to withstand; one being a uniform load of 20 psf and the other being a concentrated load of 300 pounds.

The dimensions of the beams built were 7” x 10” x 60”. Using these dimensions, the moment of each beam per load was calculated. Below, Equation 1 and 2 were used to find moment of the beam with concentrated and uniform loads respectively. In Appendix D, the hand calculations can be found.

Equation 1: Moment Demand of a Beam With a Concentrated Load.

$$Moment\ (concentrated\ load) : \frac{PL}{4} \tag{1}$$

P= Concentrated load (lbs)
L= Length of beam (ft)
w= weight of uniform load (lb/ft)

Equation 2: Moment Demand of a Beam With an Uniform Load.

$$Moment\ (uniform\ load) : \frac{wL^2}{8} \tag{2}$$

L= Length of beam (ft)
w= weight of uniform load (lb/ft)

The moment for concentrated load was found to be 375 lb-ft and the uniform load was 36 lb-ft. The beams designed would be for the extreme case which is the concentrated load. In order to calculate the total moment demand, the moment of the dead load had to be found. To be conservative, the self-weight of concrete was assumed to be 150 pcf, and using Equation 2, the moment was calculated to be 228 lbs-ft, and therefore the total moment demand equaled 603 lb-ft.

E. Design Calculations

The method of transformed sections was used in order to determine the proper placement of materials in the beam that maximized its tensile strength capacity. Since the concrete and material used were expected to act as a single member, this method was used to transform the "waste" materials into concrete. Using this method, variables such as *d* and *a* were found. In Figure 7 below, *d* is shown being the depth from the outer compression fiber, meaning the top of the beam, to the centroid of reinforcement. The variable *a*, is shown as the approximate length of the compression zone, assuming that the distribution of the compressive stress in the concrete is shaped more like a block than a curve.

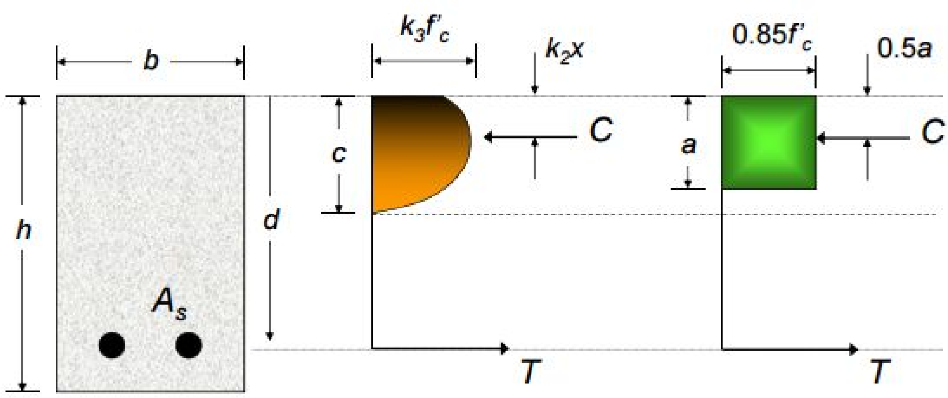

Figure 7: Diagram of a compression stress block[11].

[11] "Strength of Reinforced Concrete Beams" http://www.ce.memphis.edu/1112/notes/project_2/beam/reinforced_concrete_beams.pdf

A value for *a* was solved for in order to calculate the moment capacity of each beam. Equations 3 and 4 below were combined to get the final moment capacity, Equation 5.

Equation 3: Compression Zone Length.

$$a = \frac{A_{mat} \times f_y}{0.85 \times f'_c \times b} \tag{3}$$

A_{mat}=Area of material (in^2)
f_y= stress of material (psi)
f'_c= stress of concrete (2500 psi)
b= base (in.)

Equation 4: Moment Capacity of Beam with respect to *a*.

$$M = A_{mat} \times f_y \times (d - \tfrac{a}{2}) \tag{4}$$

A_{mat}=Area of material (in^2)
a= length of compression zone (in.)
d= depth from the compression fiber to centroid of material (in.)
f_y= stress of material (psi)

Equation 5: Final Moment Capacity of a Beam.

$$M = A_{mat} \times f_y \times (d - 0.59 \times \frac{A_{mat} \times f_y}{f'_c \times b}) \tag{5}$$

A_{mat}=Area of material (in^2)
f_y= stress of material (psi)
d= depth from the compression fiber to centroid of material (in.)
f'_c= stress of concrete (2500 psi)
b= base (in.)

