The Effects of Plastered Skin Confinement on the Performance of Straw Bale Wall Systems

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ABSTRACT

Straw bale structures are cost efficient as well as environmentally friendly. These types of buildings make use of straw, a by product of nature, and use volunteers as a labor force. This research is a part of an ongoing plastered straw bale wall project. Recent research has shown that moderate as well as complete confinement of plastered skins have been used on the straw bale wall assemblies. This project will continue this investigation and will include the results of compressive tests of confined straw bale specimens. It will also include an evaluation of construction details for confining skins, and how further research can clarify which techniques are most beneficial when building straw bale structures.

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1. ACKNOWLEGEMENTS

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2. INTRODUCTION

2.1 OVERVIEW

Load bearing straw bale wall assemblies (also called 'Nebraska-style') have been in use for more than a hundred years. During that period various structural tests were conducted on how much load these wall systems could endure. Experiments such as the ones conducted by Fibrehouse Limited (Lacinski et al., 2000) as well as tests under the direction of John Carrick, BE. M Eng Science suggests that plastered skins along with the plaster reinforcement are the main load carrying elements of a load-bearing wall system (Carrick, 1998). In other words, plastered straw bale walls act as structural sandwich composites, or stressed skin panels. Thus the real role of the straw is to then prevent the skins from deflecting under load. In a report, Structural Testing of Straw Bales and Straw Bale Walls, done by SHB AGRA, Inc. in 1993 it was stated that ignoring "the effect of stressed skin panels is to miss the point of structural straw bale walls" (Magwood and Mack, 2000). If the skins as a whole are important then paying attention to the construction details of the panels should also be crucial in the construction of plastered straw bale walls. However, currently there is very limited information on how the confinement of skins on the walls contributes to the overall load bearing capacity of the wall.

2.2 METHODOLOGY

After obtaining laboratory results, done by Dr. David Riley and Dr. Thomas Boothby Associate Professors of Architectural Engineering at Pennsylvania State University, the next step is to do a literature review of construction details for plaster confinement. After that, a visit will be made to a straw bale construction site, where literature findings can be compared to techniques used in the field. Finally, conclusions will be drawn and suggestions for further research will be made.

2.3 MOTIVATION

In the Strength-Testing of Stucco and Plaster Veneered Straw Bale Walls conducted by David Riley in 1998, it was assumed that the "confinement of the veneer finish at the bottom and two sides confined the movement of the plaster skins" (Riley et al., 1998). This indicates that skin confinement is important in the stability of a wall system. Questions are then raised, what kind of confinement gives the wall its best performance, and what are the effects of each type of confinement? From there the hypothesis is stated for this report that proper confinement of plastered skins will substantially increase the overall performance of load-bearing walls.

3. PRELIMINARY FINDINGS AND DISCUSSION

The test results for this research on the effects of plastered skin confinement support the hypothesis that confined skins strengthen straw bale wall assemblies. The literature findings are also useful in the sense that they offer options for confining Nebraska-style straw ball walls; however the literature does not elaborate on the advantages and disadvantages of each technique of confinement. Typically under vertical loads there are four types of failures that can occur in straw bale wall systems (Figure 3.1). These include (1) global buckling, (2) local buckling (3) bearing, and (4) vertical shearing.

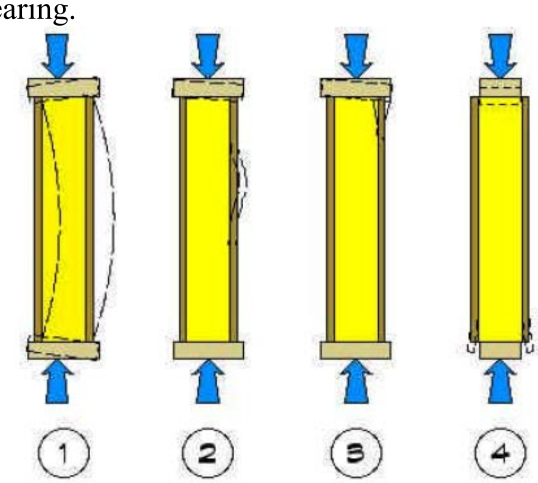


Figure 3.1- Four most common types of failures in straw bale walls (Donahue, 2003)

