A Pilot Study examining and comparing the load bearing capacity and behaviour of an earth rendered straw bale wall to cement rendered straw bale wall.

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ABSTRACT: During the last two years two straw bale walls were built and load tested to failure. One wall was constructed using a cement based render and the other with an earth based render. The walls were constructed in the University's loading frame and subjected to uniformly distributed compression loads applied to the top plate. The methods of construction for both walls were similar; using bales sourced form the same farm. The test results were noted and compared with the earth rendered wall behaving in a similar manner to the cement rendered wall. There was a small difference in the load carrying capacity of the earth rendered wall.

Keywords: compressibility, constructability, infill, load bearing, render, straw bale, sustainability, wall, earth render.

1. Introduction:

These two pilot studies were the result of some funding being made available to the School of Construction, Property and Planning in mid 2000 and 2002. The study area reflected the authors' interest in this material and was in keeping with the University's mission statement of contributing to a sustainable world through both research and teaching.[1]

The authors' background is that of practising architect/lecturer and structural engineer/senior lecturer respectively. Both were aware of this style of building from a literature review and were intrigued by the structural and practical aspects of construction using this material.

Straw bale construction is not new. Early examples date to the turn of the previous century in Nebraska (USA) [2] where enterprising homebuilders utilised a waste material to construct well insulated walls for their houses. Put simply such buildings were constructed from straw bales as "large blocks" and then rendered or plastered with an assortment of finish to weather proof the building. Over time this became known as the 'Nebraska style', some such examples still exist to day.

There are two types of wall construction; load bearing and bale infill techniques. Each has its own unique set of advantages and is often the preference of the owner/builder and the influence of the building code officials. With respect to the code aspect, infill type techniques may be preferred, as the bales are not necessarily contributing to the stability of the frame. Usually large timber sections are employed in this type of building with all the attendant and demonstrated ability of timber structures. A practical aspect might also be the construction of the frame, allowing for a roof to be put in place ahead of the walls and therefore allowing a degree of weather protection to the straw during the course of construction.

[1] University of Western Sydney Mission Statement 1998
[2] Steen A, Steen B, Bainbridge D Eisenberg D 1994 The Straw Bale House, Chelsea Green Publishing Company

Either way, many straw bale buildings have been constructed around the world to date with the structural aspects of this material becoming more clearly defined when compared to more 'conventional' construction materials. Building codes do exist (particularly in the USA) which delineate how bales should be used on site for both load bearing and infill type construction (Austin Straw Bale Code[3], Pima County Code[4], California Code[5] etc). Such codes stipulate limits for the ratio of height to thickness (5.5:1) and ratio of length to thickness (15.5:1) for load bearing walls.

The first study (in mid 2000) was set up to examine what would happen to a two-storey section of a load bearing straw bale wall as it was uniformly progressively loaded by a uniformly distributed load. The limitation of height to thickness would seem to preclude the use of load bearing straw bale walls from two-storey house construction as these limitations would only allow a wall of approximately 2500mm height to be constructed.

The significance of such research was to demonstrate either the ability of such a wall to either withstand such loading or fail and therefore contribute to the wider field of knowledge with respect to this type of construction. Two-storey load bearing construction may also allow for houses with a smaller "footprint" to be successfully constructed, therefore increasing the range and type for this form of construction.

The second study (completed in 2002) was aimed at comparing how an earth rendered straw bale wall would perform under similar loading conditions except for the overall height of the test wall (limited to single storey height). There is a current of thought amongst straw bale builders and researchers that an earth based render has great visual and sustainability appeal but a question mark hangs over issues of strength, longevity, moisture control and suitability as a building medium.

Previous studies to date by Bou-Ali (University of Arizona)[6], McCabe [7](University of Arizona), Carrick (University of New South Wales)[8], Faine and Zhang[9] (University of Western Sydney) and others indicate the structural adequacy of straw bale wall construction. Researchers have also identified the very good insulation properties of rendered straw bales (Canada)[10] and its attendant fire resistance qualities. However moisture in and through the wall have sounded some alarm bells for the obvious problems of rot and then eventual collapse, further studies are being undertaken in this area.