Once all the variables and formulas were found, it was then a process of trial and error. Appendix D shows all of the hand calculations that were done in order to solve for moment capacity. The main goal was to find out how many pieces of material it took to calculate a moment capacity greater than the demand. In Table 4 below, the results for plastic grocery bags are shown, and in Appendix C, the results of the fish netting are shown.

Table 4: Example of the iteration process with plastic grocery bags.

Plastic Grocery Bag Iterations			
# of pieces	2	3	4
Area with number of pieces	0.02	0.03	0.04
Allowable Stress (psi)	25,000	25,000	25,000
d (in)	8	8	8
Moment Capacity (lb-ft)	315	470	625
Check	**N.G.**	**N.G.**	**OK**

The final results of design calculations were that four (4) plastic grocery bags would be needed to attain a moment capacity greater than the demand. What this result means is that the cross-sectional area of four (4) plastic bags was needed. For fish netting, the amount of material needed was eight (8) pieces. Now that calculations were complete, the next step was building the beams.

IV. Description of the Designed Beam

A. Construction Process

With the remaining two materials, fish netting and plastic grocery bags, six beams (three with each material) were constructed using concrete with a 2500 psi mix design. For both materials, a drill was used to twist the pieces into rods.

For the grocery bags, one rod consisted of 16 bags of which a cross-section had two (2) bags, leaving a total of 32 bags in the concrete beam, as seen in Figure 8. Two rods were then placed into the form and kept taut by drilling holes in the formwork and running a string through to hold the bags.

Figure 8: The plastic grocery bag rods set into the formwork.

The fish netting consisted of four (4) pieces of material (each 10 inches wide) per rod. Once the fish netting was twisted together, the rods were placed in the beam and kept taut using dobies as shown in Figure 9.

Figure 9: Fish netting rod set into the formwork.

The concrete was then poured and the beams were left to cure for 28 days. During this time period, the beams were sprayed with water at least once per week to ensure the concrete did not dry out. Figure 10 shows the poured concrete beams sitting in the formwork.

Figure 10: Poured concrete beams sitting in the formwork.

B. Final Testing

On April 25, 2017 the beams were removed from the molds. Testing was done using a four-point test on the Tinius Olsen. The testing apparatus can be seen in Figure 11.

Figure 11: Example of the testing apparatus for the full size beams.

Load was carefully applied at about 150 pounds/second with the help of Brent Woodcock in the Structures Lab. All six beams were tested until failure.

C. Results

In all of the tests except one, the tensile reinforcement remained intact while the concrete failed around it. One of the plastic grocery bags snapped during the test, resulting in full failure. An example of both materials are shown in Figures 12 and 13.

Figure 12: Failed beam with fish netting reinforcement.

Figure 13: Failed beam with grocery bag reinforcement.

The results of this test were then used to determine the maximum moment of each beam. Equation 6, below, was used in order to find the maximum moment using the maximum load. That result would then be compared to the moment demand of 603 lb-ft, as well as the theoretical moment capacity. These values can be found in Tables 5 and 6 below.

Equation 6: Maximum Moment Using Maximum Load.

$$Maximum\ Moment = \frac{P \times (S_O - S_I)}{4} \qquad (6)$$

P= maximum load (lbs)
S_O= *spacing of furthest pins (in.)*
S_I= *spacing of closest pins (in.)*

Table 5: Resulting calculated values from final beam test for fish netting.

Fish Netting	**Max Load (lbf)**	**Moment (lb-ft)**	**Stress at Failure (psi)**
Beam 1	3970	3220	2.44×10^5
Beam 2	3970	3230	2.44×10^5
Beam 3	1560	1270	0.96×10^5
Average	3170	2570	1.95×10^5
Standard Deviation	1390	1130	0.86×10^5
Theoretical Moment		994	

Table 6: Resulting calculated values from final beam test for plastic grocery bags.