Shearing, the fourth failure mode is the focus of this research. Shearing occurs when unsupported skins slip past the bottom plate. This failure occurs most commonly due to improper confinement. Chris Magwood states in *Straw Bale Details* that

> "The most important structural requirement in the design of foundations is that the plaster skins bear directly on or transfer loads to the foundation, because it is the plaster skins which transfer the roof load to the foundation (Figure 3.2)" (Magwood, 2001).

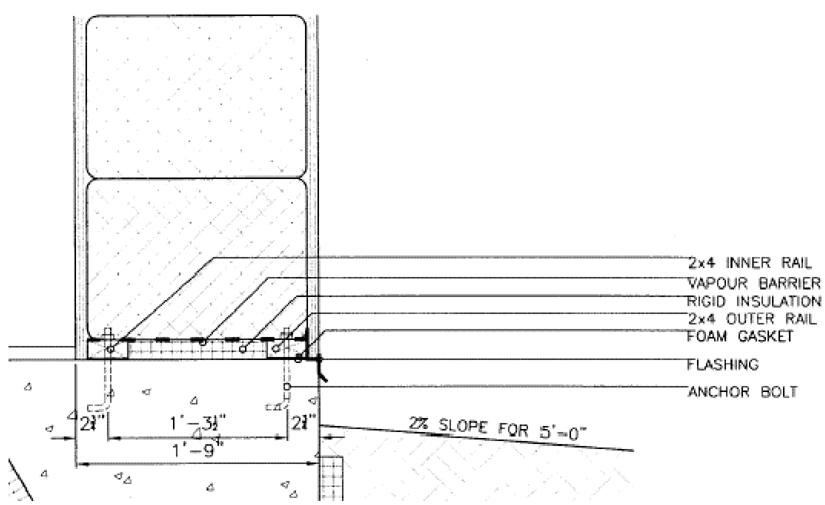


Figure 3.2- Plaster Skins Bearing Directly on Foundation (Magwood, 2001)

One of two other variations of this rule is setting curb rails one inch wider than the bales to support the skins (Figure 3.3). Curb rails are used to elevate bale walls to avoid water build up at the base of the bales. With this method it is common however "for the skins to slide over the curb rails on which the bales sit, and continue sliding until they hit the floor" (Magwood, 2001). This suggests to designers that setting skins on the rails is almost equivalent to no confinement under the skins at all.

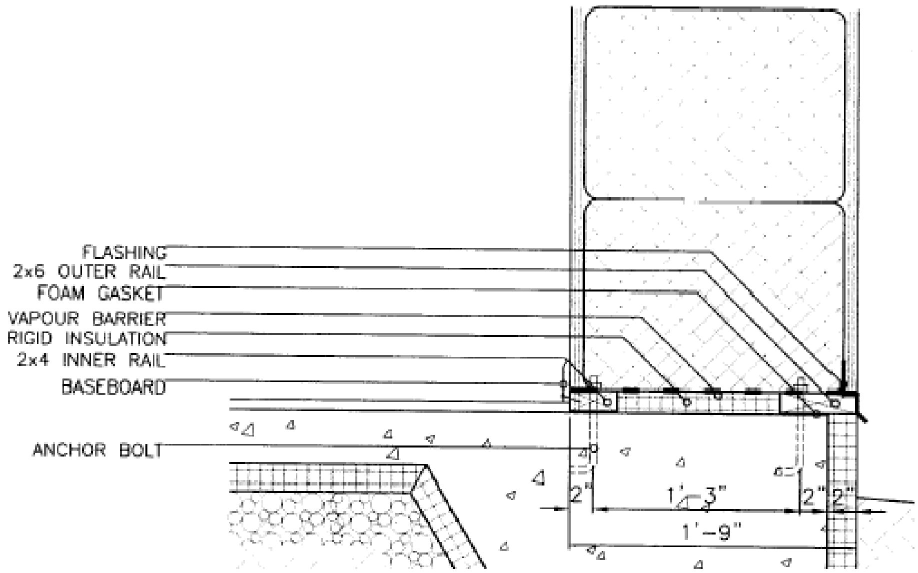


Figure 3.3- Plaster Skins Bearing on Curb Rails (Magwood, 2001)