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[3] Austin Straw Bale Code 1997, City Of Austin, www.io.com/~whetfunk/sbatcode
[4] City of Tucson and Pima County Arizona Building Code, www.sustainable.doe.gov/codes/azstraw
[5] California Code AB1314, California State Government Web site
[6] Bou-Ali G. 1993 Straw bales and straw bale wall systems, Master Thesis University of Arizona
[7] McCabe J. 1993 Masters Thesis University of Arizona
[8] Carrick J 1998 Preliminary Test Results for Straw Bale Walls, Building Research Centre UNSW (unpublished)
[9] Faine M & Zhang J 2001 "A Pilot Study examining the Strength, Compressibility and Serviceability of Rendered Straw Bale Walls for Two Storey Load Bearing Construction". First International Conference on Ecological Building Structure, Santa Sabina Centre, San Rafael, California July 2001
[10] 1995, Thermal and Mechanical Properties of straw bales as they relate to a straw house, Canadian Society of Agricultural Engineering, Ottowa, Ontario

2. Current Construction Technology:

This section is limited to a discussion on the techniques associated with load bearing construction. The main issue to be faced in dealing with straw bales is to adequately achieve pre-compression of the bales to avoid the problem of both short and long term settlement (shortening) of the wall. Such a problem obviously has a great impact upon the construction of doorways and windows not to mention the potential for cracking and damaging the render (plaster) mix applied to the wall as the finish.

Straw bale walls have been constructed both from in-ground conventional strip footings and from integrated footings and concrete slab. Other types have been tried, such as rubble filled footings, earth filled tyre footings usually to minimise or avoid the use of reinforced concrete. This material is viewed as being high technology with high-embodied energy. The usual details of waterproofing, vapour control, termite and pest control are observed with a variety of techniques available for both tie down of the roof frame and pre-compression of the wall.

These range from reinforcement rod being extended from the footing, through the straw bale wall to the top plate. This is then 'screwed down' to compress the wall and for the tie down effect of the roof and/or the floor frame. Another method is to use an air bag attached to the top of the wall frame and held in place by straps (Fibrehouse system by Chapman and Platts)[11]. The bag is then inflated and the wall is compressed down and held firmly in place by tensioning on the straps. Once the desired compression is achieved the bag is removed.

Another method is to use high tensile fencing wire straps looped around both the footing and the top plate and tensioned by means of "gripples", similar to constructing a wire fence. The wire is usually spaced at about 450 – 600mm centres and is alternatively fastened from both sides of the wall. The tensioned wire then becomes an integral part of the structure.

Usually bales are laid on flat in a stretcher or running bond, often being pinned through their centres to the footing or floor structure and pinned to each other at corners and elsewhere as required. Construction can be quite quick, unskilled labour can be used with chain saws, mallet and 'whipper-snippers' providing the finishing effects.

If the wall is to be rendered using cement based render then a wire mesh (chicken or aviary wire) is stretched from top to the bottom plate. Walls finished in an earthen render do not usually have this mesh[12] and some builders see this as an advantage. The render is applied direct to the straw bale and forced into the strands forming quite a good key for subsequent coats. Norton[13] gives advice on types of earth renders and how they should be keyed into the structure to achieve both durability and longevity. Similarly Myhrman and Macdonald [14] discuss the benefits and pitfalls of different types of render (plaster) for straw bale use.

Top plates are generally framed from 100 x 50mm or 150 x 50mm timber constructed as a ladder frame to span the width of the straw bale. Noggins at 600 or 900mm centres join the timber frame members; some advocate the use of sheet plywood. Often associated with the

[11] Chapman and Platts 1996 Developing and proof testing the pre-stressed Nebraska method for improved production of baled fibre housing, Fibrehouse Ltd with Scanada Consultants Ltd, Ottawa, Ontario
[12] Glassford J 2001 Straw Bale Building Technology Workshop Ganmain NSW (personal interview)
[13] Norton J 1997 "Building with Earth - a handbook" Immediate Technology Publications, London.
[14] Myhrman M and MacDonald S. 1999 "Build it with Bales" Version Two Out on Bale Publications Tucson

top plate is the roof tie down mechanism, being either a threaded rod or galvanised strap or tensioned wires.

3. Design and Construction of the Full Scale Walls:

The loading frame was used to contain the construction of the straw bale wall(s). Figure 1 shows the general frame arrangement with the partly completed two-storey straw bale wall framed between the large structural steel columns. The steel beams and columns were fabricated from 25mm thick steel, 400 x 400mm "I- beam" section, courtesy of a research grant and BHP steel sections.

