Adobe Brick Project Report

Written By: Civil Engineering Kuwaiti Women

Zahra'a Alqallaf-Team Leader

Zahra'a Alhusainie-Design Specialist

Hawra'a Farman-Team Supervisor

Submitted to:

Instructor/Civil Engineer Mark Lamer

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Table of Contents

1.0 Introduction

1.1 Project Description

The main objective of this project is to develop a good strategy in constructing suitable adobe bricks for Northern Arizona, using local material. And, since, Coconino County does not currently have its own sets of codes and constraints concerning adobe brick design, this project will adopt the United States standard adobe brick design codes and adjust them slightly to develop new sets of cods and constraints that are suitable for Coconino County and Northern Arizona's environment.

1.2 Project Background

The project requires developing strong and durable adobe bricks using local materials in Flagstaff, Arizona. Adobe brick's properties can be improved by performing different adobe brick testing procedures to determine the brick's failure points and the best methods used to avoid having these failure points in the final design. The final adobe brick design should decrease the negative impacts of adobe bricks on the environment by using suitable adobe brick soil content for the location of construction, and should also increase the safety factor of having a design that will support the final structure without collapsing.

1.2.1 Design Challenge

Designing Adobe brick's that is suitable for Flagstaff, Arizona is challenging especially when trying to meet the following constraints and criteria:

- Use local materials in constructing the Adobe brick.
- Perform Adobe brick testing requirements on both the soil and the brick.
- Figure out the classification of the soil used in constructing the Adobe brick.
- Figure out the water content of the Adobe brick.
- Figuring out the air content of the Adobe brick.
- Figuring out the percent of clay, silt, and sand in the soil used in constructing the Adobe brick.
- Comprehend all possible brick construction methods.
- Perform mix soil design.

1.2.2 Design constraints and criteria

This research is done to develop a good strategy in constructing suitable Adobe bricks for Flagstaff, Arizona using local material and following Arizona's brick construction uniform building code requirements. The final design should meet the following constrains and criteria:

- Decrease negative impact on the area.
- Aesthetically pleasing.
- Within budget.
- Withstand earthquakes, hurricanes, and rain.
- Strong enough to carry a certain amount of load.

- Follow Arizona's uniform building code requirements for Adobe Brick.
- Follow the standards and regulation for brick construction.
- Soil Materials should be local (Flagstaff, AZ).
- Soil Materials should be 100% Natural.

1.2.3 Stakeholders

The stakeholders of this project are Coconino County and the project clients; Instructor Mark Lamer and Instructor Thomas Nelson.

Figure1: *Coconino County*
www.CoconinoCounty.org

Figure 2: *Mr. Thomas Nelson*
www.nau.edu

Figure 3: *Mr. Mark Lamer*
www.nau.edu

2.0 Methodology

To successfully complete the objective of this project, which is designing suitable adobe bricks for Northern Arizona environment by developing new codes and constrains regarding adobe brick design for Coconino County specific tasks were performed and discussed throughout this report. These tasks include the preparatory research, soil analysis, cement analysis, adobe brick design, and brick testing.

Task 1: The preparatory research

The preparatory research is a vital component of the project and is crucial to fully understand the project and its deliverables and as a result will facilitate the project design and construction process by analyzing the pertinent work of other investigators leading up to the team's proposed work.

Task 2: Soil Analysis

The team collected four different types of soil (Floodplain, Juniper forest, Ponderosa Park, and Grass) from four different locations around Flagstaff, Arizona to have a wider range of soil types for testing. Then the team performed multiple soil tests on the obtained soil samples. These tests included the Moisture Content test, Atterberge Limit test that includes the Liquid and Plastic Limit test, and finally the Sieve Analysis test. The Moisture Content test was necessary to determine the relationship between the soil's behavior and its properties. The Atterberge Limit test and Sieve Analysis test were necessary to classify the soil using both United Soil Classification System (USCS) and

United States Department of Agriculture (USDA), which was necessary to determine whether the obtained soil samples falls in the desired range of United States standard soil type for adobe brick design.

Task 2.1: Soil Collections

The team collected four samples of soil from four different locations (Floodplain, Juniper, Ponderosa, and Grass) around flagstaff, Arizona as shown in Figure 4,5,6 and 7. The first location was South haven lane the second location was Juniper Park, the third location was Ponderosa Park, and the last location was Coconino County Community College park. The purpose for collecting soil from four different locations was to have a variation of soil types that will be tested to determine the most suitable soil for the brick design; this is done by comparing the United States standard type of soil for adobe brick development as seen in **Table 1** with the soil analysis result for the four collected soil samples, and then determine whether the soil results falls in the range of the United States standard soil type for adobe brick design. However, if the soil samples results were way off from the standard soil for adobe brick design in the United States the team will have to recollect a new set of soil samples from different locations that varies from the initial obtained soil locations and then re-preform the soil testing and re-conduct the comparison between the collected soil samples and the standard soil type for adobe brick development in the United States.

Figure 4: *Floodplain Soil*
Location: 230 south haven lane
www.trulia.com

Figure 5: *Juniper Soil*
Location: Juniper Forest
www.smartgrowthusa.wordpress.com

Figure 6: *Ponderosa Soil*
Location: Ponderosa trail Park
www.flagstaff.az.gov

Figure 7: *Grass Soil*
Location: Coconino Community College
www.azfoo.net

Table 1: United States Standard Soil Type for Adobe Brick Design in Arizona.

Standard Soil Type For Adobe Brick			
Soil type	**Sand**	**Clay**	**Silt**
Loamy sand	70% - 85%	0% - 15%	0% - 30%
Sandy loam	50% - 70%	15% - 20%	0% - 30%
Sandy clay loam	50% - 70%	20% - 30%	0% - 30%

Task 2.2: Moisture Content Test

The Moisture Content Test was conducted to determine the water content in the soils. The soil may include a really high or really low percent of water that will affect the Brick's behavior after designing the brick and may causes failure. This test was conducted on all four-soil samples. The test procedure was as follow.

1- 2500 grams was obtained from each soil.
2- The team weighed an empty try.
3- The team weighed the moist soil with the try.
4- The moist soil with the try was then placed in the oven for about 24 hours.
5- The team weighed the oven dried soil sample with the try.
6- The team then calculated the percent moist soil using the collected data from this experiment.
7- Steps 1 through 6 was repeated for each soil sample and the results are listed in **Table 2**.

Table 2: Moisture Content Raw Data and Results.

	Symbol	Units	Floodplain	Juniper Forest	Ponderosa Park	Grass
Percent moist content	w%	(g)	0.049	0.067	0.006	0.032

Where,
Percent moist soil content (W%) = (W_1-W_2)/(W_2-W_c)

The Second soil has the highest percent of water content, which means that the soil has a higher amount of void ratio. On the other hand the Third soil sample had the lowest percent of water content, which indicates a lower amount of void ratio in that sample. This test is significantly important to determine the relationship between soil behavior and its properties.

Task 2.3: Atterberg Limit Test:

The Atterberg limit test was done to determine the water content in the soils. The soil may include a percent of water that will affect the Brick's behavior after designing the brick and may causes failure. The Atterberge Limit test includes the Plastic and Liquid limit test.

