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Straw bale seismic design capacities 2

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

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entitled

STRAW BALE SEISMIC DESIGN CAPACITIES 2

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

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

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Advisor Date

_______________________________ 6/15/14
Department Chair Date

by

BETH AVON
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SENIOR DESIGN PROJECT REPORT

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the Department of Civil Engineering

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in partial fulfillment of the requirements for the degree of
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STRAW BALE SEISMIC DESIGN CAPACITIES

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Santa Clara University, Spring 2014

ABSTRACT

Straw bale is a sustainable building material that repurposes agricultural waste for use in the structural system of buildings. This material will be used as a component in the lateral force resisting systems of walls, especially helpful in the California seismic environment and under heavy wind loads. The four main components of a post-and-beam method straw bale wall are timber framing, straw bales, wire mesh, and plaster. This report will focus on the design of the exterior plaster and the design of "workhorse" and "strong" walls for simple construction and areas of higher seismic activity, respectively. Our test results will be used to validate straw bale as a viable structural material for future building code development.

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INTRODUCTION

Finding a Use for Waste Rice Straw

Straw bales come from agricultural waste, a byproduct of the food that we consume. As a waste product, the material has little to no use beyond littering stable grounds. This material was previously burned, increasing air pollution. The passing of the California Rice Straw Burning Reduction Act of 1991 required farmers to start looking into alternative ways of disposing of rice straw in the Sacramento Valley, specifically. As a result, rice straw bales were considered as a sustainable structural building material.

Early Feasibility Tests are Promising

Straw bale construction uses an alternative building material in a building's structural system that is both functional and sustainable. Tests were conducted in 2003 that provided the basic material information for straw bale construction; these tests indicated that straw bale is a viable construction material. To develop building code provisions to include structural applications in seismic environments, further testing is required. This research and wall design will be conducted under the guidance of not only our faculty advisory, but also the FEMA P695 Peer Review Group that will ensure that our tests will be compliant with introducing new materials into the building code. Through a series of three coordinated senior design projects, we will gather enough data to create a basis for code incorporation.

How the Current Work fits into the Bigger Picture

Our research will be an extension of the research done at the University of Illinois in 2003 that began the work resulting in the adoption of qualitative data for straw bale into the 2015 International Residential Code appendix. We will introduce new structural applications of straw bale that will include construction techniques to begin the process for straw bale construction's incorporation into the International Building Code. This research project will include the origin for a holistic wall design that can deliver dependable strength and a ductile failure mode. The project scope for the Straw Bale Seismic Design Capacities 2 team includes the design of cement-lime based plaster used on the exterior of the wall, the design of the 8-foot "workhorse" wall that is easy to construct, and the design of the 8-foot "strong" wall that is designed to take larger loads per foot length. Testing of these walls will not be included in this work scope.

STRAW BALE AS A CONSTRUCTION MATERIAL

Straw Bale as More than a Convenient Solution

Using straw bale in construction addresses a larger issue: what farmers are supposed to do with the straw that is produced from their rice and grain crops. Not only is straw bale a healthy, insulating, sound-dampening, safe, and earth-friendly product, but it is very structurally sound in seismic environments. The geometry of the straw bales used in the design of shear walls using the post and beam method came from the dimensions provided by the specific supplier. These dimensions can be found in figure 1; these dimensions exhibit a very thick base as compared to its length.

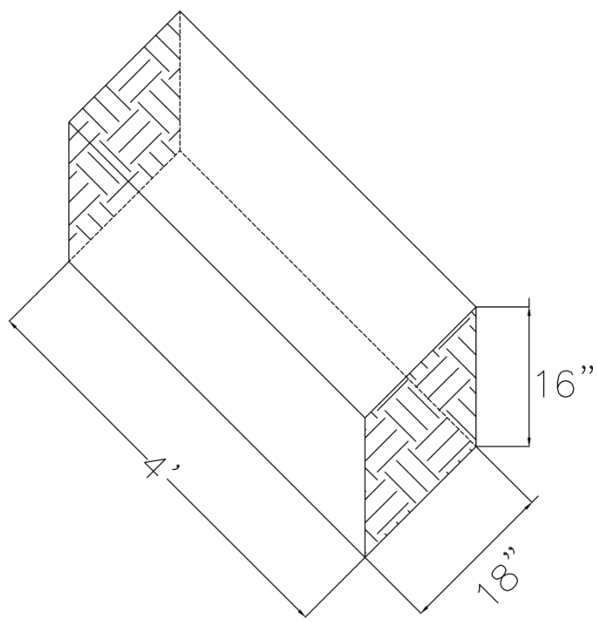

Figure 1 – The straw bale orientation within the wall will be an 18” thickness and a 16” height. The standard bale dimension is a 4’ length and may be reduced for smaller wall dimensions or a more efficient bale configuration.

Straw Bale’s Geometry Affects Material Properties

The width to height ratio of a bale causes them to have a small moment of inertia. This allows them to resist greater rotations in order to perform well under the lateral loads from earthquakes and wind. We are proposing that structural straw bale walls be constructed using the post and beam method explored in the 2003 University of Illinois study. Straw bale construction involves four basic materials:

- Straw Bale

- Timber Framing
- Wire Mesh
- Plaster

The purposes and goals of each material are outlined in Table 1.

Table 1 – The summary of the 4 main structural materials used in the post and beam framing method includes the main structural role that the individual material plays for the wall.

Material	Structural Purpose
Straw Bale	• Provides rigidity and structural backing for the structure • Acts as infill to provide the
Timber Framing	• Provides the shape of the structure • Dissipates the gravity loads applied to the structure
Wire Mesh	• Provides ductility during lateral loading • Maintains wall thickness and
Plaster	• Indicates visible failure of walls in case of emergency • Binds together mesh and straw bale to engage all components

PLASTER MIX DESIGN

Design Goals

Plaster is the outermost layer of the straw bale wall. This element creates the finishing touches for the final wall, the component that the non-technical users will appreciate the most. Beyond the aesthetics of the plaster finish, the plaster mix design is intended to do the following:

- act as a binder for the mesh to the straw bales,
- visually indicate failure before the mesh yields, and
- add a desired strength of less than 1,200 psi to the structure.

Plaster Design for Straw Bale Walls

Lateral load-resisting straw bale walls require the plaster component to help maintain the structural integrity of the wall, without being the main load-resisting material. The mesh is designed to be stronger than the plaster, creating a core capable of resisting greater deformations in a seismic event. After more research has been conducted to bring straw bale construction into the building code, the minimum standards for plaster design in straw bale walls will be set. By achieving these code minimum standards in design, contractors or home builders will find it easier to comply with city and state requirements to build a seismically stable, and earth-friendly home.

Design Materials – Plaster Mix

The four ingredients used to create the straw bale wall plaster layer are: cement, lime, sand, and water. In order to select the appropriate mix design for testing considerations, it was important to determine which proportions of each ingredient would provide the desired behavior.

Portland Cement in the Plaster Mix

Basic plaster mix designs are most commonly made up of cement, sand, and water. Type I Portland cement is utilized as our primary binding material because of its reliability as all-purpose cement. Because building code design is intended to have easy-to-find ingredients, it is important to use a material that is readily available everywhere. Any substitutions for a change in environment are only expected to help the plaster mix to perform better in its new environment.

Portland cement type I develops almost full strength at a consistent rate of 28 days of curing. A typical Portland cement mix design produces an average strength of approximately 4,000 psi. Because the design goals require a maximum of 1,200 psi strength at 28 days, an additional binder material, lime, is added to reduce the expected strength to a value close to the desired strength.

Lime in the Plaster Mix

Most often, lime is added to a mix design as a plasticizer in order to improve workability. Lime is included as a binder in these mix designs in order to create a more sustainable plaster. Slaked lime, for instance, has a 20-percent lower embodied energy than cement as it is produced at a lower temperature. Type S lime is also added to the plaster mix design to weaken the mix; average lime sand plaster has an average strength of approximately 400 psi. In weakening the design strength of the plaster, there will be a greater assurance that the plaster will fail before the mesh. This behavior not only provides a visual indication of the building strength to alert occupants of the building failure, but as the plaster breaks away from the wire mesh, it allows the mesh to yield as it provides a ductile failure.

Aggregate in the Plaster Mix

Like a typical concrete mix, aggregate will be used to provide the strength of the plaster. Several sand grain mixes will be used to determine the best plaster mix design for the walls. It is expected that the larger grains will produce stronger samples with less workability, while the smaller grains will produce weaker samples with greater workability. The final mix design will achieve a balance between the desired strength and workability.

Water in the Plaster Mix

The amount of water used in each mix design varies. While a larger quantity of water does increase the workability, making the plaster easier to apply to the structure's exterior, it can also significantly decrease the strength of the sample. This final amount is not regulated by codes and will be adjusted as needed in mix designs to determine the best balance between strength and workability.