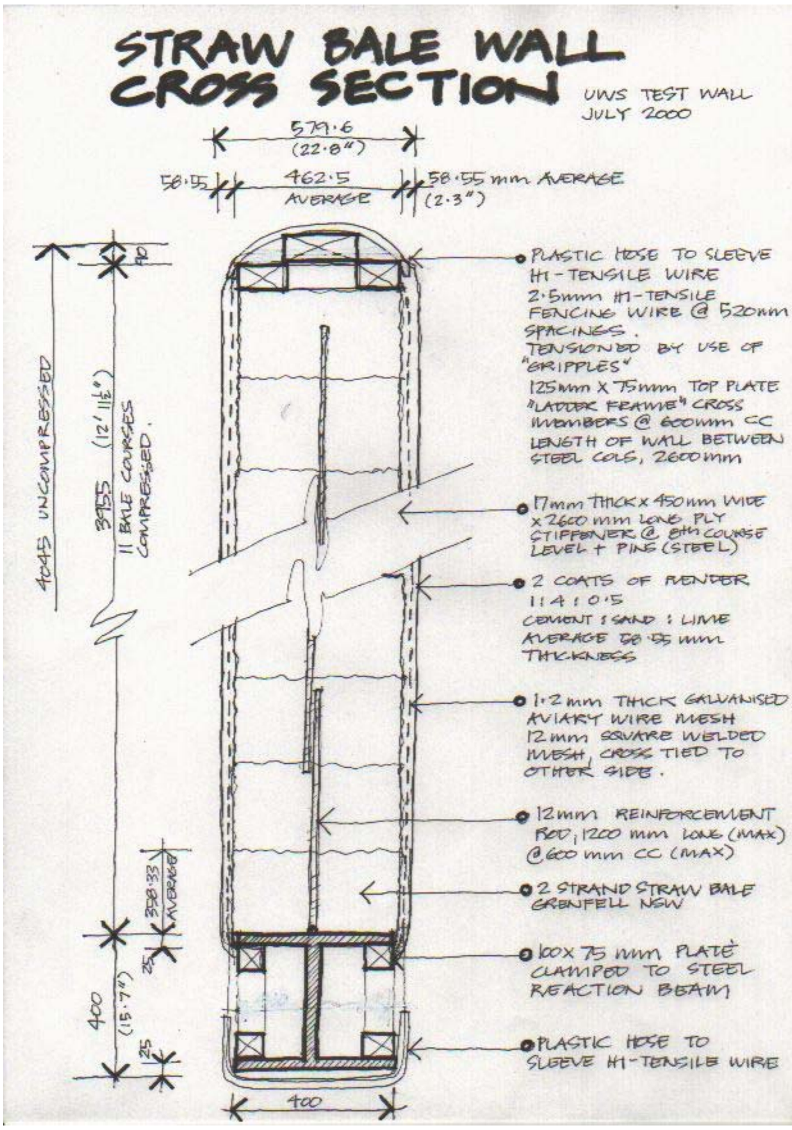
Figure 1 General view of steel test frame and partly completed wall for two-storey wall (Photograph: P. Florence)

The "two-storey" wall was constructed to a height of 4045mm (uncompressed) being 11 courses in height; the length of the wall was 2600mm between steel columns with a layer of 17mm structural plywood placed against the steel columns to prevent the straw from expanding into the web of the columns. The general arrangement for construction can be seen in Figure 2. Bales were laid in stretcher bond pattern with a number of half bales. Bales were pinned over a 12mm reinforcement rod that had been tack weld to the frame. Pinning was continued up through the bales to the top course. The lower section of steel was assumed to simulate the concrete footing. A timber infill frame was constructed between the flanges of the bottom steel beam to allow for fixing of the wire mesh. Construction generally followed details reviewed from the literature and from interviews (Mitchell R.)[15]

The top plate was constructed from 125 x 75mm timber joined together as a ladder frame. An additional length was placed centrally to help distribute the load from the hydraulic rams. The high tensile fencing wire was run as a loop under the "footing" and carried up and over the top plate. A length of galvanised iron angle was placed at both top and bottom plates to provide for a radius turn for the wire to prevent a sharp edge from cutting the wire under load.

[15] Mitchell R. 2000 Zone Zero Architects Springwood NSW (personal interview)

Figure 2. Two Storey Straw Bale Wall Cross-Section. (Illustration M. Faine)



A layer of 1.2mm thick galvanised welded wire mesh was then stretched between top and bottom plates and fixed into position. This was also stitched to the other side of the wall to bring the mesh in close to the straw bale surface.

The "earth rendered wall" was constructed in a similar manner but to an overall height of 2550mm by 2730 mm long. Plywood infill frames were constructed at either end to constrain the straw. A bottom plate of plywood and 100 x 500 mm ladder frame was used to allow the wire strands to pass through the "footing". The top plate was constructed from 100 x 50mm timber ladder frame with plywood sheeting.

The straw bale wall was 7 bales high by 3 bales long but was not pinned with rebar nor was a chicken wire mesh used to cover the face of the straw. The bales were pre-compressed by 80 mm prior to the test being carried out. A general view of this wall being trimmed to size can be seen at Figure 3.