Another commonality to the construction of load-bearing walls is to, "align the outside skin along the outer face of the bearing plate at the top and the foundation (Figure 3.4); its capacity, however, to resist imposed vertical or shear loads is limited," (King, 1996). If the exterior skin has limited strength to withstand vertical loads then perhaps the interior skin, that rest on the inner foundation, takes a larger portion of the load to prevent failure in the wall. The entire process of confining only one side of the wall leads the skins to rely solely on the strength of the staples used on the mesh and other plaster reinforcement. In Cale Ash's thesis, In-Plane Cyclic Tests of Plastered Straw Bale Wall Assemblies done at the University of Illinois, Urbana-Champaign, cement stucco walls along with earth plaster walls with various levels of plaster reinforcement were tested. The cement plastered walls were constructed using 17-gauge stucco mesh as skin reinforcement in one experiment and 14-gauge mesh, additional staples, and dowels in the skins in the other experiment. The results of the two tests under in-plane loads were 6.4 kips and 19 kips in the more reinforced wall. The capacity of skins resting solely on the strength of the staples and mesh thus varies greatly depending on the level of reinforcement used. To avoid premature failure considerable skin reinforcing in addition to skin confinement should be practiced in the field on load-bearing wall construction.

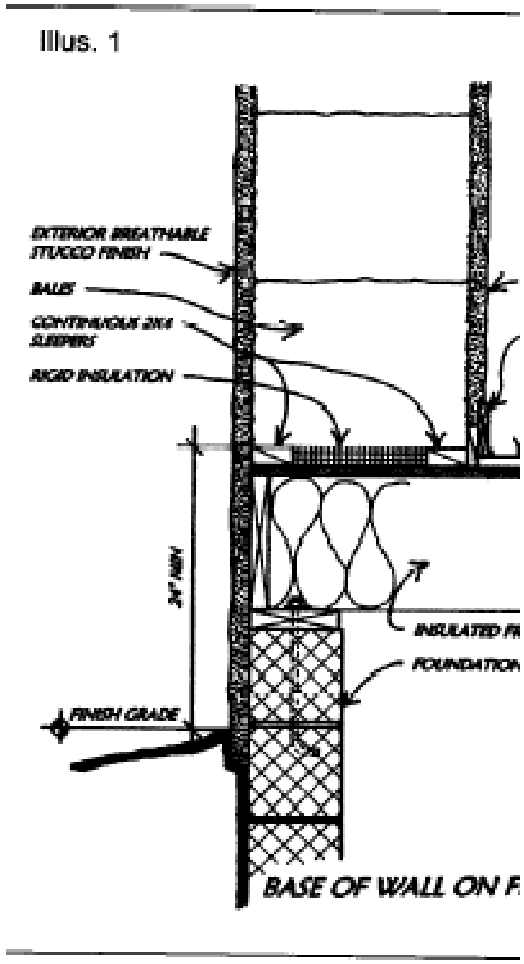
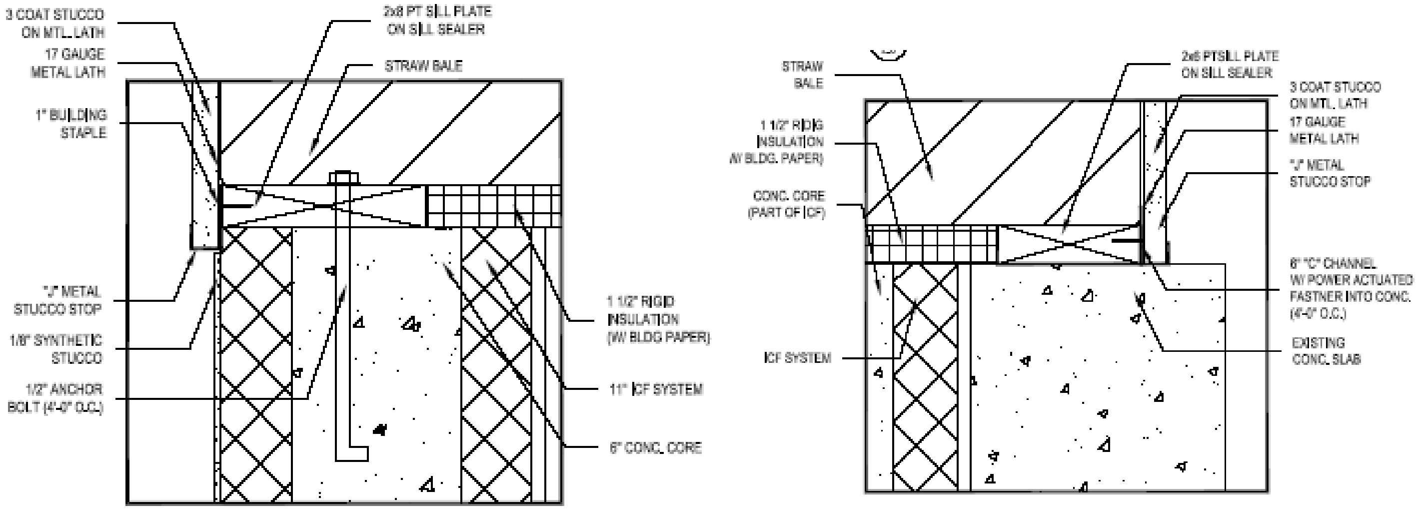