Cement-Lime Plaster Mix Design Code Considerations

Two ASTM provisions are used to guide the plaster mix design process:

- ASTM C 926: Application of Portland Cement-Based Plasters
- ASTM C 897: Aggregate for Job-Mixed Portland Cement-Based Plasters

A Closer Look at ASTM C926

ASTM section C926 Table 3 lists the requirements for mixing Portland Cement-based plasters. The requirements by volume are 1 cement: 0 to ¾ lime: 2 ½ to 4 sand per volume of cementitious material. These ranges were used in the mix design to determine the most effective ratio for the plaster mix design. This full table is listed in Appendix A Table A1.

A Closer Look at ASTM C897

ASTM section C897 describes the sieve test percent passing requirements for Portland cement-based plaster sand mix designs. The sand chosen for use with the final wall specimens will follow these grading requirements. This full table is listed in Appendix A Table A2.

Mix Design Iterations

The first set of mix designs were all made with a coarse sand mix that was readily available in the lab. This sand is typically used as fine aggregate in concrete mixes, and has much larger grains than are typically used in wall plastering. The first design mixes focused on varying sand content within the ranges specified in ASTM section C926. These ratios and test results are shown in Table 2. Three 2" cube specimens were made to test mix designs 1-2, 1-3, and 1-4.

Table 2 – The first mix design iterations with initial mixes 1-2, 1-3, and 1-4 varied the proportions of sand by volume in the mix designs.

Mix Name	Sand	Cement:Lime:Sand (by part)	Cured	Cure Time	Max Average Load (pounds)	Average (psi)	COV	Viable Option
1-2	Coarse	1 : 0.75 : 4.375	Air	7	3059	765	5%	Yes
1-3	Coarse	1 : 0.75 : 4.5	Air	7	2874	719	9%	No
1-4	Coarse	1 : 0.75 : 5.25	Air	7	2198	550	12%	Yes

Mix 1-3 was immediately eliminated from further testing due to its lack of workability. Testing was continued with mix designs 1-2 and 1-4, using different curing methods and curing time intervals.

Evaluating how Curing Environments Effects the Strength of the Plaster

ASTM C192 introduces the use of lime-saturated water baths to cure the concrete more slowly, but at a higher final strength. Mixes 1-2 and 1-4 were introduced to two curing environments: (1) lime and (2) water baths. These values are shown below in Table 3 and Table 4. The results for mixes 1-2 and 1-4 using these curing methods are listed as mixes 2-2 and 2-4, respectively.

Table 3 – The second set of mix design iterations varied the curing methods. This table shows the results for the lime-cured samples at 7-days and 41-days(past the time of fully-developed strength).

Mix Name	Sand	Cement:Lime:Sand (by part)	Cured	Cure Time	Max Load Average (pounds)	Average (PSI)	COV	Viable Option
2-2	Coarse	1 : 0.75 : 4.375	Lime	7	6318	1580	20%	Yes
2-2	Coarse	1 : 0.75 : 4.375	Lime	41	10000^{+}	2500^{+}	---	Yes
2-4	Coarse	1 : 0.75 : 5.25	Lime	7	4104	1030	16%	No
2-4	Coarse	1 : 0.75 : 5.25	Lime	41	4568	1140	36%	No

$^{+}$ Values over 10,000 pounds and were not able to be read by testing machine, therefore the value reported for mix 2-2 lime-cured for 41 days is not the true maximum load, but the maximum load that could be recorded with the load cell.

Table 4 – The second set of mix design iterations varied the curing methods. Below are the results for the water-cured samples.

Mix Name	Sand	Cement:Lime:Sand (by part)	Cured	Cure Time	Max Load Average (pounds)	Average (PSI)	COV	Viable Option
2-2	Coarse	1 : 0.75 : 4.375	Water	7	3147	790	36%	No
2-4	Coarse	1 : 0.75 : 5.25	Water	7	2468	620	27%	No

Analysis of the Water-Cured Samples

Water curing was instantly eliminated due to low strengths of less than 1,000 psi and high coefficients of variance (COV). When producing mixes 2-2 and 2-4, it was understood that both designs had low workability that needed to be corrected by adding more water to the mix.

Because water also decreases the strength of the mix design, mix 2-2 was continued to ideally decrease the strength from 1579.5 psi to below the 1200 psi goal.

Analysis of the Lime-Cured Samples

The samples cured in a lime water bath were significantly stronger than the water-cured samples. On average, these samples had lower COV values of 16-20% (compared to the water cured samples of 27-36%), indicating that more consistent strengths can be obtained with the lime-curing technique, rather than water. As compared to the air-cured samples listed in Table 2, however, the lime-cured samples nearly triple the COV from the air-cured samples of 5-12%. Moving forward, the samples were cured using lime or air curing techniques in order to receive more consistent results.

Evaluating how Aggregate Size Affects the Strength and Workability of the Plaster

Mix 2-2 was utilized with finer sands that conform to ASTM standard C897 to increase the workability of the mixture. CEMEX sand size #1/20 was used with the same mix proportions by volume as mix 2-2. The sand grain size distribution can be found in Appendix A Table A3. The results from this mix design can be seen in Table 5.

Table 5 – Another mix design iteration was made with a finer sand grain distribution using CEMEX #1/20 sand mix design to conform to ASTM C897 aggregate size distributions.

Mix Name	Sand	Cement:Lime:Sand (by part)	Cured	Cure Time	Max Load Average (pounds)	Average (PSI)	COV	Viable Option
2-2.1	#1/20	1:0.75:4.375	Lime	7	2353	590	12%	Yes
2-2.1	#1/20	1:0.75:4.375	Air	7	1858	465	3%	Yes

These values are much weaker than the coarse sand grains that had been used in the earlier mix design iterations. Mix design 2-2.1, with a finer sand grain distribution, obtained an average failure stress of less than 600 psi for a 7-day cure, while coarse aggregate lime-cured samples reached average strengths of 1,500 psi. This can be attributed to the quantity of water in the mixture; the amount was consistent with that of the coarse-grained mixes, intended to increase workability, however the smaller aggregate did not bind together as well as the larger aggregate. With the smaller void spaces in between sand particles filled with water in the mix and less friction between sand grains, the workability was much greater than necessary. This led the mix samples being weak and brittle when tested. Because this mix was weak, fragile, and too workable for the desired application, the final mix design was approached using a sand grain size with better strength and reliability.

Final Plaster Determination

The final mix design used for the wall specimens utilized a mix ratio by volume of 1 part cement to 0.75 parts lime to 5.25 parts sand. (These values correspond with the ASTM ratios as 3 parts sand per cementitious material.)The amount of water in the applied mix was approximately 9-11% water by weight, varying based on the desired workability of the mix. The values used in one batch of plaster by weight can be found in Table 6.

Table 6 – The final plaster mix values by weight and percentage weight per batch. These values were used throughout the plaster mixes applied to the final wall specimens, with percentages of water varying due to workability.

Material	Volume	Weight per Batch (lb)	Percentage of Mix by Weight
Type 1 Portland Cement	1	13.3	11%
Type S Hydrated Lime	0.75	4.9	13%
#2 Plaster Sand	5.25	76.4	65%
Water	As needed	11.1-12.8	9-11%

The strengths of the final mix design made with the above proportions are located in Table 7.

Table 7 – The final plaster mix strengths in both the lime and air-cured environments. These samples were cured for over the standard 28-days with the intention of curing the samples around the same time that the full scale walls were tested.

Sand	Cement:Lime:Sand	Cured	Max Load Average (pounds)	Average (PSI)	COV
#2 Plaster Sand	1 : 0.75 : 5.25	Lime	10984	2746	10%
#2 Plaster Sand	1 : 0.75 : 5.25	Air	6930	1732	15%

This final mix design used mix proportions and a sand grain size that were accepted by ASTM standards C926 and C897 as required for mix design proportions and sand grain size distributions for cement-lime plasters. The air-cured samples were weaker than the lime-cured samples and much closer to our goal of a strength of 1,200 psi. The water proportions (listed in table 6) allows the first layer applied to have a smaller amount of water for a workable, but not entirely liquid mix. The second layer has a greater proportion of water in order to adhere to the first layer of plaster without drying out too quickly. The success of the mix will ultimately be measured by its behavior as an integral part of the straw bale wall structure.

WALL DESIGN

Overview

The wall design by Straw Bale Seismic Design Capacities 2 entails the design and detailing of two 8-foot long walls of standard dimensions. The standard dimensions of the walls are 8-foot length by 8-foot height. Both walls are designed for the 18" thickness of two-string rice straw bales. Refer to Figure 2 for the basic detailing of the two walls.