Task 2.3.1: Liquid Limit Test

Liquid limit test is a necessary test that will be performed to determine the moister content of the adobe brick soil content. Using the Atterberg device to determine the moisture content for each soil following the Atterberg test producer:

1. A sample of soils is taken from each soil buckets.
2. 250 g of soils needed for the test by measuring 250g of soils passing #40 sieves.
3. Replace the soil in bowl and start adding water until it has creamy texture enough to begin the test then replace it in the liquid limit device.
4. Adjust the device height, and then cut a groove using grooving tools.
5. Start dropping and counting for the numbers of drops and shall be between 10 and 35 drops.
6. While dropping the device the groove should close about ½ inch then.
7. Measure the moister content can alone then the can weight with wet soil then Place amount of soil in the oven about 24 hours.
8. After 24 hours take out the soil from the oven then measure the weight of the dry soil + can to calculate the moister content for the soil.
9. This test should be done 5 times for each soil to obtain the accurate result for the moister content.

Table 3 shows the liquid limit test results for the four soils using the figures and tables in the appendix.

Table 3: Liquid Limit Test's Results

	Number of drops N	Liquid Limit LL
Floodplain	25	40.5
Juniper	25	43.0
Ponderosa	25	21.9
Grass	25	50.3

Task 2.3.2: Plastic Limit Test

Plastic limit (PL) is the percentage of water content when a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.

Plastic Limit Test’s Procedure:

1. Get 20 grams of air-dry soil that passes through No. 40 sieve in an evaporating dish
2. Mix air-dry soil with water using spatula
3. Determine the moisture can’s mass in grams (W_1)
4. Squeeze the wet soil with your fingers on the glass plate
5. When d = (3.18 mm), break the wet soil and do it again
6. Put all parts in the can and determine the mass of moisture can + wet soil = (W_2)
7. Put it in oven for 24 hours and determine the mass of dry soil + can = (W_3)

Equation used for Plastic Limit test: $PL = \frac{W_2 - W_3}{W_3 - W_1} X\ 100$

Table 4: Plastic Limit Test’s Result

	W_1 (g)	W_2 (g)	W_3 (g)
Floodplain	14.4	36.2	31.1
Juniper Forest	14.5	38.0	33.3
Grass	21.7	40.0	37.2

Task 2.4: Sieve Analysis

This test was conducted to determine the percentage of different grain sizes contained within a soil, which is then used to classify the soil using both AASHTO and USCS soil classification methods. This test was conducted on all four-soil samples. The test procedure was as follow.

1. Place 500g of oven dried soil sample in a ceramic dish (oven dried for 24hrs).
2. Break the 500g-soil sample using a rubber tipped pestle.
3. Prepare a stack of sieves between sieve number 4 and sieve number 200, where the sieve with the larger opening (sieve number 4) is placed above the sieve with the smaller opening.
4. Weigh each sieve separately using an electronic balance, and then restack the sieves the same way.
5. Place the 500g of soil into the stack of sieves and place the stack of sieves in a sieve shaker for 15min.

6. Remove the stack of sieves for the sieve shaker and re-weigh each sieve to determine percent-retained soil.
7. Utilize the obtained data from this experiment to create a sieve analysis graph in *Microsoft Excel* as illustrated in figure 8.
8. Use the created graph to determine the uniformity coefficient (Cu), the coefficient of gradation (Cc), and to classify the soil.

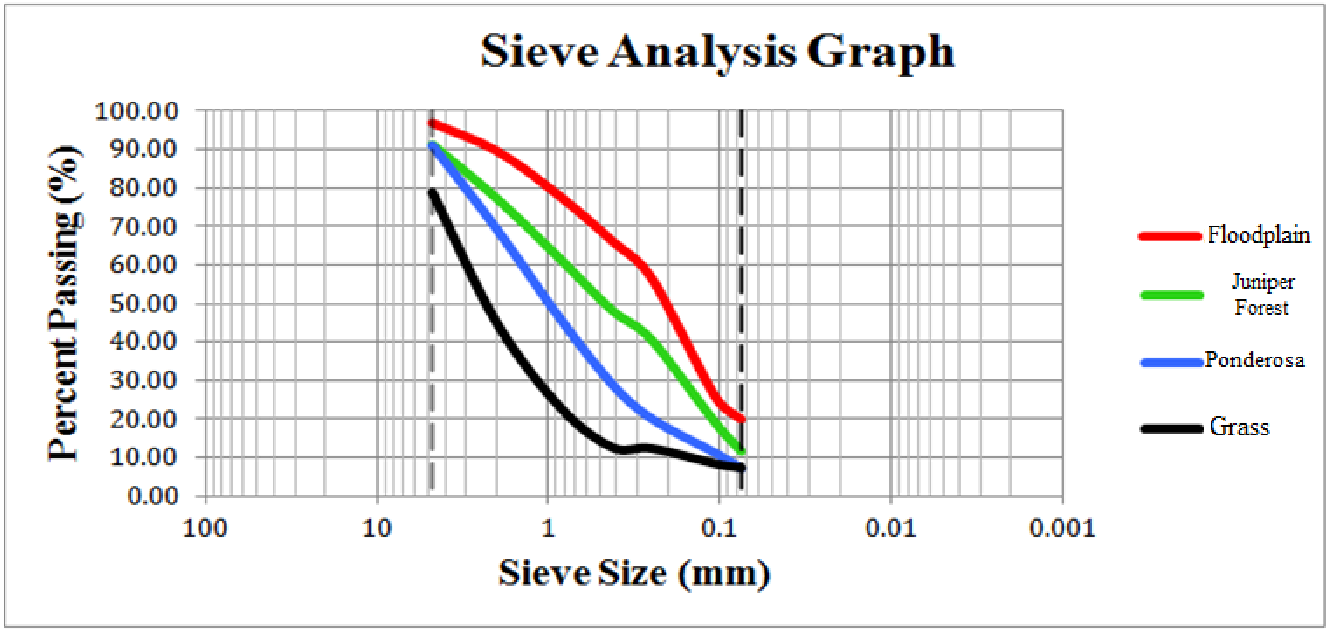

Figure 8. *Sieve Analysis Graph for ALL the Soil Samples.*

The Equations used for this test are as follow.

The uniformity coefficient (Cu):

(Cu) = D_{60}/D_{10}

The coefficient of gradation (Cc):

(Cc) = $(D_{30}^2)/\ (D_{60}*D_{10})$

Where,

D_{10} = Diameter corresponding to 10% finer

D_{30} = Diameter corresponding to 30% finer

D_{60} = Diameter corresponding to 60% finer

Task 2.5: Soil Classifications.

All the obtained soil samples for this project were classified using both Unites Soil Classification System (USCS) and the United States Department of Agriculture (USDA) and are provided under the appendices. After classifying all the obtained soil samples using the USCS classification method the first, second and third soil sample were classified as well graded sand and silt using and the last obtained soil sample was classified as only sand and silt. And after classifying all the obtained soil samples using the USDA classification method the first, second and forth obtained soil samples were classified as loamy sand however, the third soil sample was classified as sandy clay loam. When comparing the obtained soil samples with Arizona's standard soil type used for adobe brick design we noticed that the first, second, and last obtained soil samples fit that range. However, the third obtained soil sample did not fall in the range of the standard soil type for Arizona's environment, therefore it shall be excluded from the project and shall not be used for the final adobe brick design.