Plastic Bag	**Max Load (lbf)**	**Moment (lb-ft)**	**Stress at Failure (psi)**
Beam 1	2110	1710	1.06×10^5
Beam 2	2820	2300	1.42×10^5
Beam 3	2080	1690	1.04×10^5
Average	2340	1900	1.17×10^5
Standard Deviation	420	340	0.21×10^5
Theoretical Moment		625	

D. Compressive Strength Testing

All of the beams, even the weakest one that failed at approximately 1500 lbs, exceeded the theoretical moment capacities. The beams did better than expected or calculated, and could have potentially done better if the concrete had not failed first. This fact led to further testing to determine the actual compressive strength of the concrete used.

Three concrete cylinders were tested, and the the compressive strength was found. Through calculations and design, the compressive strength was assumed to be 2500 psi. However tests showed an average compressive strength of 1,020 psi as shown in Table 7.

Table 7: Results from Cylinder Testing.

Concrete Cylinders	Max Load (lbf)	f'c (psi)
1	12,515	1,000
2	18,000	1,400
3	8,300	660
Average	13,000	1,020

Since the compressive strength was less than expected, the theoretical moment capacities of each type of material were recalculated. These capacities can be seen in Table 8 and 9 below.

Table 8: Calculated moment capacity values from cylinder testing for grocery bags.

Plastic Grocery Bags	
Original Theoretical Moment Capacity (lb-ft)	625
Recalculated Theoretical Moment Capacity (lb-ft)	622

Table 9: Calculated moment capacity values from cylinder testing for fish netting.

Fish Netting	
Original Theoretical Moment Capacity (lb-ft)	994
Recalculated Theoretical Moment Capacity (lb-ft)	984

The recalculated theoretical moments decreased, and therefore it does not affect calculations or design due to the fact that the actual beams tested exceeded the theoretical capacities.

E. Pull-Out Testing

Steel reinforcement bars are often ribbed in order to facilitate adhesion with the concrete. This grip keeps the rebar from being pulled out when a load is applied. This pull out strength was a concern when dealing with the plastic grocery bags and fish netting because of this issue with adhesion. In order to test the pull-out strength of these materials, six (6) cylinders were created, three (3) for each material. Both the fish netting and the plastic grocery bags were embedded about six (6) inches into a 2500 psi concrete cylinder, leaving about two (2) inches of cover, while another six (6) inches were sticking out. One (1) knot was placed inside the concrete at the bottom. A piece of No. 3 steel reinforcing bar was placed horizontally along the bottom to facilitate testing. The cylinders were then placed in a lime bath for 28 days to allow for curing.

Pull-out testing was done using the 10-kip machine in the structures lab at Santa Clara University. The rebar placed through the cylinder was attached to the machine while the material was fastened at the opposite end. An example using the fish netting test can be found in Figure 14.

Figure 14: Testing Apparatus for pull-out test using fish netting.

The results of the pull-out tests can be found in Tables 10 and 11.

Table 10: Pull-Out Test results for fish netting.

Fish Netting Pull-Out Test		
Test #	**Pull-Out Load (lbs)**	**Pulled Out?**
1	260	NO
2	260	NO
3	300	NO
Average	273	

Table 11: Pull-Out Test results for grocery bag.

Grocery Bag Pull-Out Test		
Test #	**Pull-Out Load**	**Pulled Out?**
1	90	NO
2	30	YES
3	75	YES
Average	65	

In all tests, both materials were substantially pulled out. For the fish netting, the material did not entirely pull out from the concrete cylinder in any test. On the other hand, for two out of the three grocery bag tests, the material was entirely pulled out. For tests 1,2 and 3 of the fish netting tests and test 1 of the plastic grocery bag test in which the material stayed in the cylinder, the test was stopped because the machine had hit its full capacity in terms of distance to pull.

Given the values in Tables 10 and 11, fish netting proved to be stronger in terms of pull-out strength. A theory for this result is that because fish netting has more “ribbing” or is more coarse, it creates more adhesion with the concrete. Plastic grocery bags, even though they were twisted and not completely smooth, were more smooth than fish netting.

V. Cost Estimate

For the purposes of this project, different materials were purchased for the different phases of testing. The costs of these materials can be found in Table 12 below.

Table 12: Materials purchased and used for testing.

Item Purchased	Project Cost	Typical Cost
Throwing Net for Fishing	$150	$0
Plastic Grocery Bags	$50	$0
Rubber Tires	$0	$0
Plastic Soda Bottles	$20	$0
Plastic Soda Rings	$0	$0
Portland Cement (4-94 lb bags)	$0	$40
Plywood/Lumber	$100	$100
Total	*= $320*	*= $140*

Most of these materials were purchased new to determine how the tests would result when the materials were in the best condition. Materials like the used rubber tires, however, were donated from a local bike shop.