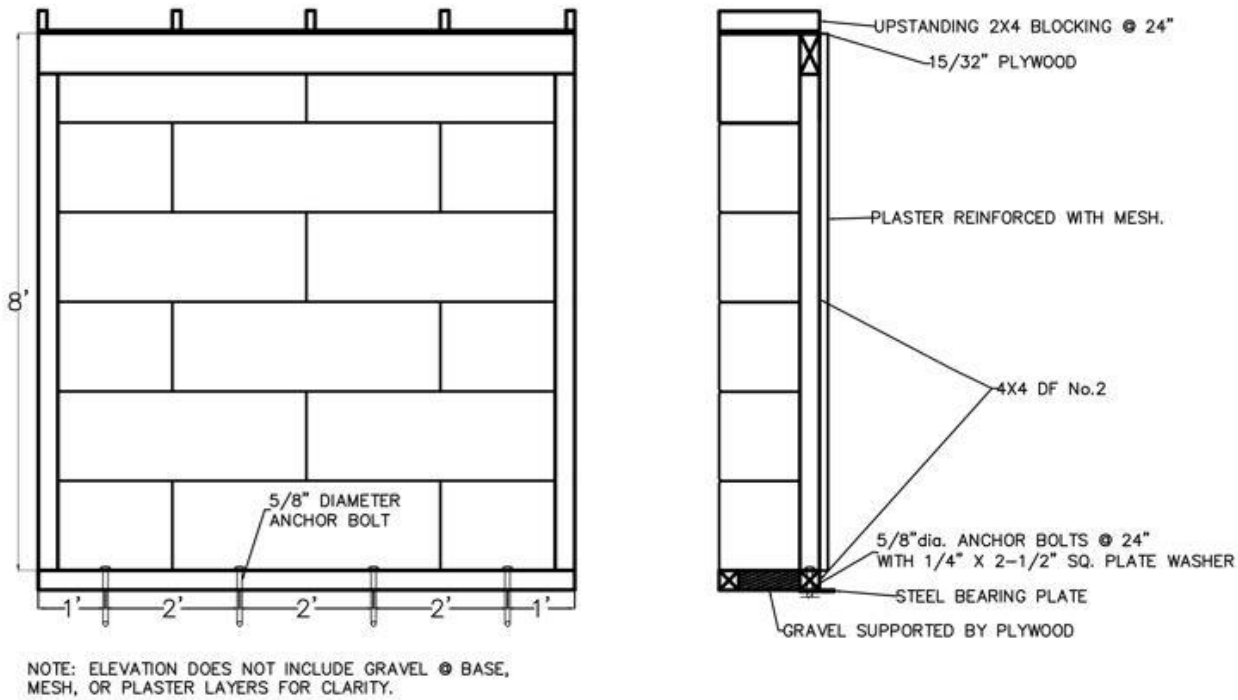

Figure 2 – This picture indicates the basic 8' long wall elevation based on the timber framing used to define the wall dimensions. This image also indicates the 8' length that both the "workhorse" and "strong" wall will be designed for and the common detailing that was used for both walls.

The timber framing acts as the wall boundaries and is used to take the gravity loads experienced by the building. The straw bales, as the wall infill, provide thermal, acoustic, and rigidity properties based on the thickness of the bales. Wire mesh sizes were selected based on their strength and ductility properties, in addition to their behavior when combined with the cement-lime based plaster. This plaster is used as a binder to join the mesh to the straw bale; it is also used to indicate high stresses in the wall that visually represent the beginnings of material failure. These elements are used to complete the wall and give it the smooth appearance that owners desire.

In order to ensure that the walls can be tested in similar conditions to the ones in the finished structure, 5/8” diameter anchor bolts are used to fasten the 4x4 sill to the ½” steel bearing plate at the base; this steel bearing plate simulates the concrete or steel foundation that the straw bale wall is resting on. The 2x4 blocking and 15/32” plywood provide an evenly-supported structure on which to apply the loads for testing. Figure 3 illustrates the locations of the basic wall components in relation to the other materials in the finished wall construction.

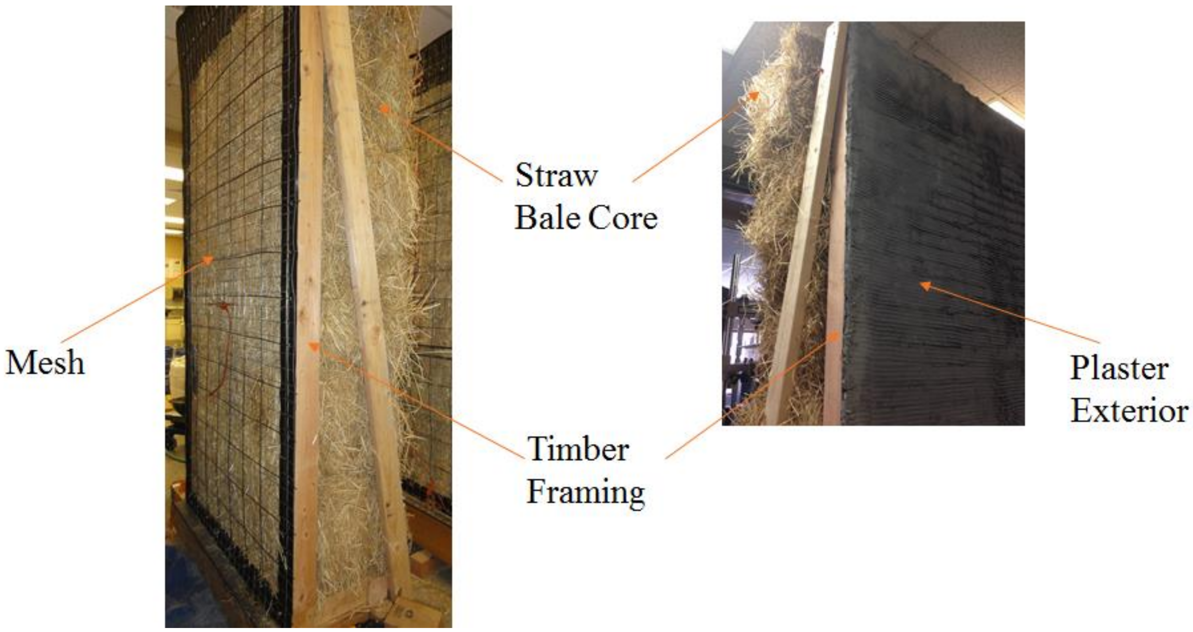

Figure 3 – This picture indicates the basic configuration of the 4 types of materials used in the straw bale post and beam method. This includes the timber framing, straw bale core, mesh (detailing and type differ for the two walls), and the plaster exterior layer.

Note: As indicated in figure 3, the wall specimens used for testing will be constructed with only one side completed with the mesh-plaster detailing. Only one side of the wall is detailed in order to take the full load that the wall demands; these walls are intended to prove that both sides of the wall can be plastered if additional strength is needed within the given wall length. The side of the wall with the mesh reinforcement and plaster layer will be referred to as the “strong side” of the wall samples.

Preliminary Design Methodology

The design of the workhorse and strong walls are intended to encourage ductile failure modes, so the four materials indicated in figure 3 must work together. In order to design the walls for basic structural code, it is important to determine the appropriate design constraints to evaluate the goals of the structural design. As in all structural design, it is important to design the structure to have a strength capacity that is much higher than the applied load, or demand. The desired failure mode is a flexural failure within the wall, not at the boundary or connection conditions. This failure mode provides a very ductile failure that is safer for building occupants in the event of an earthquake.

The loads applied to the walls include the dead loads imposed by the material weights, where the weights of the mesh and timber framing were considered negligible compared to the weights of the plaster and straw bales. The live loads were calculated as the applied loads provided by the test fixture as a simulated earthquake.

For the calculations, it was determined that the only materials that will be absorbing the lateral loads would be the cement-lime plaster and the steel mesh, while the straw bales would be absorbing gravity loads and adding rigidity to the mesh-plaster structure. The nominal shear strength of the wall, V_n, based on these material properties was calculated using equation 1:

$$\mathrm{V_n = V_c + V_s} \qquad (1)$$

where V_c is the shear based on the plaster shear capacity and V_s is the shear based on the total steel mesh capacity. These values are compared to the shear based on the moment resulting from the applied load and material dimensions, V_{mp}. This shear is calculated using equation 2:

$$V_{mp} = (M_b + M_t)/h \qquad (2)$$

where M_b is the moment resultant in the base of the calculated wall segment, M_t is the moment resultant at the top of the wall segment, and h is the effective height of the wall.

The ratio of V_{mp} to V_n is calculated for each wall design to determine the governing failure mode. A V_{mp}/V_n ratio of greater than 1 indicates a shear failure while a ratio less than 1 indicates a desired flexural failure.

Note: the material property data from the mesh types specified for the “workhorse” and “strong” walls was determined by the Straw Bale Seismic Design Capacities 1 team and was provided to the Straw Bale Seismic Design Capacities 2 team to design the full scale walls. These values are used in the following design calculations.

"Workhorse" Wall Design

Description

Our workhorse wall design is intended to be easy to reproduce by both experienced contractors and novice home builders. The overall design focuses on using standard and well-known building materials to create a simple-to-construct straw bale lateral force resisting system (LFRS). Figure 4 is the elevation view of the workhorse wall with the mesh and plaster layers removed for clarity. It indicates the straw bale layout with alternating rows of two 4-foot straw bales and one 2-foot bale, one 4-foot bale, and one 2-foot bale. It also indicates the locations of the 5/8" diameter anchor bolts that are used to connect the wall to the structural foundation.