Task 3: Adobe Brick Wood Form Design

On Monday October 19th, 2015 the team designed the wood form that will be used in developing the adobe brick samples with instructor Mark Lamer's help. The development process was conducted in Northern Arizona University field station. The equipment used to design the form were a three 8ft. long (2inX 4in) wood, wood glue, one lb. (2.5") Nail box, Drill, sliding table saw, and cutoff saw. The team used the sliding table saw to sharpen the edges of the wood, then the team used the cutoff saw to cut the one 8ft (2inx4in) wood every four inch, then the team glued and screwed the 4in pieces of wood in between the other 8ft (2inx4in) wood. The final design is shown in figure 8.

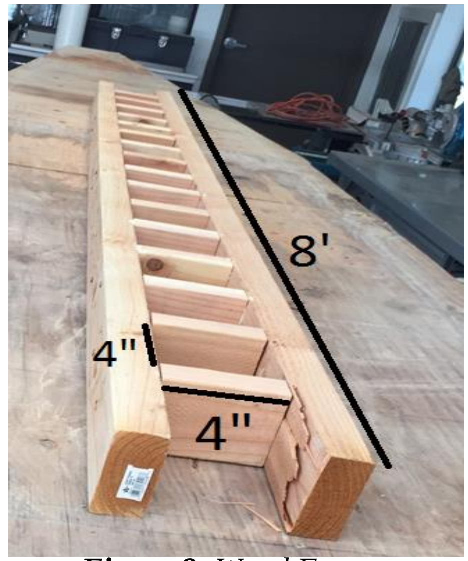

Figure 8: *Wood Form*

Task 3: Cement Analysis

The team used varying percentage of cement in the soil mix for each soil sample in order to examine the effect of cement on the strength of the adobe brick. The soil mixture will have 9-18% of cement. For the first trial the percentage of cement in the soil mix was 12%, for the second trial 18%, and for the final trial 9% cement was added to the soil mix as shown in **Table 5**.

Table 5. The Percentage of Materials used to Design the Brick Samples

	Cement (%)	Water (%)	Soil (%)
Trial 1	12%	18%	70%
Trial 2	9%	24%	67%
Trial 3	18%	24%	58%

The adobe brick sample's strength for each trial was then determined to recognize the appropriate amount of cement, water, and soil that will guarantee maximum strength in the final adobe brick design.

Task 4: Adobe Brick Sample Development

Task 4.1:Adobe Brick Building Code Requirements:

- The clay content of the soil used in producing adobe bricks must be greater than 25% and less than 45%.
- Bricks shall not have more than three shrinkage cracks. No shrinkage crack shall exceed 3 inches (7.6cm.) in length.
- The minimum compressive strength acceptable is 300 pounds
- The average modulus of rupture for five bricks must be 50 pounds inch

Task 4.2: Preparing The Soil For Designing The Adobe Brick Samples

The team obtains more soil samples for testing from South haven lane, juniper forest, Ponderosa Park, and Coconino community college. The obtained soil samples were placed in a dry location for approximately 48 hours to dry, since the obtained samples of soil were wet due to the rainy weather in Flagstaff Arizona. After 48 hours the obtained soil samples were cleaned by passing the soil sample through a (3/8) sieve. The process was done in the geotechnical engineering lab provided by Northern Arizona University.

Brick Molding Consideration:

- Start small—until you learn the right blend
- Use soils with high sand and low clay content
- The bricks will erode easily in wet weather

Task 4.3: Developing brick samples containing water and soil only

The team conducted the following steps to complete this task.

1. Measured the appropriate percentage of soil and water
2. Placed the soil with the water in a bucket and started mixing
3. Washed the form then filled it with the mixture
4. Compressed the mixture in the form and stroked the edge.
5. This procedure was repeated several times to have a good amount of brick samples for testing.
6. The samples were then removed after 24 hours and were placed in clean dry location for curing; the curing time was three weeks.

Task 4.4 Developing brick samples containing water, soil, and Portland cement

This task is similar to preparing brocks made of water and soil the only difference was adding cement. In the first trial the team used 12% cement in the mixture, for the second trial the team used 9% cement, and for the last trial the team used 18% cement. The team procedure performed by the team was as follow.

1. Measured the appropriate percentage of soil, water, and cement based on **Table 5.**
2. Mixing the soil, cement, and water in a bucket
3. Washed the form then filled it with the mixture
4. Compressed the mixture in the form and stroked the edge
5. This procedure was repeated several times to have a good amount of brick samples for testing.

6. The samples were then removed after 30 minutes and were placed in a clean dry location for curing; the curing time was three weeks.

The team developed 18 brick samples per trial; the total developed brick samples were 54.

Task 5: Brick Testing

Brick testing is necessary for evaluating the quality of the brick in general and the quality of the soil used in constructing the brick. Geotechnical engineers came up with various testing procedures that could define and describe the soil's behavior. The following are some of the major geotechnical testing required for constructing the adobe brick.

Task 5.1: Hardness and Soundness Test

Task 5.1.1: Hardness Test

This test was conducted by scratching the brick's surface using a nail and observing the results. If the scratch leaves a significant mark that means it's a poor quality bricks and it's not Strong enough. The team conducted this test on all three trial and the results are provided in Table 6 below.

Table 6: Hardness Test Results

Hardness Test			
Soil Type	**12%** Cement	**9%**Cement	**18%**Cement
Floodplain	Good Quality	Good Quality	Good Quality
Juniper Soil	Good Quality	Bad Quality	Good Quality
Grass	Good Quality	Good Quality	Good Quality

From **Table 6** it's concluded that the only bad quality brick based on the hardness test results is the brick developed from juniper forest soil and that included 9% cement in the soil mixture.

Task 5.1.2 Soundness Test

This test is conducted by beating two bricks with one another. If the bricks give a strong metallic sound without shattering then those are good quality bricks. This test was also conducted on all three trials. And the test results are shown in **Table 7**.

Table 7: Soundness Test Results

Soundness Test			
Soil Type	**12%** Cement	**9%**Cement	**18%**Cement
Floodplain	Bad Quality	Good Quality	Bad Quality
Juniper Soil	Good Quality	Bad Quality	Bad Quality
Grass	Good Quality	Good Quality	Bad Quality

From **Table 7** it's concluded that almost trial 3 which was using 9% cement in the soil mix was a failure. Therefore, 9% cement in the soil mixture will be excluded from the final design.

Task 5.2 Size, Shape, and Color Test

The purpose of this test is to verify the uniformity of the brick samples per trial. This test is conducted by staking the bricks along lengthwise, widthwise and height wise at the end of each trial to measures the variation of brick sizes per trial, verify that all brick edges are sharp, and to verify that the colors of the bricks are uniform per trial **Table 8** shows the results of this test.

Table 8: Size, Shape, and Color Test Results

Size, Shape, and Color Test			
Soil Type	**12%** Cement	**9%**Cement	**18%**Cement
Floodplain	Good Quality	Bad Quality	Good Quality
Juniper Soil	Bad Quality	Good Quality	Good Quality
Grass	Good Quality	Bad Quality	Good Quality

From **Table 8** it's concluded that the developed brock samples in trial three were the mixture had 18% cement was the best in comparison with trial one and two.

Task 5.3 Compressive Strength Test

This test is performed to determine the compressive strength of the brick. Three samples of bricks per trial were tested one by one. This test was conducted by placing each adobe brick sample under the compressive strength machine, then pressure is applied gradually the maximum pressure at which the brick sample breaks is the maximum load that the brick can withstand. The maximum load is then divided by the bedded area of the brick, which is 4inx4in, resulting in determining the bricks compression strength. The average result per trial is then determined. Results of this test are provided in **Table 9**.