Figure 3: General view of earth rendered straw bale wall at time of trimming. (Photograph S.Overmeyer)

Figure 4: Trimming two-storey bale wall to size. (Photograph P. Florence)

The wall was trimmed to remove stray fibres and nocked into a reasonable straight line prior to the wall being compressed. Once the team was satisfied with the result the rendering process began. Two coats were applied over a period of two weeks, with the coats being applied in about a day and a half by a team of four (inexperienced) renderers. The mix design was 1: 4: 0.5 being cement: sand: lime. This was a strong mix with the addition of the lime to 'self heal' any later cracking. The rendering process for the two-storey wall can be seen in Figure 5.

A similar method was used to apply the earth based render. The mix design was 3:3:1 being earth: river sand: chaff for two coats (about 35-40 mm thick total) and the finish coat mix design was 3:3:1:0.6 being earth:sand:slaked lime:chaff for a final coat thickness of about 3-5mm. The earth based render was easier to apply direct to the straw wall, which had been lightly wetted by a fine spray of water. The earth render was later subjected to a compressive test; see the appendix Table 2 for details.

Figure 5: Render application over mesh for two-storey wall. (Photograph P. Florence)

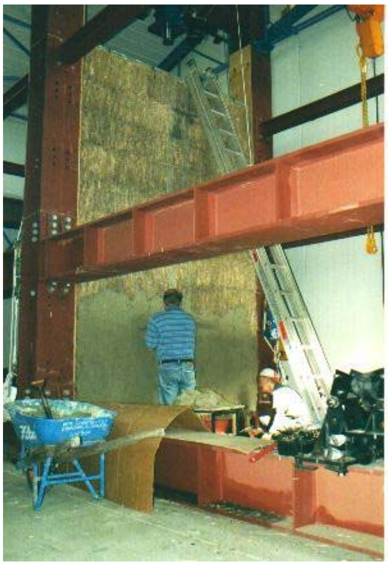


Figure 6: Earth render application. (Photograph P. Florence)

The straw bales used in the construction of these walls were sourced from 'Elderslie' at Grenfell NSW and were two-string bales 840-x 460 x 360mm dimension. The bales were sourced from this farm as the farmer had prepared bales for other straw bale projects and was familiar with the requirements to provide tightly bound bales. The average moisture content was calculated to be 12.11%, well within the allowable range (see appendix Table 1). The California Code permits a moisture content of up to 20% of the total weight of the bale.[16] The New Mexico straw bale construction guideline advocates a similar limit. [17]

The test set up was fairly simple. Two 10 tonne capacity Enerpac hydraulic rams were coupled together and attached to the top steel reaction frame. 2 x 10 tonne load cells (HBM Agezelle) were placed in between the ram and steel spreader bars designed to distribute the

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[16] State of California Health and Safety Code, Guidelines for Straw Bale Construction www.skillful-means.com/CALIFORNIA
[17] New Mexico Straw-bale Construction Guidelines www.earthbuilding.com/nm-straw-bale-code

load at 450 mm centres were stacked on top of the plate. The general arrangement can be seen in Figure 6 for the two-storey wall and at Figure 7 for the earth rendered wall.

Figure 7: Hydraulic rams and top plate assembly for two-storey wall.
(Photograph P. Florence)

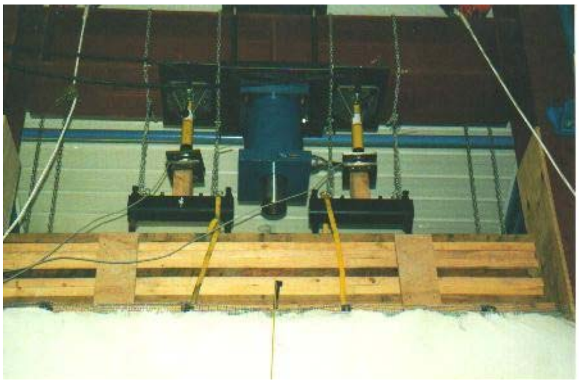


Figure 8: Hydraulic rams and top plate assembly for earth rendered wall (after test).
(Photograph P. Florence)

The load cells were calibrated and the two electronic display units were set up to give a read out of the load from each hydraulic ram in newtons. During the test(s) the readout from each unit would be noted against time and deflection/deformation of the wall(s). A steel scale had been attached to either side of the wall(s) at the midpoint and this was to be read against a static point set up from the floor of the laboratory. Figure 9 shows the steel scale attached to the top plate of the two-storey wall and Figure 10 shows the data acquisition units. The set up was similar for the earth rendered wall test and can be seen at Figure 11.