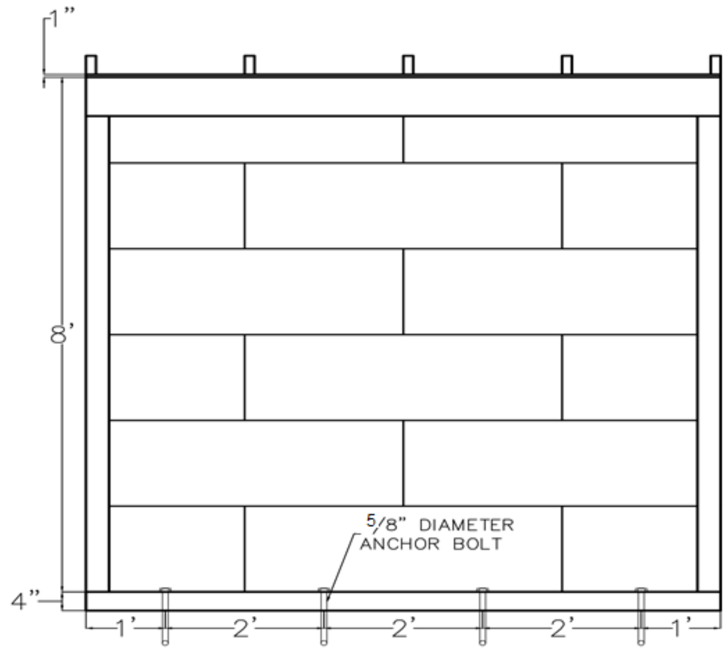

Figure 4 – The "Workhorse" wall elevation indicates the basic wall height, the straw bale layout, and the anchor bolt layout.

The workhorse wall section, cut straight through the length of the wall, shows the detailing of the four primary structural components and materials. The wall section is can be seen in Figure 5.

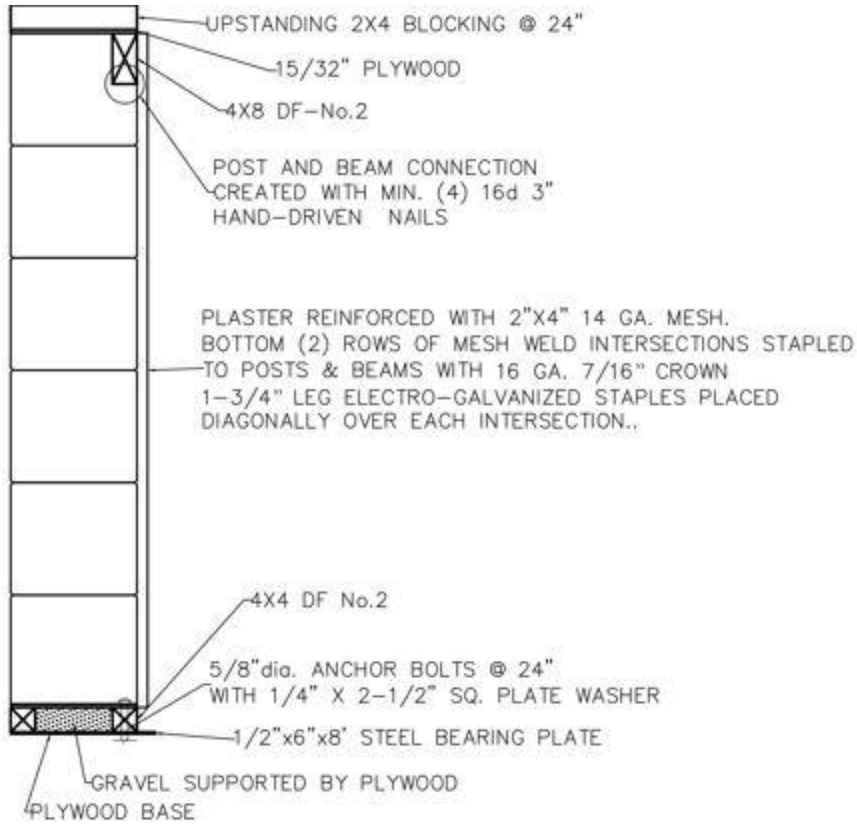

Figure 5 – The "Workhorse" wall section indicates the material layout and connections made to create the material structure.

The 8-foot long 4x8 top plate is connected to two 4x4 posts at 96-inch height using hand driven nails. These pieces are attached to the 8-foot long 4x4 sill plate that will rest on the foundation of the structure. These connections are made with 0.162" diameter nails. The mesh and plaster layers are attached to this framing on only one side of the wall. This was done intentionally to provide a basic understanding of the wall strength when only one side provides the strength required of the entire wall. Should the opposite side also be plastered, then the strength is expected to be approximately doubled. Figure 6 describes the detailed connections made to the boundary conditions of the "workhorse" wall for the mesh and plaster connections on the strong side of the wall.

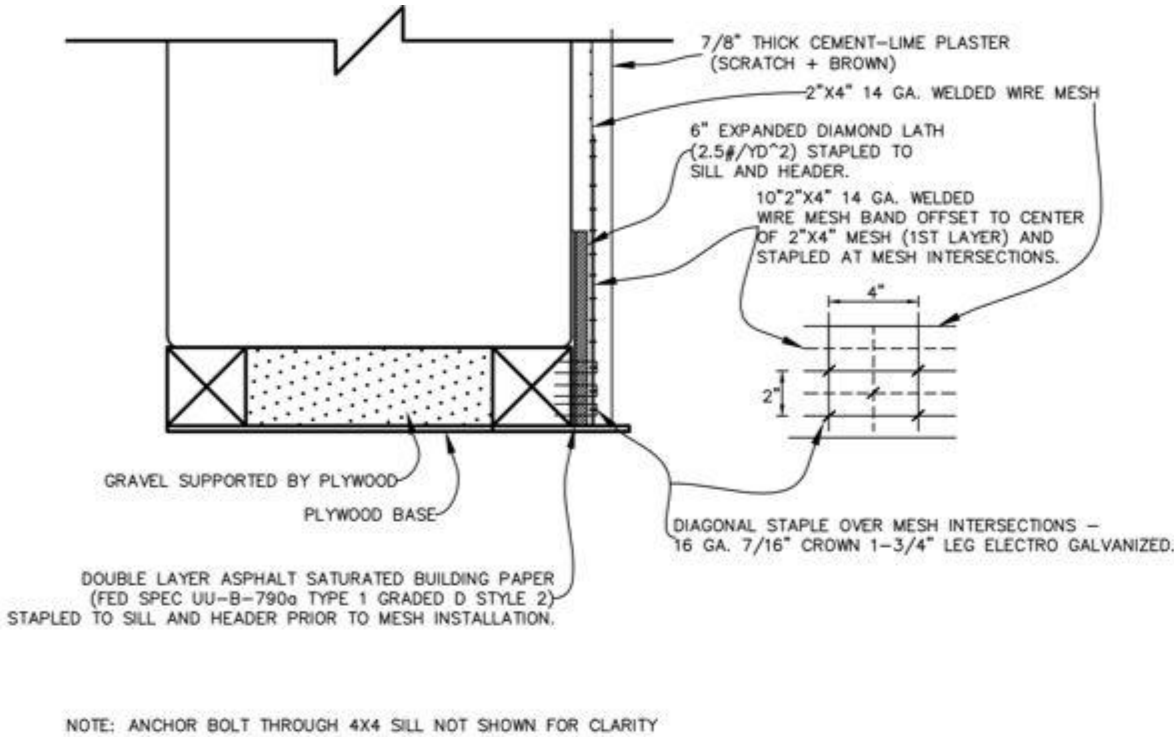

Figure 6 – The "Workhorse" wall boundary condition detail provides the detailing requirements for the layers added to form the mesh and plaster layers that deliver the ductile behavior of the wall.

Two layers of asphalt-saturated building paper are stapled to each of the boundary timber framing members. One 6" wide section of expanded metal lath is attached to the top and bottom timber framing pieces with structural grade staples. A 8-foot long by 8-foot tall layer of 2"x4", 14 gauge mesh is attached to both the top and bottom beams by diagonal staples at mesh weld intersections. An additional 10-inch band of the 14 ga. 2"x4" is offset at the base of the wall and attached to the wall with diagonal staples at mesh weld connections.

Cement-lime based plaster is finally added to the exterior of the mesh. The plaster is applied in 2 coats (the scratch and brown coats) to create approximately a 7/8-inch thick moisture barrier, and to bind the other building materials together. The final wall is left to cure for a minimum of 28 days, so that the plaster can achieve its full strength. A list of the building elements required for the 8-foot long workhorse wall can be seen in Table 8.

Table 8 – These base material quantities used for the "workhorse" wall are the rough material estimates made to construct an 8' long wall with simpler nailed or stapled connections for construction.