Figure 3.4- Interior Skin Bearing Directly on Foundation and Exterior Skin Unconfined (Koko, 2001)

All three of the previous techniques follow Magwood's direction, but all possess notable flaws with their performance. This demonstrates that his statement is very true, but can be interpreted in many ways. Thus, researchers and engineers have come up with their own load transferring methods of confining skins other than the three methods mentioned above.

A current case study of new confinement methods is seen in the designs from the American Indian Housing Initiative (AIHI) group. This summer the AIHI group worked on building a technology center for the Chief Dull Knife College located in Lame Deer, Montana. The American Indian Housing Initiative (AIHI) is a program whose overall goal is to develop sustainable designs and construction processes to aid in the solution of the housing crisis of tribal based communities, such as the Northern Cheyenne Nation of southeastern Montana. The structure is to be 64' x 44' and 19'- 4" in total height. The exterior of the building has three layers of stucco, the first two of which are thicker; the final outside coat is thin and colored for appearance. The interior has the same three coats, all applied. The final colored coat will be applied in a few months once the first two coats have had a chance to thoroughly dry. The interior skin rests upon a concrete ledge which allows the skins to transfer roof loads to the foundation.

The upper portion of the exterior wall will rest on strips of J-channel, while the bottom section of the wall, composed of Insulated Concrete Forms, will be plastered with synthetic stucco and remain unconfined. (Figure 3.5 a and b)



a- exterior wall b- interior wall

Figure 3.5- Onsite construction technique for exterior and interior wall

The designers for this project plan compare the amount of cracking under the window in the exterior skin to the amount of cracking in last years project to see if cracking decreased using this method. It is also projected that the wall will act like a wall that is plastered in one continuous coat of stucco and not like two separate skins. All the techniques mentioned should be tested and compared with one another for additional strength and weaknesses. By researching these methods and finding other strengths and weaknesses in them, straw bale enthusiast can find new and conceivably better ways of confining veneer.