Figure 12 records the team in action during the two storey-wall test, similar personnel were used for the earth rendered wall test.

Figure 9: View of top plate, ram and measuring tape for two-storey wall test. (Photograph P. Florence)

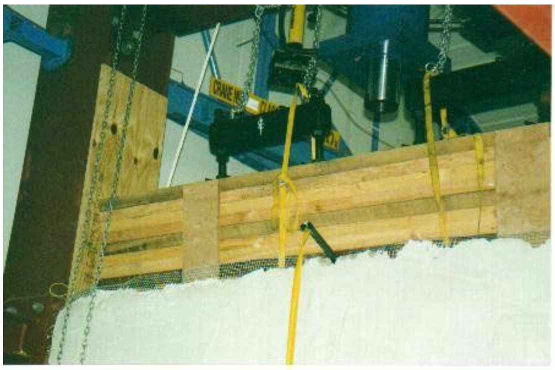


Figure 10: View of electronic display units and end of tape. (Photograph P. Florence)

Figure 11: View of deflection measurement process for earth rendered wall. (Photograph P. Florence)

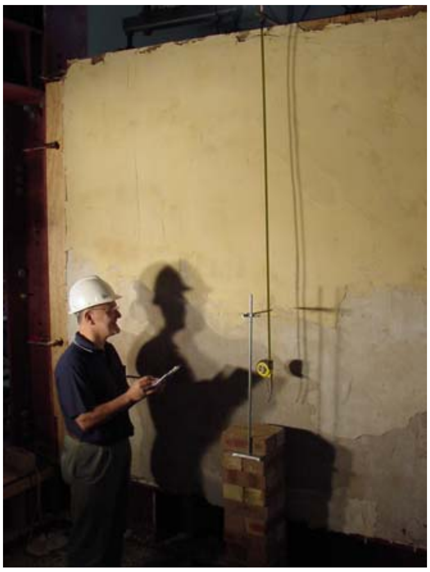


Figure 12: Team in action for the two-storey test. (Photograph P.Love)

4. Test Observation and Results:

The two-storey wall test was carried out on Friday 4 August 2000 and took about one hour to complete. The process was to progressively apply more load to the wall via a hand pump hydraulic unit, note the load cell readings, time and deflection/deformation of the wall.

The team worked through clearly defined cycles lasting about 2.5–3.5 minutes to progressively load the wall, note and record impressions, note and record actual load and deformation/deflection and note the time. Each cycle represented an increase in load of approximately 5kN. The results of this cycle can be seen in Figure 13.

Figure 13. Total Load on two-storey wall versus wall deformation table. (Source: J Zhang)

Load (kN)	Vertical Deformation (mm)		
	left	right	average
0	0	0	0
4.266	0	0	0
8.885	0	0	0
19.818	0	2	1
29.836	-1	4	1.5
39.292	-2	7	2.5
50.416	0	12	6
60.389	9	17	13
72.931	19	23	21
80.491	37	39	38
90.425	69	102	85.5
100.556	69	117	93
110.681	72	127	99.5
120.717	73	137	105
125.786	77	147	112

The total load on the wall is measured in kN. The left and right 'verticals' columns refer to the vertical measurements of the steel tape measures. The third column is the average vertical deformation for the whole wall. A similar test regime was instituted for the earth rendered wall test shown at Figure 14. The test methodology was the same with various team members assigned tasks to record, observe and note the vertical deformation, load and time.

Figure 14. Total load on earth rendered wall versus wall deformation table. (Source M Faine)