Building Element	Material	Quantity
Timber Framing		
Posts	4x4	(2) @ 96" length
Top Beam	4x8	(1) @ 96" length
Sill	4x4	(1) @ 96" length
Wall Infill	Straw Bale	12 for (1) 8'x8' wall
Wire Mesh	2x4, 14 gauge	8' x 8' plus extra slack
Connections		
Mesh to Timber Framing	16 ga. 7/16" crown 1-3/4" leg electro galvanized staples	(1) Per mesh loop @ 2" (96"L)
Post to Beam	3" length 0.162" diameter nails	(1) per side of post (8 total per post)
Wall to Foundation	5/8" anchor bolt	(1) @ 24" o.c. (4 total)
Exterior Surface Binder	Cement-Lime Plaster	5.5 Cubic Feet (96"x99"x1")

Calculations

This wall design was calculated to have an effective height, h, of 7.17 feet based on the reduced height from the additional 10-inch band of mesh applied to the base boundary. The nominal shear (calculated using equation 1) based on the expected strength of 1200 psi plaster and the 2"x4" 14 gauge mesh was calculated to be 13.4 kips (approximately 13,400 lbs --- 1 kip is 1000 lbs), with a shear due to applied moment, V_{mp} (calculated using equation 2), of 5 kips. The V_{mp}/V_n ratio is calculated to be 0.39, which is much less than 1, indicating that a flexural failure is expected in this wall. This flexural failure is expected to correspond to a shear loading of approximately 5 kips. These values are summarized in Table 9.

Table 9 – The values were used to determine the expected failure mode of the workhorse wall.

Plan Length, Li	8.00 feet
Height, h	7.17 feet
$V_n = V_c + V_s$	13.4 kips
V_{mp}	5 kips
V_{mp}/V_n	0.39
Failure mode (assumed)	Flexure Governs
Shear corresponding to failure	5 kips

"Strong" Wall Design

Description

The purpose of our "strong" wall was to create a wall that was appropriately detailed to achieve the necessary strength for heavy seismic regions. This detail was expected to be extremely useful for shorter lengths or wall openings like windows and doors; the detailing is expected to resist more shear loads than the workhorse wall per unit length, and distribute the loads around the openings. It is intentionally designed for the experienced professional to construct as the detailing requirements are much greater than for the "workhorse" wall. This includes establishing a stronger and more ductile behavior for the mesh-plaster interaction. The "strong" wall can be seen in Figure 7.

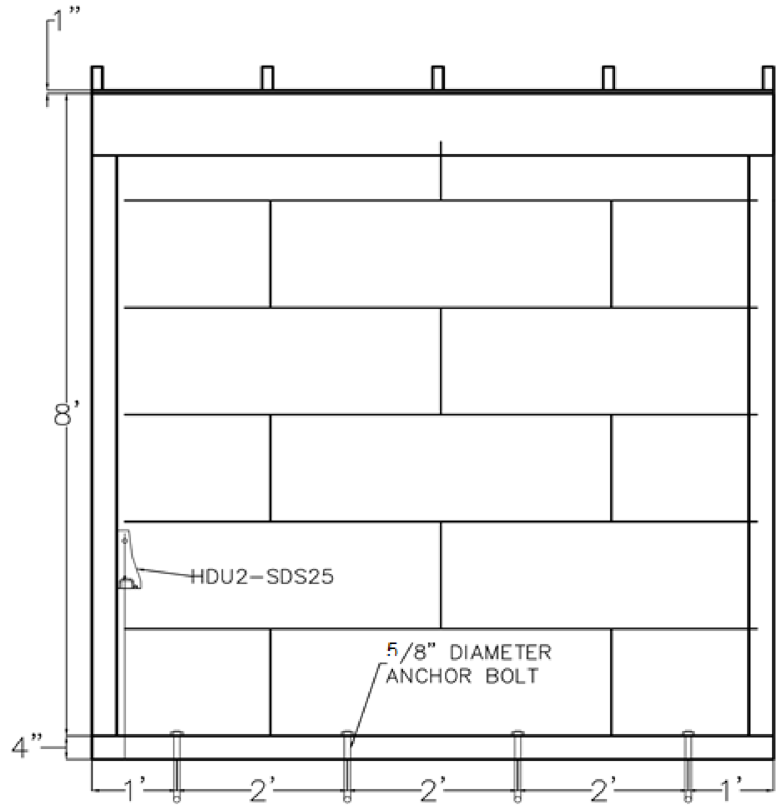

Figure 7 – The “strong” wall elevation indicates the basic wall height, the straw bale layout, and the anchor bolt layout. The main difference between the workhorse and strong wall elevations is the Simpson Strong Tie hold down located on the left side of the wall.

The strong wall design mechanically differs from the workhorse design in the final specimen’s detailing. The strong wall is attached to the foundation using a Simpson Strong Tie hold down in addition to 5/8” diameter anchor bolts. This detail is intended to provide the extra protection from shear uplift forces on the foundation. The straw bale shear walls have both timber framing and a concrete-like plaster coating. Because a plywood shear wall and a reinforced concrete shear wall transfer the loads to the foundation differently, a hold down was added to only one side of the wall. Figure 8 illustrates the load transfer of shear loads applied to a plywood shear wall and a concrete shear wall.

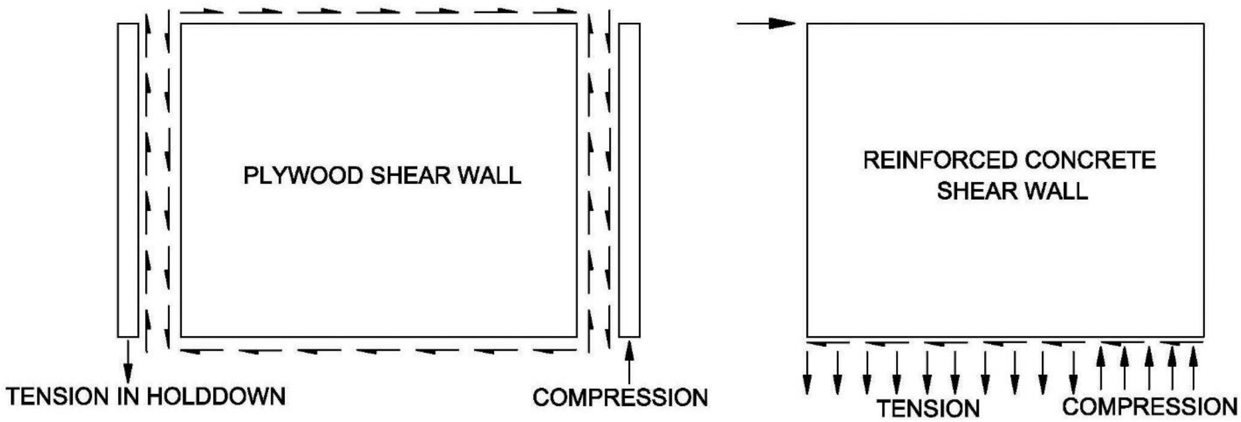

Figure 8 – These diagrams illustrate the ways that loads are transferred from the wall into the foundations for plywood shear walls versus reinforced concrete shear walls. The single holddown in the "strong" wall is intended to help illustrated which behavior is prevalent in the straw bale walls constructed using the post and beam method.

This allows us to determine whether the wall behaves most like a plywood shear wall, where the load is transferred around the boundaries of the structure and into the foundation through a hold down; or a reinforced concrete shear wall, where the load is distributed along the length of the member and then straight into the foundation through the base connection design. Figure 9 expands on the differences between the workhorse and strong wall with a section view of the wall.

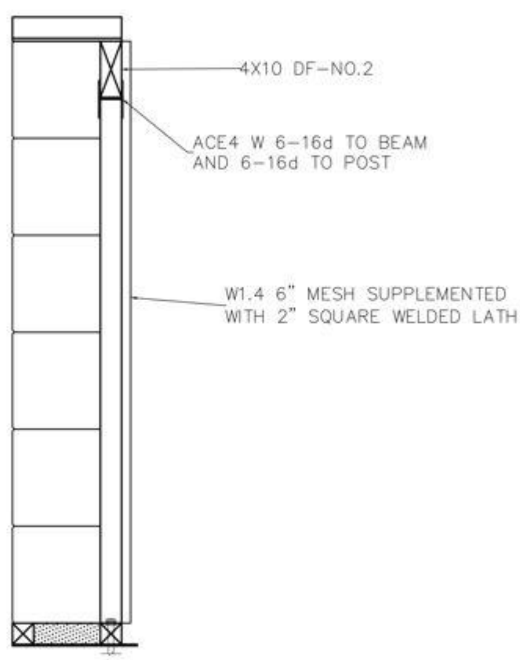

Figure 9 – The "strong" wall section indicates only the differences in the cross section between the workhorse and strong walls. These differences include the header, the post to beam connections, and the mesh layers.

In addition to the extra foundation requirements, this “strong” wall has a 4x10 top beam (as opposed to the 4x8 of the “workhorse” wall) to better take the gravity and shear loads that are present. The timber framing elements (post and beams) are connected using Simpson Strong Tie ACE4 post to beam connections with six 16d nails. The mesh types and layers also differ and are more clearly detailed in Figure 10.