Realistically the only materials that should be purchased when implementing this project would be the Portland Cement and any lumber needed for formwork. As of May 2017, the cost of cement in Egypt is about 735 Egyptian Pounds per ton, equivalent to about $40 US Dollars per ton[12]. The remaining materials are to be pulled (in the best condition possible) from local landfills, dumpsters or off the streets, free of charge.

[12] "Cement Egypt," http://cementegypt.com/en/price (May, 2017).

VI. Relevant Non-Technical Issues

A. Political Constraints

Egypt is a country currently led by Abdel Fattah al-Sisi who removed his predecessor, President Mohammed Morsi, from office through a coup. Throughout its history, Egypt has been the setting of many political uprisings with one of the most memorable being "Arab Spring" in 2011. The U.S. Department of State warns on their website for tourists to be cautious of political protests that can begin out of nowhere and often become violent. With such heated political conditions and possible aversion towards foreigners, it was not possible to actually travel to the country to get a first hand look at the issue. Instead, research was done in the United States using first hand accounts and existing knowledge and documentation.

B. Financial Constraints

Funding of $800 was granted from the Engineering Department at Santa Clara University in order to pay for materials for this project. Budgeting was also crucial because affordability is such a large part of the design. It was important to mimic the fact that those implementing this project abroad would have limited money and resources.

C. Architectural Constraints

In order to create an efficient design that will be welcomed by the communities that are being served, it is crucial to look at existing architecture in these areas. Implementing a roof that stands out may call unwanted attention and lead to conflict within the community in some way. The idea is to create something that will blend in as much as possible and keep to the existing architectural culture of the area.

D. Possible Building Code Constraints

In this case, the International Building Code was used as the primary source for codes mainly due to the fact that it is used in Egypt as well. The American Society for Testing and Materials (ASTM) standards were also used as a guide. More research, however, is needed to determine how applicable these guides are in Egypt and adapt as necessary.

VII. Conclusion

Following testing, there were promising results for the fish netting and plastic grocery bags as tensile reinforcement in concrete to be used for roofing systems in Egypt. The materials surpassed the theoretical moments while also meeting the moment demand. In terms of pull out strength, however, both materials have some more work that needs to be done with respect to how to improve on the adhesion to the concrete.

Unfortunately it was not possible to calculate the one-way slab roof because more research needed to be done in order to comfortably and responsibly do so.

It would be of great interest for a group in the coming years to take on this project and continue research. The hope is to eventually give a fully functioning and safe design to an NGO or organization that can successfully implement this project not only in Egypt but in many developing countries.

VIII. References

[1-2]. “Housing Poverty in Egypt,” https://www.habitatforhumanity.org.uk/what-we-do/where-we-work/europe-middle-east-and-africa/egypt

[3] “Good Home Design” http://cdn.goodshomedesign.com/wp-content/uploads/2015/05/Bamboo-Roof-5.jpg

[4] Roach, Mary, “The Bamboo Solution,” http://discovermagazine.com/1996/jun/thebamboosolutio784 (June 1, 1996).