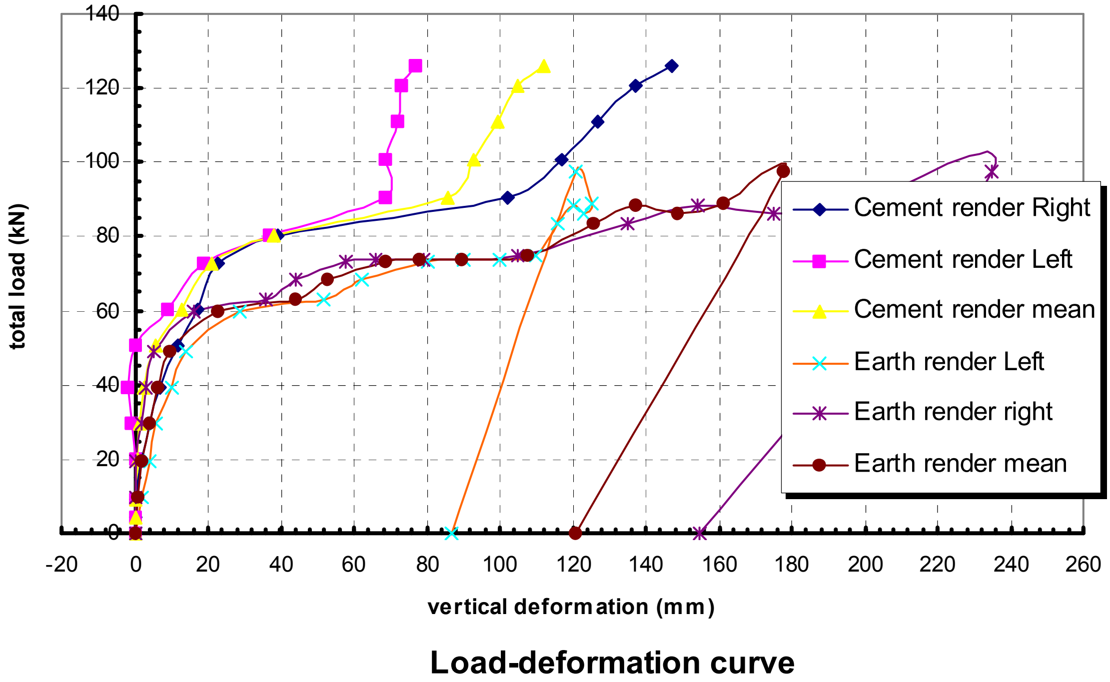
Load	Vertical deformation mm		
(kN)	Left	Right	Average
9.75	2	0	1
19.28	4	0	2
29.54	6	2	4
39.16	10	3	6.5
49.04	14	5	9.5
59.65	29	16	22.5
62.93	52	36	44
68.5	62	44	53
73.38	80	58	69
73.73	90	66	78
73.58	100	79	89.5
74.81	110	105	107.5
83.44	116	135	125.5
88.41	120	154	137
86	123	175	149
88.58	125	198	161.5
97.7	121	235	178

A significant difference between the two tests was that the earth rendered wall showed more obvious signs of compression, both by sound and by the appearance of cracks when compared to the cement rendered two-storey wall. The time involved in this test was of a much shorter duration when compared to the two-storey wall test, taking only about 16 minutes before the test was stopped. By this time the wall had a number of severe cracks and delamination of the render. This can be seen at Figure 15.

Figure 15: Earth rendered wall after test, note cracking (Photograph S.Overmeyer)

The following graph shows the results for both walls for load versus vertical deformation. The curve for both tests reveals a classical material behaviour with a yield point for both walls as the curve changes to a more horizontal line.

Figure 16 Load Deformation Curves for both walls (Source J. Zhang)

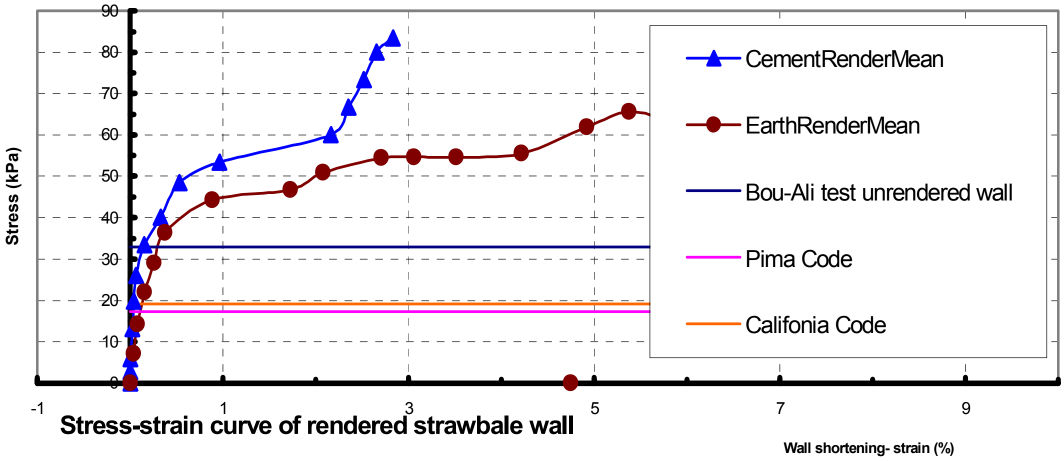


The two-storey wall demonstrated some interesting and fascinating structural characteristics. Apart from the obvious failure region when the load reaches about 80 kN, it also reveals that the post-failure behaviour has a distinct feature of post-stiffening effect due to the compressibility of the material.