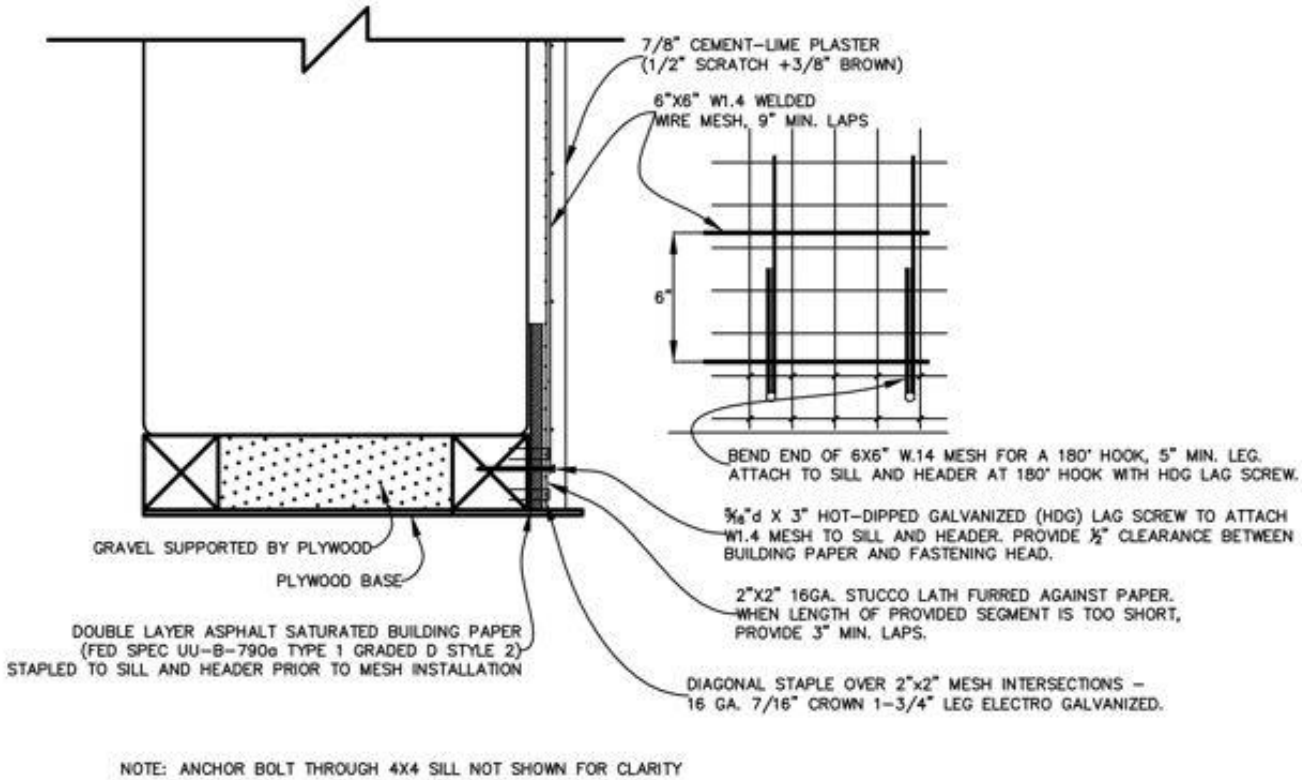

Figure 10 – The “strong” wall boundary condition detail provides the detailing requirements at the base and top boundary locations. This design differs from the workhorse wall primarily by mesh types and fasteners.

The asphalt building paper is first attached to the timber framing. A double layer of wire mesh is used in the design, with the initial layer of 2x2 wire stucco mesh stapled to the timber framing. The stucco mesh is overlapped by the W1.4 wire mesh attached to the wall by looping the ends of the wires 180-degrees around the 9/16”diameter 3” long hot-dipped galvanized (HDG) lag screws installed at each of the mesh intersections. These provide extra resistance to weld failure, increasing the strength in the boundaries and pushing the failure towards the center of the wall height. Once attached, the cement-lime plaster is added in 2 layers to form the 7/8” desired thickness for testing. A general list of the materials used in the construction of the 8-foot long strong wall can be seen in Table 10.

Table 10 – The base material quantities used for the "strong" wall.

Building Element	Material	Quantity
Timber Framing		
Posts	4x4	(2) @ 96"
Top Beam	4x10	(1) @ 96"
Sill	4x4	(1) @ 96"
Wall Infill	Straw Bale	12 for (1) 8'x8' wall
Wire Mesh		
	W1.4 Mesh (10 ga.)	8' x 8' plus extra slack for 180-degree loops
	2x2 Wire stucco mesh (paperback)	8' x 8'
Connections		
Mesh to Timber Framing	5/16"d x 3" HDG lag screws	(1) Per W1.4 mesh loop @ 2" (96"L)
	16 ga. 7/16" crown 1-3/4" leg electro galvanized staples	(1) Per 2x2 stucco mesh weld intersection @ 2" (96"L)
Post to Beam	Simpson ACE4 w/ (6) 16d nails	(1) per post to beam connection (2 total)
Wall to Foundation	5/8" anchor bolts	(1) @ 24" o.c. (4 total)
	Simson HDU2-SDS25 Hold-Down	(1) at left side
Exterior Surface Binder	Cement-Lime Plaster	5.5 Cubic Feet (96"x99"x1")

Calculations

The shear strength of the 8-foot strong wall was calculated assuming a 7.73-foot height based on the W1.4 mesh layer and lag screws providing extra strength at the boundaries in order to move the failure away from the base or top plates. The shear strength of the steel mesh, V_s, was calculated with the use of a composite mesh strength based on the total volume of 2x2 wire stucco mesh and W1.4 mesh that contributes to the reinforcing ratio of the plaster. Equation 1 was used to calculate the nominal shear, V_n, based on the steel and plaster material properties of approximately 30.2 kips. As with the workhorse wall, the shear based on the applied moment was calculated using equation 2. This resulting shear, V_{mp} was calculated to be around 23 kips. The V_{mp}/V_n ratio was 0.76 based on the V_n and V_{mp} values being much closer than the workhorse wall. Because 0.76 can be very easily rounded up to 1 and the material properties of the wall are still being understood, it is not yet possible to state definitively whether the wall will fail in either flexure or shear. For this reason, the failure mode is assumed to be mixed: either flexural or shear failure are assumed to occur based on the given loading condition. Table 11 is a summary of these values.

Table 11 – The values were used to determine the expected failure mode of the workhorse wall.

Plan Length, Li	8.00 feet
Height, h	7.73 feet
$V_n = V_c + V_s$	30.2 kips
V_{mp}	23 kips
V_{mp}/V_n	0.76
Failure mode (assumed)	Mixed
Shear corresponding to failure	23 kips

NEXT STEPS

The walls are constructed and are awaiting testing; these tests are outside of the current scope. Their behavior under cyclic loading will be recorded both quantitatively and qualitatively in order to refine the wall design and detailing for the straw bale post and beam method. It is expected that flexural failure will occur and the qualitative behavior will be analyzed to improve the wall's structural response in events of high seismic activity.

Refer to the completed thesis by Straw Bale Seismic Design Capacities 3 to learn more about the design of shorter lengths of straw bale wall segments and the additional detailing required for walls with windows or doors.

ETHICAL ANALYSIS OF STRAW BALE MATERIAL USE

Straw bale construction employs an alternative material for structural design for lateral loads (i.e. earthquake and wind loads). Several ethical concerns come into play when introducing a new material to the construction industry, especially when there are current building methods that have been around for hundreds, if not thousands, of years. It is also important to note that straw and plaster have been used as building materials for generations; we are just trying to set a standard so structures can be safely and easily designed and built for areas of high seismicity.

Straw Bale as a Solution for Engineer's Challenges

The majority of the problems that civil engineers face, deal with overpopulation, diminishing resources, and/or climate change. Our collaboration with the two other senior design groups will incorporate the design of the structural components of a simple straw bale building for the California seismic environment. Our ultimate goal is to introduce straw bale into the California Building Code, however we recognize that our efforts will just be the beginning of design iterations to eventually reach this end goal. With the introduction of straw bale into the California Building Code, we can find solutions to help positively impact these areas.

Economic Advantages to Straw Bale Construction

The population in the US grows approximately 0.7-0.8% each year, adding approximately 2.1 million people each year to the over 300 million people currently residing in the United States. This population increase demands an equivalent increase in housing development. Straw bale can accommodate this need as each bale costs approximately $3.50, which is far less than traditional construction materials. The material is also very readily available; as the waste product of barley, oats, rice, rye, and wheat, straw bale is readily produced and discarded. For the purposes of our project we focused on rice straw bales. By repurposing the material, there is less waste deposited in landfills and more affordable housing to accommodate the growing population.

Embodied Energy of Straw and Comparative Construction Materials

With diminishing resources in the United States, the demands of steel, concrete, and lumber on the environment is increasingly devastating. Straw bale, as a natural biomaterial, that requires less energy in the manufacturing process than typical building materials. The embodied energy (energy required for the manufacture of the material) of straw bale is approximately 0.91 MJ/mg, compared to 20.10 MJ/mg, 1.11MJ/mg, and 10.00 MJ/mg of steel, concrete, and timber, respectively. These demands cannot be taken lightly. Straw bale fulfills a need without requiring much energy for production. Because straw bale is a waste product and is used in its raw form, very little energy is used to bring the material up to industry standards. The material is readily available for use as the food industry is already financing the agriculture that produces this structural material.