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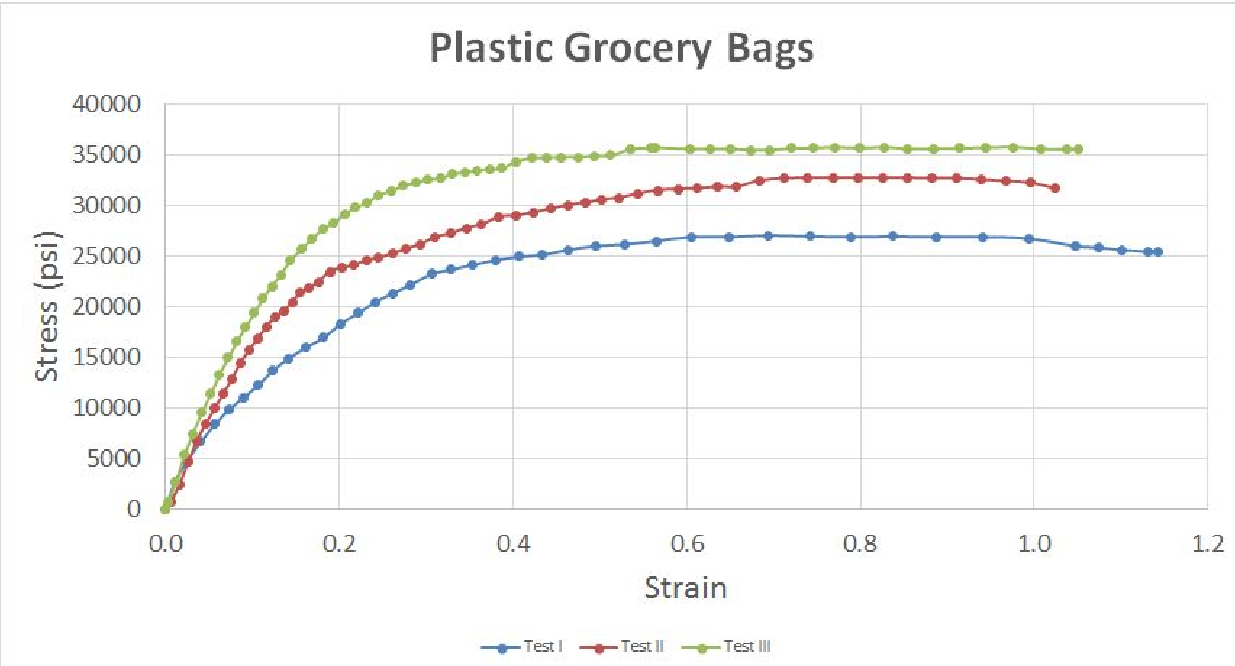