4. LAB RESULTS

4.1 INTRODUCTION AND DESCRIPTION OF TEST SPECIMENS

Laboratory test conducted by David Riley and students in 2003-2004, at Pennsylvania State University, showed some of the benefits to confining plaster skins. In this program, they tested walls with moderately confined skins and walls with completely confined skins. The test specimens were four feet long three bales high plastered straw walls. The bales were pinned with rebar, sandwiched in 17-gauge wire mesh using pins, and plastered with cement stucco. Each wall had top and bottom box beams placed on them that were strapped to the bales with polypropylene strapping. On the top of the upper box beam laid a steel plate to evenly distribute the load to the bales. The entire specimen rested on a bottom plate that had threaded rods connected to the floor. The stucco was confined with Z-channel on the top of the skin and J-channel on the bottom. The confined specimen had additional 2x6 and 2x4 battens along the top and bottom of the plaster skins (Figure 4.2a). The other specimen did not have the extra batten on the bottom of the skins for support (Figure 4.2b), so the skins rested solely on the J-channel. Two 20 kip hydraulic pumps electronically applied the load pressure to the walls. Both specimens under went compression tests. The testing frame to which the specimens were hooked up comprised of the potentiometers three along either side and two, front and back. Strain gauges were also placed vertically along the front and backside of the wall.

4.2a

4.2b

Figure 4.2- Unconfined(a) and Confined(b) test specimens

4.3 TEST RESULTS

During the compression test with moderate confinement the total wall system withstood about 7,000 pounds, and the skins vertically sheared off the lathe. In the first case of complete confinement the wall failed at about 16,000 pounds and the skins remained in place with minor cracking. This specimen also continued to fall forward as greater load was applied. The second fully confined specimen tested did not reach failure in the lab. At a load of 20,000 pounds the specimen incurred little cracking in the plaster, and stood perfectly erect. The second specimen compares quite well with the highly reinforced specimen in Cale Ash's test which withstood 19kips.

4.4 DATA ANALYSIS

The potentiometers connected to the wall specimen in the completely confined test incurred technical difficulties. Before the test began it was hypothesized that the bottom potentiometers would receive the biggest recording of deflection, since all loads were being applied from the top of the wall and transferring downward.

Figure 4.5 potentiometers attached to testing frame

It was also assumed that the wall would hold more than the wall with moderate confinement. The middle potentiometers did not give any recording of data on either side of the wall, which would infer there was no deflection in the center of the bale. This conclusion however is unreasonable to assume due to the unlikely hood of a wall deflecting on the top and bottom with out going through the center. The illogicality of the graphs is explained by the potentiometers being secured to the testing frame and not the actual test specimen (Figure 4.5). This setup allows for the potentiometers to record the movement of the frame in addition to the deflection in the wall, which is not what researchers were looking for in this test. To address this issue, the second test specimen had the potentiometers attached to the upper box beam of the wall instead of the testing frame (Figure 4.6), in an attempt to eliminate the bias incurred from the frame during the previous test. Despite the fact that the data did not come out as clear in the first test of complete confinement, there is assurance that the results for the second specimen, when made available, will be very accurate. Even without the exact load versus deflection pattern it is evident that the wall held substantially more than the moderately confined specimen.

Figure 4.6 – Improved test setup with potentiometers attached to box beam

4.7 DISCUSSION OF LAB RESULTS AND CONCLUSION

Placing additional supports on the frame, kept the frame in place as load was applied to the wall. Having a steady setup applying load, allows the load to transfer directly into the wall and not to the frame. This test gives a more accurate picture of what a well confined wall can do. The moderately confined skins withstood 7kips on J-channel alone. This shows that J-channel is just the beginnings of obtaining a well built wall. Just the addition of one 2x4 tripled the holding capacity of the wall. This experiment only strengthens the reason why skins should be placed on the foundation of straw bale structures. Other methods to look into when testing plastered wall is placing the wall close to the ground, and letting the skins rest on the floor. A test of this nature would give the most realistic results compared to setting skins on the foundation on construction sites. Also conducting test with wall assemblies that have fully confined skin on one side and unconfined skin on the other, will give researchers an idea to how “half confinement” works compared to confinement of both sides. Results from a test of this kind can address the question, is there a possible long-run disadvantage to only confining interior skins, and if not what makes confining only one skin work? Until these questions are addressed the best and most reliable method of confining plastered skins is to place both skins on the foundation of the structure. So far this is the only full proof method of allowing the skins to transfer roof loads directly to the foundation.

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