Global Warming and Benefits of Straw Bale Construction

Global warming has been a growing concern as scientists have realized that the carbon dioxide emissions that we create in our developed world are actually collecting in the atmosphere, trapping the sun's heat and increasing temperatures worldwide. Straw bales are biomaterials that sequester, or take in, carbon dioxide from the surrounding air. This material should be in greater demand to have a more profound impact on the environment. The use of this material can slow global warming efforts by taking in more carbon than it produces while being used as a structural material.

American Society of Civil Engineer's Views on Sustainable Building

As engineers and members of the American Society of Civil Engineers (ASCE), we look to make decisions that will benefit the environment and also encourage the use of natural materials. Our project aligns with the first fundamental canon of ASCE:

> *Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.*

In line with this fundamental canon, ASCE defines sustainable development as: "the process of applying natural, human, and economic resources to enhance the safety, welfare, and quality of life for all of society while maintaining the availability of the remaining natural resources." As we repurpose this waste material, we use the already overproduced waste product to create a structure that is safe under high seismic activity, healthy as a natural and minimally-processed material, and encourages the advancement of building techniques to accommodate renewable building materials. In our journey to become professional engineers, we accepted a project that would further our understanding of current building methods and expand on them to create a sustainable and reliable alternative building material. Creating the building codes for easier implementation in design makes this method a more affordable and approachable building method.

Analyzing Risk

For as beneficial as this material is to the environment, there are still many risks involved with the use of a natural building material. As engineers, we need to analyze these risks in terms of the end users and those who may be remotely affected by the use of straw bales in building construction.

Dangers of Building with Straw Bale

In construction projects, the final products are large and often dangerous elements until secured. Straw bale creates an additional safety concern as the bales themselves can cause allergies for the builders. Our project employs rice straw bales, and rice straw, in particular, has a very high silica content. When homebuilders are constructing the straw bale structure, it is important that proper precautions are taken to avoid the inhalation of high quantities of this silica-rich material. After the plaster has been applied, the bales are no longer openly exposed to the air, and straw bale dust inhalation is severely reduced. When constructing exterior walls, this inhalation risk is minimized due to the large amount of air flow. Throughout our construction process we found that using simple dust masks helped allergies greatly.

Concerns of Building with Straw Bale

As straw bale construction is relatively new to the construction industry, it is important that workers understand how to design and construct the straw bale buildings to industry standards. With few experts in this field, it is important that information be readily available and utilized properly in order to employ straw bales as the primary lateral force resisting elements. It must also be noted that the use of straw bale as a building element will remain a voluntary decision as specified by the owner or architect and understood by the structural designer. Additionally, construction for these buildings is highly weather dependent; because the straw bales cannot be exposed to moisture due to the risk of mold causing the eventual degradation of the structure, it is important to keep the bales dry throughout the construction process until each element has been provided a water barrier by the plaster.

Other Environmental Considerations

It is also important to consider the environment for which the building is being designed. While the greatest risk is on the person with the greatest financial investment, there is still a concern with the people who are in the surrounding area, especially during construction. Because straw contains many allergens and can be a very labor intensive and messy project, it is important to be aware of the effects that this material can have on the public and to exercise care to ensure that the straw bale waste is disposed of in a clean and contained manner. However, there is large risk working on any construction site, and as straw bale becomes a more viable building material people will understand how to better work with it.

Verifying Quality in Our Research and Design

Throughout the design process, our small scale and full scale specimen designs have been reviewed by external sources to the project. Peer reviewers from the FEMA P695 Peer Review group have been evaluating our material testing and design, in addition to validating our research findings. Several members of the group also worked on the initial straw bale material testing to prove that this is a safe and viable building material. During our construction process, several volunteers from the California Straw Bale Association (CASBA) were able to lend their expertise in material construction, ensuring that our test specimens will be constructed with the quality expected in the field. Additionally we had assistance from several professional natural earth plasterers to help ensure a quality binding between the straw and the wire mesh. These forms of quality control will help to develop future quality assurance practices for industry standards.

Straw Bale as a Solution

Overall, straw bale seismic design is beneficial to the world and can solve many of the problems that civil engineers face in the design and construction processes. Our goal is to create building code provisions that allow California, especially, to take a step towards a more sustainable and ethically sound future.

WORKS CITED

American Society for Testing and Materials. Philadelphia, Penn.: Society, n.d. Print.

"Climate Basics." *Global Warming*. Natural Resources Defense Council, n.d. Web. 3 Dec. 2013.

"Code of Ethics." *Code of Ethics*. American Society of Civil Engineers, n.d. Web. Sept. 2010.

"Earthquake and Seismic Resistance Is a Major Advantage of Topsider's Prefab Home Designs." *Seismic & Earthquake Resistant Homes*. Topsider Homes, 2012. Web. 9 Jan. 2014.

"Ellensburg Straw Bale Construction Workshop." *Straw Bale Construction Workshop for Ellensburg Barn Raising and Wall Building Class*. Celebrate Big, Oct. 2007. Web. 14 Mar. 2014.

"Embodied Energy." *GreenSpec*. Srccreative.net, n.d. Web. 4 Dec. 2013.

"Graniterock: Technical Note: Quail Hollow #2 Plaster Sand." Graniterock: Technical Note: Quail Hollow #2 Plaster Sand. N.p., n.d. Web. 02 Jan. 2014. <http://www.graniterock.com/technical_notes/140_quail_hollow_2_plaster_sand.html>.

King, Bruce, and Mark Aschheim. *Design of Straw Bale Buildings: The State of the Art*. San Rafael, CA: Green Building, 2006. Print.

"LAPIS LUSTRE SAND GRADING PARAMETERS Cumulative Percent Passing US Sieves." Cemexusa.com. CEMEX Technical Services, 8 Nov. 2010. Web. Mar. 2014. <http://www.cemexusa.com/ProductsServices/files/MaterialGrading.pdf>.

Morison, Andrew. "We Have a National Straw Bale Building Code!" *Strawbalecom RSS*. Strawbale Innovations LLC, 4 Oct. 2013. Web. 14 Dec. 2013.

Portland Cement Association. Portland Cement Plaster/Stucco Manual. N.p.: Portland Cement Association, 2003. Print.

"Straw Bale Codes Updates | California Straw Building Association." *Straw Bale Codes Updates | California Straw Building Association*. N.p., Oct. 2013. Web. 7 Nov. 2013.

Wing, Nick. "Census: U.S. Population Growing Again, But At Lowest Level Since Great Depression." *The Huffington Post*. TheHuffingtonPost.com, 20 Dec. 2012. Web. 4 Dec. 2013.

APPENDIX A: PLASTER MIX DESIGN REFERENCES

Table A1 – ASTM C 926-06 Table 3 listing the different plaster mix designs possible within ASTM standards. The chosen design is from plaster mix CL.

Cementitious Materials						Volume of Aggregate per Sum of Separate Volumes of Cementitious Materials	
Plaster Mix Symbols	Portland Cement or Blended Cement	Plastic Cement	Masonry Cement		Lime		
			N	M or S		1st Coat	2nd Coat
C	1	…	…	…	0 - 3/4	2 1/2-4	3-5
CL	1	…	…	…	3/4 - 1 1/2	2 1/2-4	3-5
M	…	…	1	…	…	2 1/2-4	3-5
CM	1	…	1	…	…	2 1/2-4	3-5
MS	…	…	…	1	…	2 1/2-4	3-5
P	…	1	…	…	…	2 1/2-4	3-5
CP	1	1	…	…	…	2 1/2-4	3-5

Table A2 – ASTM C 897 sieve test requirements to for acceptable sands to be used for cement-lime based plaster.

U.S. Standard Sieve Size	Percent Retained (by weight)			
	Natural Sand		Manufactured Sand	
	max	min	max	min
No. 4	0	0	0	0
No. 8	10	0	10	0
No. 16	40	10	40	10
No. 30	65	30	65	30
No. 50	90	70	80	60
No. 100	100	95	90	75
No. 200	100	97	100	90

Table A3 – These are the sieve test grading that the CEMEX #1/20 and 30 Mesh samples are graded under used in mix designs 2.2-1, 3.1, 3.2, and 4.2. These aggregate mixes were not used due to failing to meet the ASTM C897 standards listed in Table A2. (CEMEX Testing Services)

Nominal Sieve Size		#1/20	30 Mesh
US	mm	20x40	30x70
#4	4.75	100±0	100±0
#8	2.36	100±0	100±0
#12	1.7	100±0	100±0
#16	1.18	100±0	100±0
#20	0.850	88±8	100±0
#30	0.600	18±11	95±5
#40	0.425	1±1	73±23
#50	0.300	0	25±11
#70	0.212	0	3±2
#100	0.150	0	1±1

Table A4 – These are the ASTM C 897 sieve test requirements and the final plaster mix design sand gradation results, indicating that the material complies with ASTM standards for cement-lime plaster. (Graniterock)