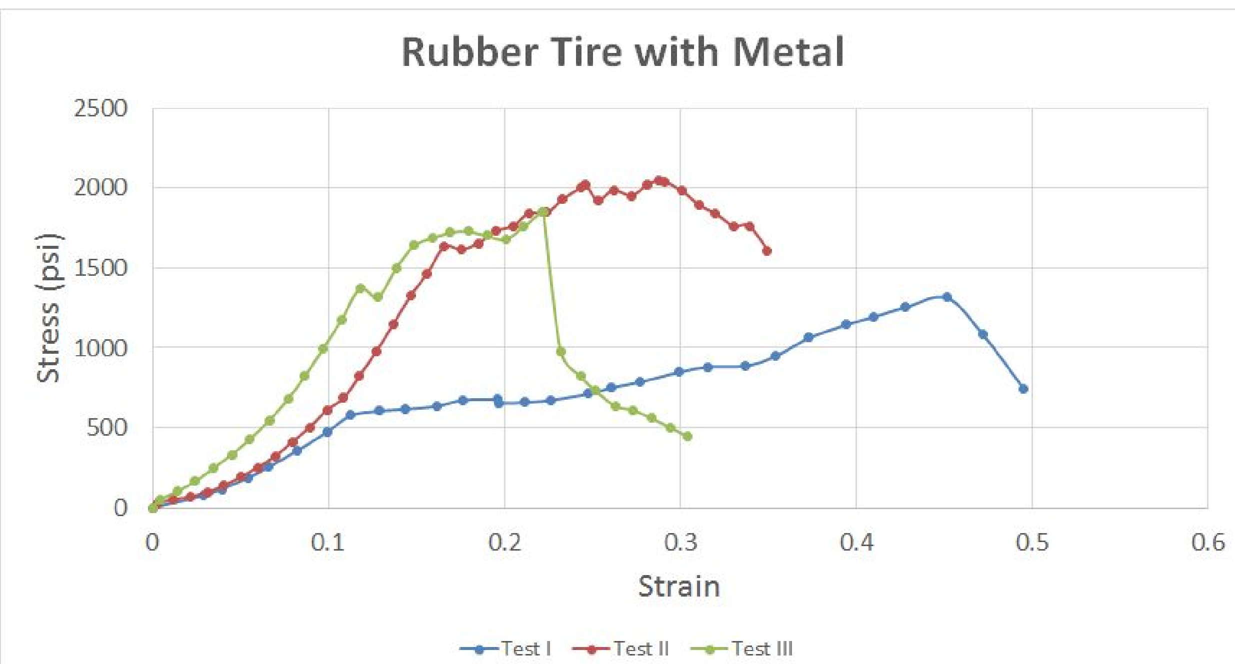
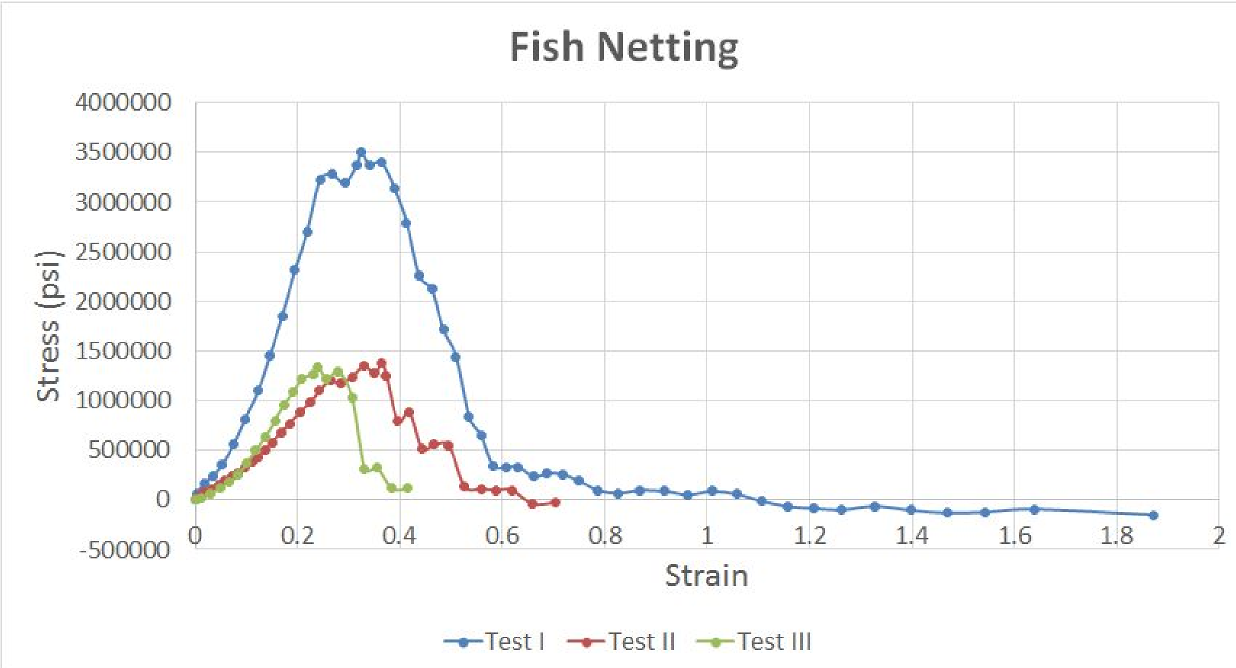
Appendix A