Table 9. Compression Test Results

Compressive Strength (psi)			
Soil Type	**12%** Cement	**9%**Cement	**18%**Cement
Floodplain	0.49	1.94	3.33
Juniper Soil	0.66	2.07	2.73
Grass	0.56	2.54	3.13

Task 5.4: Structure Test

In this test the broken bricks from the compression strength test are obtained and are closely observed. If flows, cracks, or holes appeared on the broken face then the brick is considered bad quality otherwise its good quality brick. **Table 10** shows the results of this test.

Table 10. Structure Test Results

Structure Test Results			
Soil Type	**12%** Cement	**9%**Cement	**18%**Cement
Floodplain	Bad Quality	Good Quality	Bad Quality
Juniper Soil	Good Quality	Good Quality	Good Quality
Grass	Good Quality	Good Quality	Good Quality

Task 5.4 Water Absorption Test

This test was conducted to by weighing the dry brick samples, then re-weighing the brick samples after immersing them in water for approximately 24 hours.

Table 11 shows the water absorption results.

Table 11. Water Absorption Test Results

Water Absorption Test Results			
Soil Type	**12%** Cement	**9%**Cement	**18%**Cement
Floodplain	19.9%	19.4%	23.4%
Juniper Soil	15.8%	23.0%	20.8%
Grass	15.1%	17.1%	20.2%

From this test results we can see that 18% cement had the highest amount of water absorption.

Task 6: Project Management

Task 6.1: Development Process

The brick development process is an important part of the project that displays the overall team's efforts in meeting all the requirements of the final project to the client. The design process will include all the performed soil and brick testing, cement testing, Adobe brick design method, and the uniform building code requirements of Flagstaff, Arizona.

Task 6.2: Team Meetings

Team meeting are held every week to discuss the team's progress in meeting every upcoming deliverable for this class. Team meeting are also held to discuss any feedback provided by the instructor or technical advisor regarding any aspect of the project. Team meetings are important tools for managing team tasks and productivity.

Task 6.3: Final Report

The final Report is the main deliverable for this project other than the final adobe brick design. It includes all the conducted tasks that lead to the final development of the adobe brick, the project schedule, and cost analysis.

Task 6.4: Final Presentation

The final presentation is an important task that needs to be completed in order to gain the clients attention and approval of the project, where the team is required to prepare a short presentation to their client that describes their overall Adobe brick back development process, deliverables, project schedule, and the cost analysis of the project.

Task 6.5: Project Website

Designing a project website is one of the deliverables of this project. An effective website should fulfill some key elements to grab the client's attention which are appearance, content, functionality, and usability.

Task 7: Exclusions

The Team shall not analyze or study the items below due to the given time length to complete the project deliverables.

- Cement types.
- Load Path.
- Constructing a building out of the designed adobe brick.
- The third soil sample obtained from Ponderosa Park.

Task 8: Broader Impacts

Broader impact describes the environmental, heath, and economic impacts of the Adobe brick design. This project has many environmental, social, and political impacts. Economically, the project would profit the starters. Since, Coconino County does not have its own sets of codes and constrains regarding adobe brick design, which means there will be a place in the market for this project as soon as the project is complete and good adobe bricks are designed and new codes for Coconino County are developed. Socially, the project encourages sustainability and growth. In addition to that, adobe bricks are also safe to produce, because the materials used in developing the bricks are in people's exposal and they do not lead to any major health hazards. This project is educational as well in perusing sustainability in the reuse of local materials, which means it's cost-effective as well.

3.0 Discussion

The soil Analysis helped classify the obtained soil samples according to both United Soil Classification System and United States Department of Agriculture. After classifying the obtained soil samples and comparing them with the United States range of adobe brick soil types, the soil obtained from Ponderosa was found to be out of range because it had a higher amount of sand than the given range. Ponderosa Park soil was then excluded from the project. The rest of the obtained soil samples that were Floodplain, Juniper, and Grass were used to develop a 4inx4inx4in adobe brick samples. This sample had different percentage of cement in order to determine the appropriate amount of cement that gives the brick maximum strength. The conducted brick tests were the Water Absorption test, Hardness and Soundness test, Size, Shape and Color test, Compressive Strength test, and the Structure test. The conducted test helped determine the best soil for Northern Arizona's environment.

From the water Absorption test results 12% of cement in the mixture was found to have the best quality brick sample that had the least amount of water absorption, which meant having the least amount of void ration. The Hardness and Soundness test results revealed that the soil obtained from Juniper forest had the worst quality bricks; they shattered easily and had high amount of void ratio. The Structure test showed that the soil obtained from South haven lane had the worst quality bricks. For the compressive strength test the team tested the bricks that had 18% cement in the soil mix using the concrete compressive machine located in the concrete lab provided by Northern Arizona University, the results were very low, which meant that the bricks was very small in comparison with the machine size therefore a different machine was needed to complete the test. The team calculated the brick's compressive strength for the second and third trial that had 9% cement and 18% cement in the soil mix using the unconfined compression machine. This machine also provided low compressive strength results. After debating the issue the team concluded that the main reason for that would be that the unconfined compressive machine was created to determine the compressive strength of brick's that were smaller in size and cylindrical in shape. The best way to overcome this issue and get accurate results for the compressive strength would by utilizing a new machine that is specifically designed for adobe brick testing. Other solution would be by increasing the bricks size, increasing the cement percent, and adding aggregates to the soil mix which as a result would increase the brick's strength. From the brick testing it was concluded that grass soil obtained from Coconino County College park reveled the best quality brick and the best percentage of cement, soil, and water for the grass soil was found to be 18%cement, 58% soil, and 24% water.

4.0 Costs and Staffing

Table 12: Staff Classifications and their Codes

Classification	**Code**
Senior Engineer	SE
Engineer	E
Lab Technician	I.T
Administrative Assistance	A.A

Table 13: Hours Spent in Conducting each Task Pertaining the Project

Task	Hours
Preparatory Research	24
Background Research	8
Professional Consultation	30
Soil analysis	60
Cement Analysis	40
Soil And Brick Testing	30
Project Management	90
Construction Process	60
Team Meetings	40
Total Hours	314

Table 14: Staffing Cost

Classification	Hours	Pay Rate/ Hour	Cost $
Senior Engineer	72	95	6840
Engineer	113	55	6215
Lab Technician	58	30	1740
Administrative Assistance	23	25	575
Total Cost			15,370

Table 15: Hours Spent on the Project per Team Member

Role	Name	Hours
Team Leader	Zahraa Alqallaf	107
Design Specialist	Zahraa Alhusaini	102
Team Supervisor	Hawraa Farman	105

Table 16: Equipment's Cost

Equipment's Cost		
Equipment name	Quantity	Cost $
8ft. (2" X 4") wood.	3	18
wood glue	1	4
(2.5") Nail box.	1lb	3
Drill	2	190
Sliding Table Saw	1	2,970
Cutoff Saw	1	900
Cement Bag	900 lb	12
Total Cost		4,097

Total Project Cost = Total Staffing Cost + Total Equipment's Cost
**19,467$** = 15,370$ + 4,097$

5.0 Conclusion

The main objective of this project is to create a standard code to be used by Coconino County that is suitable for northern Arizona environments. There were tests applied on the soils that collected from four locations in flagstaff. Than mixed the tested soil with water and cement in order to create a brick samples for brick testing. Soil analysis shows that Grass soil is have the best result between the other options because it fit the range of standard soil type for adobe brick design. Grass soil have the highest score of plastic limit equal to 18.06 and liquid limit of 50.8. There were five testes preformed in the brick samples. The structure test, size, shape and color test, and Hardness and soundness test were all good in trial 3 for 18% cement for grass soil. The water absorption test for grass soil is the most reasonable result between the others soil for trial 3. The compressive strength test for grass soil trail 3 is the maximum compressive strength the bricks withstand and equal to 3.13 psi. The test results concluded that the best quality soil was found to be grassy soil for a 4inx4inx4in adobe brick that weighs 4 ib. with a maximum compressive strength of 3.13 psi. And the recommended Soil characteristics are 58% soil, 24% water and 18% cement.