When the wall is first loaded, the behaviour follows a typical linear path. The left side deformation reading is negative indicating it is moving upward instead of downward as one would expect. This is due to the eccentricity in the applied load and in the wall itself. This eccentricity creates a significant bending effect so that the wall is bent toward the right hand side.

For this reason the average deformation between the left and right sides provide a more meaningful interpretation of the result. It can be seen on the average curve at the load level of just above 40 kN, there is a significant increase in deformation, demonstrated by the change of slope in the curve. One would stipulate that due to the compression of straw bale, the interaction between the straw and the cement render becomes less significant resulting in the 'softening' of the wall. As the load increases the wall starts to 'yield'. At the load level of 70 kN there is a significant increase in deformation, which marks the failure of the wall. This failure is probably due to the significant separation between the straw bale and the cement render. As the load increases further, the straw bale becomes fully compressed, therefore becoming more solid as the load starts to increase further. Although this post-failure capacity cannot be used in the design of straw bale wall, it does illustrate that the post-failure behaviour is rather stable.

Figure 17 Stress (in kPa) versus wall shortening strain. (Source J.Zhang)



The maximum allowable stress that a straw bale wall can support depends on a number of factors. Of these the wall slenderness (height/thickness) and the unsupported length ratio (unsupported wall length/thickness) are the major influencing factors. The Pima County, Arizona, Straw bale building code limits h/t ratio to 5.6 and L/t ratio to 13. The maximum permissible stress provided by the straw bale alone is limited to 2.5 psi (17.24 kPa) in the Pima Code. California's model straw-bale code allows an L/t ratio of 15.7 and a maximum allowable load of 2.77 psi (19.10 kPa).

These allowable values are for straw-bale alone. Virtually all straw-bale walls are rendered, the contribution by renders is significant, however this contribution is difficult to quantify. King [18]suggests that the render should be regarded as a thin wall restrained by straw bale at a discrete distance, and the strength model for the concrete column/wall be applied. However that treatment only works if both straw-bale and renders are directly loaded at the top.

In these experiments only straw bales are loaded, the loading applied to the render is indirect through the interaction due to bonding. The maximum allowable values given in both the Pima and California codes are also plotted in Figure 17.

If the ultimate failure load is taken as 73 kN (48.44 kPa for the two-storey wall) and the safe working load is taken as 40 kN (26.55 kPa) when the loading curve 'softens' significantly, this gives an equivalent safety factor of 1.82. When compared with both the Pima and California codes, their safety factors are equivalent to 2.81 (Pima code) and 2.51 (California's code), respectively.

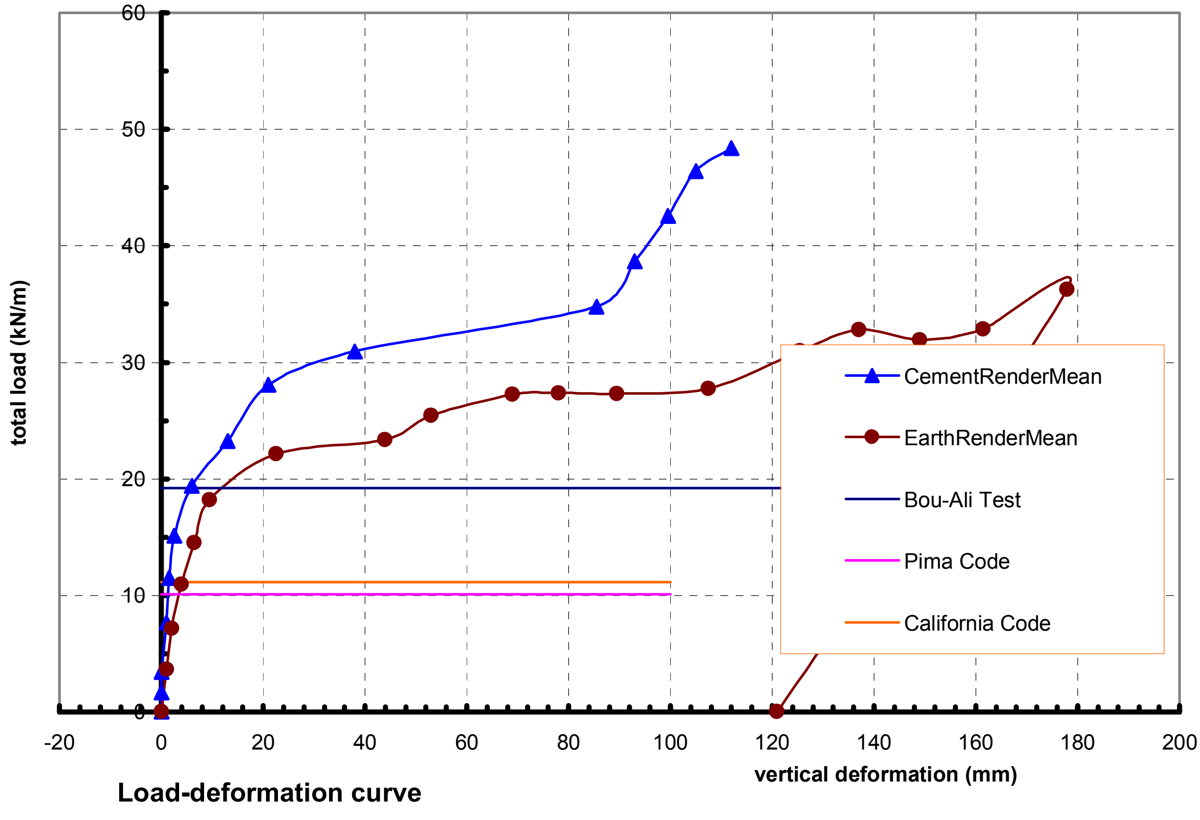
[18] King B.1996 Building of Earth and Straw Ecological Design Press