Tensile Testing Graphs






Fish Netting
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
-500000
Stress (psi)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Strain
Test I
Test II
Test III

Appendix B

Standards and Code Requirements

TABLE 1607.1-continued MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_0, AND MINIMUM CONCENTRATED LIVE LOADS[g]

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (pounds)
23. Penal institutions		
Cell blocks	40	-
Corridors	100	
24. Recreational uses:		
Bowling alleys, poolrooms and similar uses	75[m]	
Dance halls and ballrooms	100[m]	
Gymnasiums	100[m]	
Ice skating rink	250[m]	-
Reviewing stands, grandstands and bleachers	100[c, m]	
Roller skating rink	100[m]	
Stadiums and arenas with fixed seats (fastened to floor)	60[c, m]	
26. Roofs		
All roof surfaces subject to maintenance workers		300
Awnings and canopies:		
Fabric construction supported by a skeleton structure	5 Nonreducible	
All other construction, except one and two-family dwellings	20	
Ordinary flat, pitched, and curved roofs (that are not occupiable)	20	
Primary roof members exposed to a work floor		
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages		2,000
All other primary roof members		300
Occupiable roofs:		
Roof gardens	100	
Assembly areas	100[m]	
All other similar areas	Note 1	Note 1

Appendix C

Calculation Results

grocery bag	
length (in)	12
base(width) (in)	12
thickness (in)	0.0008
area (in^2)	0.0096
Yield Stress (psi)	24,528
E (psi)	150,805
number of pieces	4
area with number of pieces	0.0384
n	0.0529
A'mat	0.00203
d	8.00
x (in)	0.068
yt	7.93
I(transformed) in^4	0.129
Moment in Beam (lb-in)	7,504
Moment in Beam (lb-ft)	625
Check compared to charts	good

fish net	
length (in)	5
base(width) (in)	2.5
diameter (in)	0.01
area (in^2)	0.003377
Yield Stress (psi)	55,809
E (psi)	222,719
number of pieces	8
area with number of pieces	0.0270
n	0.0781
A'mat (in^2)	0.00211
d (in)	7.96
x (in)	0.069
yt (in)	7.89
I(transformed) in^4	0.132
Moment in Beam (lb-in)	11,926
Moment in Beam (lb-ft)	994
Check compared to charts	good

Appendix D

Detailed Calculations

A. Modulus of Elasticity

Formulas:

$$E = \sigma \div \varepsilon$$

E= Young's Modulus (psi)
σ= Tensile Stress (psi)
ε= Tensile Strain

Grocery Bag:

$Test\ 1: \frac{9833.3}{0.0734} = 90,000\ psi$

$Test\ 2: \frac{9944.4}{0.0566} = 144,279\ psi$

$Test\ 3: \frac{9555.6}{0.0417} = 207,650\ psi$

Rubber Tire:

$Test\ 1: \frac{576.7}{0.1129} = 7,506\ psi$

$Test\ 2: \frac{190.6}{0.0501} = 5,499\ psi$

$Test\ 3: \frac{428.6}{0.0554} = 9,306\ psi$

Fish Netting:

$Test\ 1: \frac{354000}{0.053} = 6,534,091\ psi$

$Test\ 2: \frac{265000}{0.084} = 2,465,909\ psi$

$Test\ 3: \frac{176000}{0.065} = 3,033,333\ psi$

B. Moment Demand

Formula:

$$Moment\ (concentrated\ load): \frac{PL}{4}$$

$$Moment\ (uniform\ load): \frac{wL^2}{8}$$

P= Concentrated load (lbs)
L= Length of beam (ft)
w= weight of uniform load (lb/ft)

Loads Used
Uniform Load: 20 psf
Concentrated Load: 300 lbs
Dead Load: 73 lb/ft

Moment of Concentrated load:
$\frac{300\times5}{4} = 375\ lb - ft$

Moment of Uniform load:
$\frac{(20\times0.583)\times(5)^2}{8} = 36\ lbs - ft$

Moment of Dead load:
$\frac{73\times(5)^2}{8} = 228\ lbs - ft$

Total Moment Demand:
$375 + 228 = 603\ lbs - ft$

C. Beam Design

Formulas:

$$Area\ of\ a\ rectangle:\ b \times t$$

$$Area\ of\ a\ circle: \Pi \times r^2$$

$$n = \frac{E_{material}}{E_{Concrete}}$$

$$A'mat = n \times area\ of\ material$$

$$d = h - cover - (\tfrac{1}{2} \times t)$$

$$x = \frac{-A'mat + \sqrt{A'mat^2 - 4 \times \frac{b}{2} \times (-A'mat) \times d}}{b}$$

$$y_t = d - x$$

$$I = \tfrac{1}{3} \times b \times x^3 + A'mat \times (d - x)^2$$

$$M = A_{mat} \times f_y \times (d - 0.59 \times \frac{A_{mat} \times f_y}{f'_c \times b})$$

b= base (in.)
t= thickness (in.)
r= radius (in)
n= factor
$E_{material}$= modulus of elasticity of material (psi)
$E_{concrete}$= modulus of elasticity of concrete (2,850,000 psi)
d= depth from the compression fiber to centroid of material (in.)
h= height (in.)
cover= 2 in.
x= length of compression zone (in.)
I= moment of inertia (in.^{4})
M= moment capacity of beam (lbs-in)
f_y= stress of material (psi)
f'_c= stress of concrete (2500 psi)