Table 17: The Recommended Adobe Brick Characteristics

	Percentage (%)	Soil Type
Soil	58%	Grass
Cement	18%	
Water	24%	

6.0 Acknowledgment

The Civil Engineering Kuwaiti Women group would like to present their gratitude towards Northern Arizona University for providing beneficial courses, great professors, and a great study environment that increased the team's knowledge towards the entire subject pertaining this project. The team would also like to express their gratitude's towards the CENE 486 class Instructors Bridget Bero, *Ph.D., P.E.,* Professor and Chair Wilbert Odem, Ph.D.,P.E., Professor, and Mark Lamer, *P.E.,* Professor for guiding us through the course and providing helpful feedback on all are submitted deliverables . A special thanks goes to Instructors Thomas Nelson for providing us with good feedbacks throughout this project. The group also thanks instructor Gerjen Slim for allowing us to utilize the geodetic lab in conducting all the necessary soil testing needed for this project, also for assisting us in performing the compressive strength test with the help of Junyi Shan.

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7.0 Appendix

Appendix A: Soil Analysis

Table A-1 Moisture Content Test Raw Data and Results.

	Symbol	Units	Floodplain	Juniper Forest	Ponderosa Park	Grass
Weight if Empty Try	(Wc)	(g)	310.75	87.14	85.98	115.98
Weight of Tray + Moist Soil	(W1)	(g)	2810.75	2587.14	2585.98	2615.98
Weight of Tray + Dry Soil	(W2)	(g)	2694.49	2431.1	2569.91	2538.73
Weight of Moist	(W1-W2)	(g)	116.26	156.04	16.07	77.25
Weight of Dried Sample	(W2-WC)	(g)	2383.74	2343.96	2483.93	2422.75
Percent moist content	w%	(g)	0.049	0.07	0.01	0.032

Where,
Percent moist soil content (w%) = (W1-W2)/(W2-Wc)

Table A-2: Moisture content of Floodplain Soil.

Floodplain	drops	Empty can	Can + wet soil	Can+ dry soil	Water content
1	10	22.73	41.17	35.82	40.87
2	15	13.74	30.2	25.51	39.85
3	12	22.52	49.67	41.77	41.04
4	21	21.7	48.5	40.65	41.42
5	12	14.14	34.09	28.2	41.89

Table A-3: Moisture Content of Juniper Forest Soil.

Juniper Forest	drops	Empty can	Can +wet soil	Can +dry soil	water content
1	16	21.77	70.08	54.88	45.91
2	15	24.65	48.72	41.18	45.61
3	22	13.79	38.67	31.13	43.48
4	29	14.08	40.24	32.44	42.48
5	25	13.85	42.79	34.16	42.49

Table A-4: Moisture Content of Ponderosa Park Soil.

Ponderosa Park	drops	Empty can	Can +wet soil	Can +dry soil	water content
1	18	22.33	42.83	39.11	22.17
2	23	21.88	40.29	36.96	22.08
3	35	13.65	24.74	22.77	21.60
4	35	13.22	24.67	22.66	21.29
5	35	14.12	30.28	27.53	20.51

Table A-5: Moisture Content of Grass.

Grass	drops	Empty can	Can + wet soil	Can + dry soil	Water content
1	11	13.8	50.19	41.82	29.87
2	15	14.44	51.14	33.51	92.45
3	19	14.12	49.14	42.44	23.66
4	22	11.71	45.01	43.54	4.62
5	22	13.85	38.61	30.24	51.07

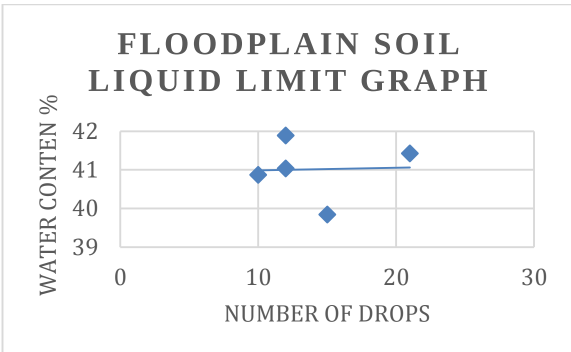

Figure A-1: Floodplain Liquid Limit Graph

$LL = w_n(\%)(\frac{N}{25})^{0.121}$, LL= 40.55 Since this soil close at 22 drops maximum the equation used above to determine the liquid limit for the soil.

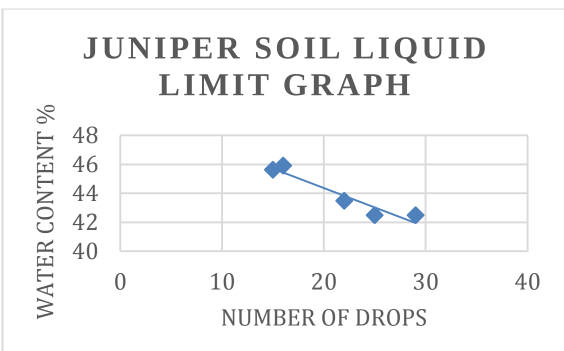

Figure A-2: Juniper Liquid Limit Graph

LL = 43%. , the graph shows the number of blows vs the moisture content and the moister content corresponding to the N= 25 drops.

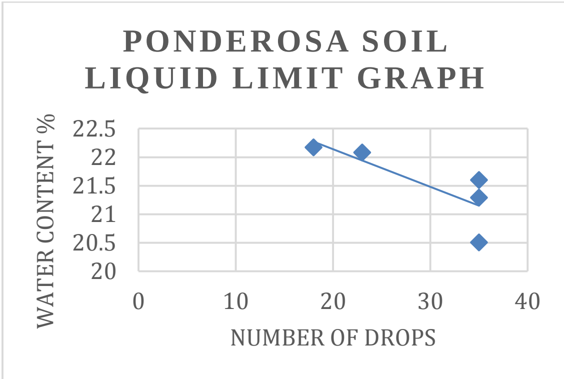

Figure A-3: Ponderosa Liquid Limit Graph

LL=21.85, the graph shows the number of blows vs the moisture content and the moister content corresponding to the N= 25 drops.

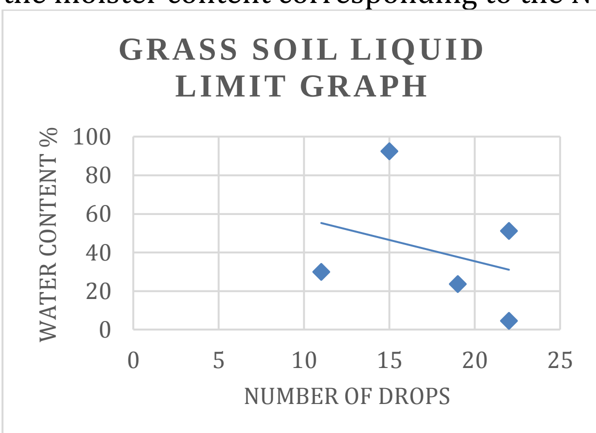

Figure A-4: Grass Liquid Limit Graph

$LL = w_n(\%)(\frac{N}{25})^{0.121}$, LL=50.28 Since this soil close at 22 drops maximum the equation used above to determine the liquid limit for the soil.