Sieve Size	ASTM Spec. No. C-897	Quail Hollow #2 Plaster Sand
3⁄8″	100	100
No. 4 (4.75 mm)	100	100
No. 8 (2.36 mm)	90–100	100
No. 16 (1.18 mm)	60–90	87.7
No. 30 (600 um)	35–70	55.1
No. 50 (300 um)	10–30	28.9
No. 100 (150 um)	0–5	2.1
No. 200	0	0.6

APPENDIX B: BUDGET FOR PROJECT SCOPE

Table B1 – Project budget for plaster design, workhorse wall construction, and strong wall construction

	Each		Required		Total
Straw Bale Walls					
Wire	$ 160.00	per 3'X100' roll	1	3'X100' rolls	$ 160.00
Rice Straw Bale	$ 3.50	per bale	40	bales	$ 140.00
Wood Framing	$ 8.00	per 8-foot section	10	8-foot sections	$ 80.00
Cement Stucco					
sand	$ 6.00	per bag	30	bags	$ 180.00
cement	$ 10.00	per bag	8	bags	$ 80.00
slaked lime	$ 50.00	per bag	15	bags	$ 750.00
Testing Platform					
Lumber	$ 15.00	per 6 foot section	8	6-foot section	$ 120.00
Simpson Strong Tie	$ 10.00	per hanger	10	hangers	$ 100.00
Sum					$ 1,610.00
Tax (9.25%)					$ 148.93
Contingency (15%)					$ 241.50
TOTAL					$ 2,000.43

APPENDIX C : PLASTER MIX DESIGN SAMPLE DESCRIPTIONS AND STRENGTHS

Table C1 – These are the 2" cube plaster sample mix design iterations arranged in order of trial number and dates mixed. The final mix design is not included.

Date Mixed	Mix Name	Sand	Specimen	C:L:S	Comments	Cured	Cure Time	Max Load Average (pounds)	Compressive Strength (PSI)	COV
11/7/2013	1	Coarse	2X2	0.5:0.5:3	1 part = 2.5"X6"X3"	Air	7	2137	534	13%
11/7/2013	1	Coarse	2X2	0.5:0.5:3	1 part = 2.5"X6"X3"	Air	70	1767	441	24%
11/7/2013	2	Coarse	2X2	0.6:0.4:3	1 part = 2.5"X6"X3"	Air	7	3135	783	6%
11/7/2013	2	Coarse	2X2	0.6:0.4:3	1 part = 2.5"X6"X3"	Air	70	4035	1008	7%
11/7/2013	3	Coarse	2X2	0.7:0.3:3	1 part = 2.5"X6"X3"	Air	7	1941	485	8%
11/7/2013	3	Coarse	2X2	0.7:0.3:3	1 part = 2.5"X6"X3"	Air	70	2533	633	18%
11/19/2013	1-1	Coarse	2X2	1:0.5:3.75	Middle proportion Lime Normal Sand	Air	7	3027	756	6%
11/19/2013	1-2	Coarse	2X2	1:0.75:4.375	High proportion Lime normal amount Sand	Air	7	3059	764	5%
11/19/2013	1-3	Coarse	2X2	1:0.75:4.5	Middle proportion Lime High amount Sand	Air	7	2874	718	9%
11/19/2013	1-4	Coarse	2X2	1:0.75:5.25	High proportion Lime High amount Sand	Air	7	2198	549	12%
11/19/2013	1-5	Coarse	2X2	1:1:5.5	Extreme	Air	7	2839	709	13%
11/19/2013	1-6	Coarse	2X2	1:0.75:2.625	High Proportion Lime Low Proportion Sand	Air	7	3153	788	4%
12/6/2013	2-2	Coarse	2X2	1:0.75:4.375	1 part = 2.5"X6"X3" 652 grams of water	Lime	7	6318	1579	20%
12/6/2013	2-2	Coarse	2X2	1:0.75:4.375	1 part = 2.5"X6"X3" 652 grams of water	Lime	41	>2500 PSI		
12/6/2013	2-2	Coarse	2X2	1:0.75:4.375	1 part = 2.5"X6"X3" 652 grams of water	Water	7	3147	786	36%
12/6/2013	2-4	Coarse	2X2	1:0.75:5.25	1 part = 2.5"X6"X3" 626.4 grams of water	Lime	7	4104	1026	16%
12/6/2013	2-4	Coarse	2X2	1:0.75:5.25	1 part = 2.5"X6"X3" 626.4 grams of water	Lime	41	4568	1142	36%
12/6/2013	2-4	Coarse	2X2	1:0.75:5.25	1 part = 2.5"X6"X3" 626.4 grams of water	Water	7	2468	617	27%
1/16/2014	2-2.1	1/20	2X2	1:0.75:4.375	1 part = 2.5"X6"X3" 2.5 lb of water	Lime	7	2353	588	12%
1/16/2014	2-2.1	1/20	2X2	1:0.75:4.375	1 part = 2.5"X6"X3" 2.5 lb of water	Air	7	1858	464	3%

Table C2 – These are the 4” diameter , 8” long cylinder plaster sample mix design iterations in order of trial number and dates mixed. The final mix design is not included.

Date Mixed	Mix Name	Sand	Specimen	C:L:S	Comments	Cured	Cure Time	Max Load Average (pounds)	Compressive Strength (PSI)	COV
2/2/2014	2-2.2	Coarse	Cylinder	1:0.75:4.375	1 part = 2.5"X6"X3"	Air	7	15596	1242	8%
2/2/2014	2-2.2	Coarse	Cylinder	1:0.75:4.375	1 part = 2.5"X6"X3"	Air	28	7840	156	
2/3/2014	2-2 .2	Coarse	Cylinder	1:0.75:4.375	1 part = 2.5"X6"X3"	Lime	7	4288	341	61%
2/3/2014	2-2 .2	Coarse	Cylinder	1:0.75:4.375	1 part = 2.5"X6"X3"	Lime	28	7968	634	18%
2/9/2014	3-1	1/20	Cylinder	1:0.75:7	1 part = 2.5"X6"X3"	Air	7	3189	254	18%
2/9/2014	3-1	1/20	Cylinder	1:0.75:7	1 part = 2.5"X6"X3"	Lime	7	2823	225	19%
2/17/2014	3-2	1/20	Cylinder	1:0.75:5	1 part = 2.5"X6"X3"	Air	7	12848	1023	4%
2/17/2014	3-2	1/20	Cylinder	1:0.75:5	1 part = 2.5"X6"X3"	Lime	7	10358	825	15%
2/17/2014	4-2	30 mesh	Cylinder	1:0.75:5	1 part = 2.5"X6"X3"	Air	7	7839	624	12%
2/17/2014	4-2	30 mesh	Cylinder	1:0.75:5	1 part = 2.5"X6"X3"	Lime	7	5846	465	6%

APPENDIX D: TEAMWORK PHILOSOPHY

We believe that it is important to solve this environmental problem with ethics in the forefront of our minds. Together, the Straw Bale Seismic Design Capacities 2 team members established a code of ethics for incorporating our work together with previous research done by our advisor for our final project. We will:

- treat each other's ideas with respect, understanding the delicacy of the brainstorming process,
- take great care to express the previous work done on straw bale construction in a manner that gives the researchers and designers full credit,
- work cooperatively and respectfully with the other groups doing projects on straw bale construction, making sure that they receive the proper credit for the information that they have provided,
- treat our advisor, faculty, professionals, and other students with respect, taking their suggestions and input into consideration but ultimately remembering that it is our senior design project so the final decisions, hardships and work are our responsibility
- represent Santa Clara University well when working with industry professionals and code specialists making sure we enter meetings prepared to the best of our abilities, treat them with the respect they deserve and be grateful for their time and assistance.

Ethical Obligations to Our Sponsors, School and Selves

Regardless of the situation, we will not misrepresent any of our findings, nor will we take any credit for work that is not ours. If a sponsor, faculty member, or other student requests this of us, we will walk away from the situation. We take pride that the project is ours and we will not be pushed into representing anything in a way that s not accurate. If we end up in an ethically challenging situation, we will speak openly about our concerns. If we cannot agree on the ethically correct action, we will seek guidance from Santa Clara University's Markkula Center for Applied Ethics.

Ethical Obligations in Designing the Building Code

After researching the ethical obligations of our senior design process, the main ethical concern we have is making sure that we accurately record our process and represent our results. We understand that the work that we are doing will likely be adopted into the California Building Code, so we must accurately portray the process and results. It is our moral obligation as future engineers to ensure detailed reports of the systems. This will allow us to influence the incorporation of straw bale building design for more widespread use of this agricultural byproduct in construction.

Ethical obligations to Represent Data Accurately

We recognize that it is more important to show truthful results than it is to manipulate the data so that the project appears to be a success. We acknowledge that this representation must be accessible to future straw bale construction users. We will guarantee the safety of users by providing fully representative descriptions of our work and detailed construction techniques.

Ethical obligations to Contributing Research

Previous research has been done regarding straw bale construction, a large part of which was done by our advisor, Dr. Mark Aschheim. This research is an invaluable resource for us and we will treat is as such as we acknowledge what findings were ours, and what findings were provided to us. We will do this by clearly citing information and data that we did not generate, as well as, verifying with Dr. Aschheim that the work that we have done is original.