Grocery Bags:

$$Area\ of\ one\ piece\ of\ material = 12 \times 0.0008 = 0.0096\ in.^2$$

$$Total\ area\ (4\ pieces) = 4 \times 0.0096 = 0.0384\ in.$$

$$n = \frac{150{,}805}{2{,}850{,}000} = 0.0529$$

$$A'mat = 0.0529 \times 0.0384 = 0.00203\ in.^2$$

$$d = 10 - 2 - \frac{1}{2} \times (5 \times 0.0008) = 8\ in.$$

$$x = \frac{-0.00203 + \sqrt{0.00203^2 - 4 \times \frac{7}{2} \times (-0.00203) \times 8}}{7} = 0.068\ in.$$

$$y_t = 8 - 0.068 = 7.93\ in.$$

$$I = \frac{1}{3} \times 7 \times 0.068^3 + 0.00203 \times (8 - 0.068)^2 = 0.129\ in.^4$$

$$M = 0.0384 \times 24{,}528 \times (8 - 0.59 \times \frac{0.00203 \times 24{,}528}{2500 \times 7}) = 7{,}504\ lb-in \rightarrow 625\ lb-ft$$

Fish Netting:

$$Area\ of\ one\ piece\ of\ material = \Pi \times 0.005^2 \times 43 = 0.0034\ in.^2$$

$$Total\ area\ (8\ pieces) = 8 \times 0.0034 = 0.0270\ in.^2$$

$$n = \frac{222{,}719}{2{,}850{,}000} = 0.0781$$

$$A'mat = 0.0781 \times 0.0270 = 0.00211\ in.^2$$

$$d = 10 - 2 - \frac{1}{2} \times (8 \times 0.01) = 7.96\ in.$$

$$x = \frac{-0.00211 + \sqrt{0.00211^2 - 4 \times \frac{7}{2} \times (-0.00211) \times 7.96}}{7} = 0.069\ in.$$

$$y_t = 7.96 - 0.069 = 7.89\ in.$$

$$I = \frac{1}{3} \times 7 \times 0.069^3 + 0.00211 \times (7.96 - 0.069)^2 = 0.132\ in.^4$$

$$M = 0.0270 \times 55,809 \times (7.96 - 0.59 \times \frac{0.00211 \times 55,809}{2500 \times 7}) = 11,926\ lb - in \rightarrow 994\ lb - ft$$

D. Final Beam Maximum Moment Calculations

$$Maximum\ Moment = \frac{P \times (S_O - S_I)}{4}$$

P= maximum load (lbs)
S_O*= spacing of furthest pins (in.)*
S_I*= spacing of closest pins (in.)*

Grocery Bags:

$$M(beam\ 1) = \frac{2107 \times (48-9)}{4} = 20543\ lbs - in. \rightarrow 1712\ lbs - ft$$

$$M(beam\ 2) = \frac{2826 \times (48-9)}{4} = 27554\ lbs - in. \rightarrow 2296\ lbs - ft$$

$$M(beam\ 3) = \frac{2084 \times (48-9)}{4} = 20319\ lbs - in. \rightarrow 1693\ lbs - ft$$

Fish Netting:

$M(beam\ 1) = \frac{3965\times(48-9)}{4} = 38659\ lbs - in. \rightarrow 3222\ lbs - ft$

$M(beam\ 2) = \frac{3974\times(48-9)}{4} = 38747\ lbs - in. \rightarrow 3229\ lbs - ft$

$M(beam\ 3) = \frac{1560\times(48-9)}{4} = 15210\ lbs - in. \rightarrow 1268\ lbs - ft$

E. Concrete Cylinders Compressive Strength

$$F'_c = \frac{P}{A}$$

F'_c= compressive strength of concrete (psi)
P= maximum load (lbs)
A= Area of cylinder ($in.^2$)

$F'_c\ (cylinder\ 1) = \frac{12514}{12.57} = 996\ psi$

$F'_c\ (cylinder\ 2) = \frac{17393}{12.57} = 1384\ psi$

$F'_c\ (cylinder\ 2) = \frac{8278}{12.57} = 659\ psi$

F. Recalculated Theoretical Moment Capacities

$$M = A_{mat} \times f_y \times (d - 0.59 \times \frac{A_{mat}\times f_y}{f'_c \times b})$$

Grocery Bag:

$M = 0.0384 \times 24,528 \times (8 - 0.59 \times \frac{0.00203\times 24,528}{1013\times 7}) = 7,460\ lb - in \rightarrow 622\ lb - ft$

Fish Netting:

$M = 0.0270 \times 55,809 \times (7.96 - 0.59 \times \frac{0.00211\times 55,809}{1013\times 7}) = 11,813\ lb - in \rightarrow 984\ lb - ft$