Test 3: Sieve Analysis

Table A-6: Floodplain Sieve Analysis Data.

Sieve #	**Sieve Opening (mm)**	**Mass Retained (g)**	**Percent Retained (%)**	**Cumulative Weight**	**Cumulative Percent (%)**	**Percent passing/finer (%)**
4	4.75	43.4	8.69	43.4	8.69	91.3
10	2.00	70.4	14.1	113.9	22.8	77.2
20	0.85	78.7	15.7	192.6	38.5	61.5
40	0.43	66.5	13.3	259	51.8	48.2
60	0.25	38.6	7.72	297	59.5	40.5
140	0.11	107	21.5	405	81.0	18.9
200	0.075	36.7	7.33	441	88.4	11.6
Pan	0	57.9	11.6	499	99.9	0.05
Led	0	0	0	499	99.9	0.05

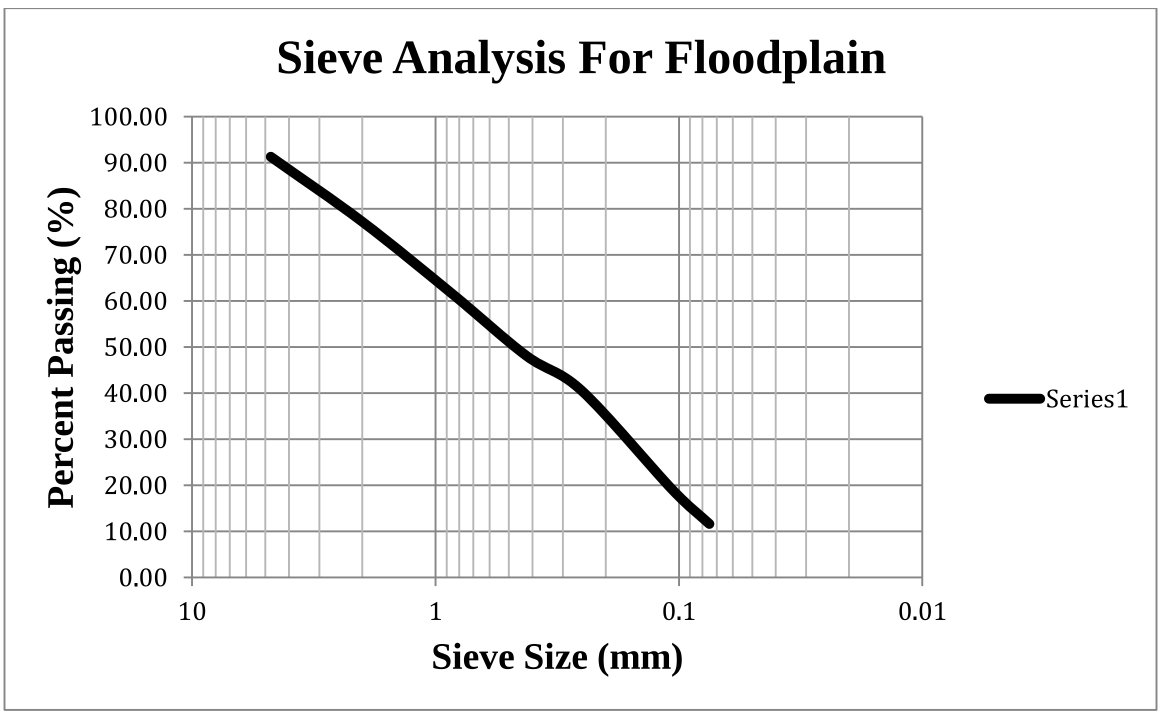

***Figure A-5:**. Floodplain Soil Grain Size Distribution Graph*

Table A-7: Juniper Forest's Soil Sieve Analysis Data.

Sieve #	**Sieve Opening (mm)**	**Mass Retained (g)**	**Percent Retained (%)**	**Cumulative Weight (g)**	**Cumulative Percent (%)**	**Percent passing/finer (%)**
4	4.75	44.8	8.97	44.8	8.97	91.0
10	2.00	109	21.8	154	30.8	69.2
20	0.85	116	23.3	270	54.0	45.9
40	0.43	84.5	16.9	354	70.9	29.0
60	0.25	44.8	8.96	399	79.9	20.0
140	0.11	44.6	8.92	444	88.8	11.2
200	0.08	19.9	3.97	464	92.8	7.19
Pan	0	35.8	7.15	499	99.9	0.04
led	0	0	0	499	99.9	0.04

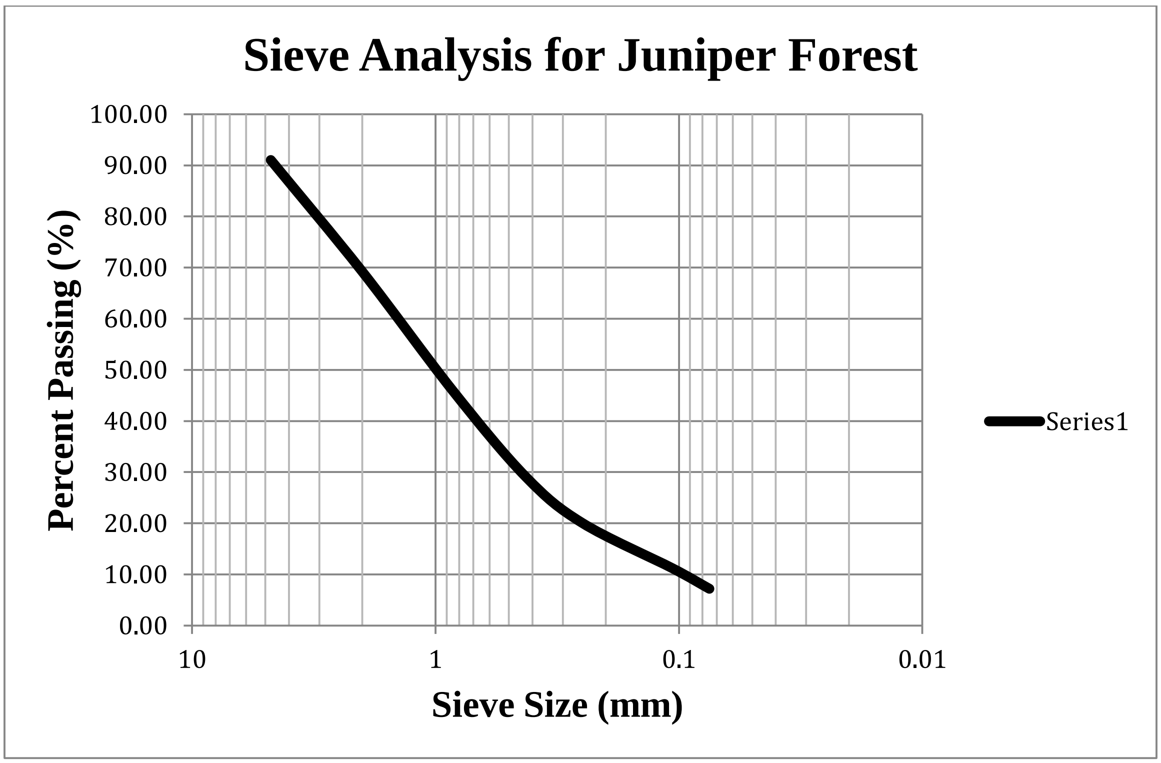

Figure A-6:. *Juniper Forest Grain Size Distribution Graph*

Table A-8: Ponderosa Park's Soil Sieve Analysis Data.

Sieve #	**Sieve Opening (mm)**	**Mass Retained (g)**	**Percent Retained (%)**	**Cumulative Weight**	**Cumulative Percent (%)**	**Percent passing/finer (%)**
4	4.75	106	21.2	106	21.2	78.8
10	2	169	33.9	275	55.1	44.9
20	0.85	109	21.9	385	77.0	22.9
40	0.42	51.6	10.3	437	87.4	12.6
60	0.25	1.26	0.25	438.	87.6	12.4
140	0.11	19.8	3.95	457	91.6	8.43
200	0.08	5.52	1.10	463	92.7	7.33
Pan	0	13.2	2.63	476	95.3	4.70
led	0	0	0	476	95.3	4.70

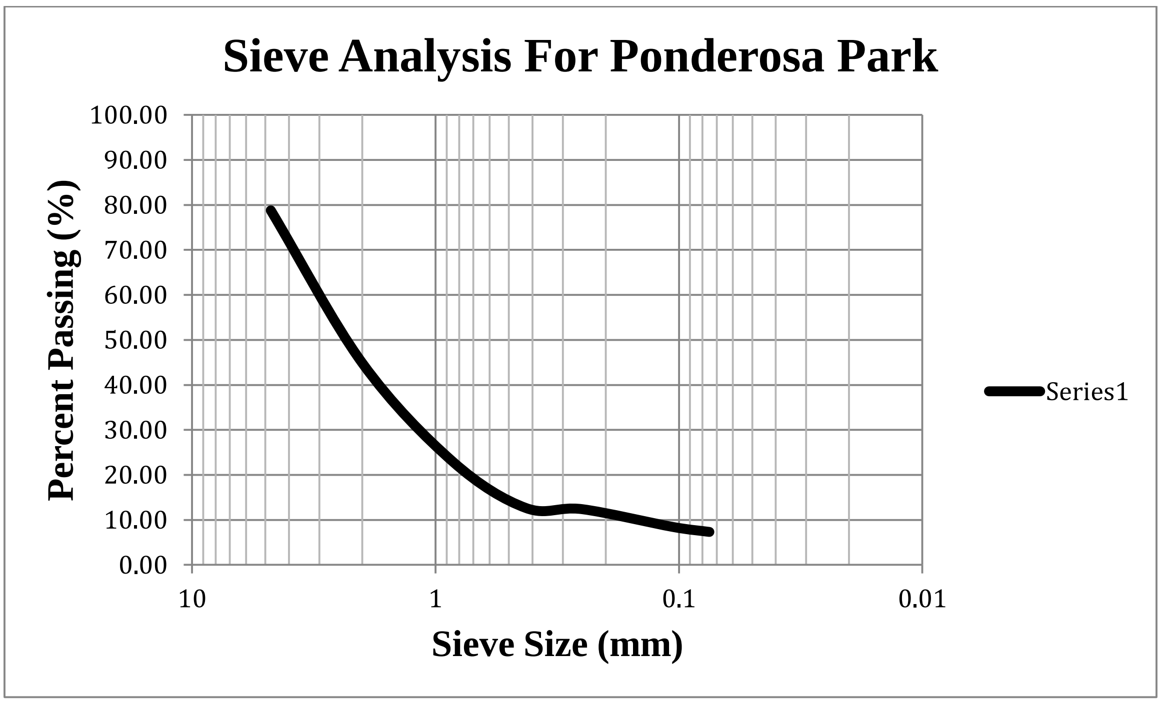

Figure A-7:*. Ponderosa Park Grain Size Distribution Graph*

Table A-9: Grass's Soil Sieve Analysis Data.

Sieve #	**Sieve Opening (mm)**	**Mass Retained (g)**	**Percent Retained (%)**	**Cumulative Weight**	**Cumulative Percent (%)**	**Percent passing/finer (%)**
4	4.75	15.8	3.16	15.8	3.16	96.8
10	2.00	36.3	7.25	52.0	10.4	89.6
20	0.85	59.6	11.9	111	22.3	77.7
40	0.43	57.3	11.5	168	33.8	66.2
60	0.25	48.6	9.7	217	43.5	56.5
140	0.11	154	30.9	372	74.3	25.7
200	0.08	28.8	5.76	400	80.1	19.9
Pan	0	96.2	19.2	497	99.3	0.66
led	0	0	0	497	99.3	0.66

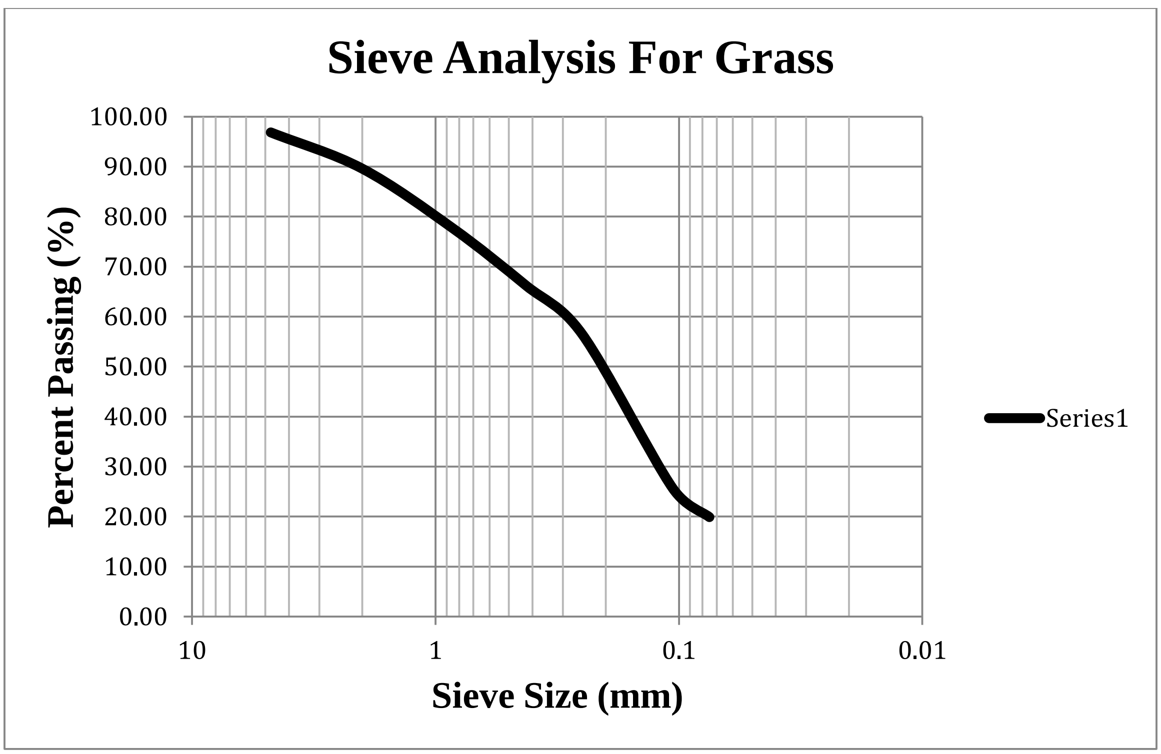

Figure A-8: *Grass Grain Size Distribution Graph*

Table A-10: USCS Soil Classification Data and Results

United Soil Classification System										
Soil Type	%Silt	%Clay	%Sand	D10	D30	D60	Cc	Cu	USCS Symbol	USCS Name
Floodplain	11.64	8.69	79.67	0	0.18	0.8	No value	No value	(SW-SM)	Well Graded Sand and Silt
Juniper Forest	7.19	8.966	83.842	0.1	0.46	1.5	1.41	15	(SW-SM)	Well Graded Sand and Silt
Ponderosa Park	7.33	21.21	71.46	0.2	1.2	3	2.4	15	(SW-SM)	Well Graded Sand and Silt
Grass	19.89	3.16	76.95	0	0.13	0.3	No value	No value	(SM)	Sand and Silt

Table A-11: Comparison between the Sample Soil and the Standard Soil for Adobe Brick Design

Sample	USCS Classification	USDA Classification	Comments
Floodplain	Will Graded Sand and Silt (SW-SM)	Loamy Sand	It fits the range of standard soil type for adobe brick design.
Juniper Forest	Will Graded Sand and Silt (SW-SM)	Loamy Sand	It fits the range of standard soil type for adobe brick design.
Ponderosa Park	Will Graded Sand and Silt (SW-SM)	Sandy Clay Loam	It doesn't fits the range of standard soil type for adobe brick design.
Grass	Sand and Silt (SM)	Loamy Sand	It fits the range of standard soil type for adobe brick design.

Appendix B: Brick Testing

Table B-1: Hardness Test Results

Hardness Test Results																		
	12%Cement, Flood Plain						12%Cement, Juniper						12%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Average Quality	Good						Good						Good					
	9%Cement, Flood Plain						9%Cement, Juniper						9%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Good	Good	Good	Good	Good	Bad	Bad	Bad	Bad	Bad	Bad	Good	Good	Good	Good	Good	Good
Average Quality	Good						Bad						Good					
	18%Cement, Flood Plain						18%Cement, Juniper						18%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Good	Good	Good	Good	Good	Bad	Good	Bad	Good	Good	Good	Good	Good	Good	Good	Good	Good
Average Quality	Good						Good						Good					

Table B-2: Soundness Test Results.

Soundness Test Results																		
	12%Cement, Flood Plain						12%Cement, Juniper						12%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Bad	Bad	Bad	Bad	Bad	Bad	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Average Quality	Bad						Good						Good					
	9%Cement, Flood Plain						9%Cement, Juniper						9%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Good	Good	Good	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Good	Good	Good	Good	Bad	Good
Average Quality	Good						Bad						Good					
	18%Cement, Flood Plain						18%Cement, Juniper						18%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Bad	Bad	Bad	Bad	Bad	Bad	Good	Good	Bad	Bad	Good	Bad	Good	Good	Bad	Bad	Bad	Bad
Average Quality	Bad						Bad						Bad					

Table B-3: Size Shape, and Color Test Results

Size, Shape, and Color Test Results																		
	12%Cement, Flood Plain						12%Cement, Juniper						12%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Bad	Good	Good	Good	Good	Good	Good	Bad	Bad	Bad	Bad	Good	Good	Good	Good	Good	Good
Average Quality	Good						Bad						Good					
	9%Cement, Flood Plain						9%Cement, Juniper						9%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Good	Bad	Bad	Bad	Bad	Good	Good	Good	Good	Good	Good	Good	Good	Bad	Bad	Bad	Bad
Average Quality	Bad						Good						Bad					
	18%Cement, Flood Plain						18%Cement, Juniper						18%Cement, Grass					
Brick Sample Number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Sample Quality	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Bad	Bad	Good	Good	Good	Bad	Bad	Good
Average Quality	Good						Good						Good					

Table B-4: Water Absorption Test Results

Water Absorption tests									
	12%Cement, Floodplain			12%Cement, Juniper			12%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Dry Brick Weight (g)	1256	1159	1169	1316	1323	1441	1412	1308	1360
Wet Brick Weight (g)	1560	1426	1490	1560	1565	1715	1633	1559	1610
Water Absorption (%)	19.5	18.7	21.5	15.7	15.5	16.0	13.5	16.1	15.5
Average Water Absorption (%)	19.9			15.7			15.0		
	9%Cement, Floodplain			9%Cement, Juniper			9%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Dry Brick Weight (g)	1286	1240	1280	1105	1148	1186	1390	1308	1420
Wet Brick Weight (g)	1578	1532	1610	1434	1497	1537	1650	1602	1717
Water Absorption (%)	18.5	19.0	20.5	23.0	23.3	22.8	15.7	18.3	17.3
Average Water Absorption (%)	19.4			23.0			17.1		
	18%Cement, Floodplain			18%Cement, Juniper			18%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Dry Brick Weight (g)	1057	1059	1080	1121	1240	1087	1128	1192	1137
Wet Brick Weight (g)	1378	1390	1404	1396	1566	1390	1408	1482	1438
Water Absorption (%)	23.3	23.8	23.1	19.7	20.8	21.8	19.9	19.6	21.0
Average Water Absorption (%)	23.4			20.8			20.2		

Table B-5: Compressive Strength Test Results

Compression Strength Test Results									
	12%Cement, Floodplain			12%Cement, Juniper			12%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Area of bed Face (in^2)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Max Load at Failure (lb.)	8.4	8.3	6.7	8.5	10.5	12.5	10.9	8.2	7.7
Compressive Strength (lb./in^2)	0.53	0.52	0.42	0.53	0.66	0.78	0.68	0.51	0.48
Average Compression Strength per trial (lb./in^2)	0.49			0.66			0.56		
	9%Cement, Floodplain			9%Cement, Juniper			9%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Area of bed Face (in^2)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Max Load at Failure (lb.)	24.0	39.0	30.0	18.6	56.0	25.0	47.0	34.0	41.0
Compressive Strength (lb./in^2)	1.50	2.44	1.88	1.16	3.50	1.56	2.94	2.13	2.56
Average Compression Strength per trial (lb./in^2)	1.94			2.07			2.54		
	18%Cement, Floodplain			18%Cement, Juniper			18%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Area of bed Face (in^2)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Max Load at Failure (lb.)	67.0	55.0	38.0	29.0	54.0	48.0	51.0	44.0	55.0
Compressive Strength (lb./in^2)	4.19	3.44	2.38	1.81	3.38	3.00	3.19	2.75	3.44
Average Compression Strength per trial (lb./in^2)	3.33			2.73			3.13		

Table B-6: Structure Test Results

Structure Test Results									
	12%Cement, Floodplain			12%Cement, Juniper			12%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Sample Quality	Bad	Bad	Bad	Good	Good	Good	Good	Good	Bad
Average Sample Quality	Bad			Good			Good		
	9%Cement, Floodplain			9%Cement, Juniper			9%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Sample Quality	Good	Good	Good	Good	Good	Good	Good	Good	Good
	Good			Good			Good		
	18%Cement, Floodplain			18%Cement, Juniper			18%Cement, Grass		
Sample Number	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3	Sample1	Sample2	Sample3
Sample Quality	Bad	Bad	Bad	Good	Good	Good	Good	Good	Good
	Bad			Good			Good		