The two-storey wall did not fail as expected, in fact very little cracking was observed to have formed in the face of the wall. Both faces of render had acted like a 'curtain' and followed the compression of the wall.

The earth rendered wall was much more spectacular in its failure mode, more visible cracking and spalling of render and more noise associated with increase in load and less time to failure. This resulted in a number of large cracks and rotation of the top plate, probably due to a differential settling form one side to the other.

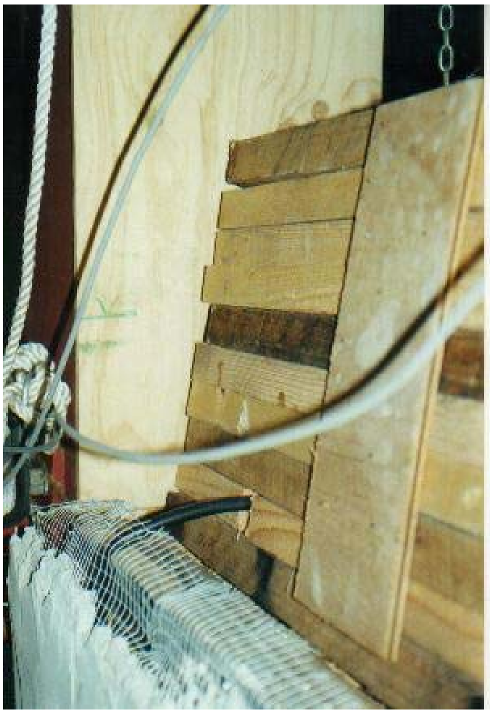
Figure 18 plots the total load against vertical deformation for both walls. Both walls have similar curve properties with the earth render wall failing at a lower total load when compared to the cement render wall. However both walls compare quite well to the limits imposed by both the Pima and California Code.

Figure 18: Total load per metre wall versus vertical deformation. (Source J Zhang.)



The top plate of the two-storey wall was observed to have rotated during the test. It is possible that the load was slightly off centre or that the straw was less stiff on one side. Another possibility could be that the wall was not perfectly plumb and square when constructed but was within reasonable limits for a bale wall. Figure 19 records a view of the top plate after the test. The wall had rotated through about 80mm.

Figure 19. View of two-storey wall top plate after the test. (Photograph P. Florence)



Similarly for the earth render wall test the top plate had rotated out of plane inducing horizontal cracking on one side of the wall with a vertical crack to the other face. Figure 20 is a photograph of the earth rendered wall after the test. The wall has deflected in about 90mm as the top plate has rotated over.

Figure 20: View of earth rendered wall (near top) after test (Source S. Overmeyer)

Figure 21: General view of the earth rendered wall in test frame. (Source S.Overmeyer)

5. Recommendation and Conclusions:

From these tests there are a number of aspects worth considering. The first relates to the construction detail of a straw bale walls. It goes without saying that achieving the best pre-compression of the bales (by whatever method) is very important. Pinning of the bales by using reinforcing rod is probably 'overkill' but some pinning is required as the wall progresses for practical reasons (stability) – particularly for the two-storey height.

The location of the top plate in relation to the render finish is another important practical aspect. These tests allowed for loading of the straw bales in compression, as the top plates did not directly bear on the render finish. At the safe working load of 40kN the deformation (average) for the two-storey wall (cement render) is about 5mm and for the earth rendered wall about 8mm. This is quite tolerable but suggests careful detailing of the finish of the render against adjacent surfaces (floor or slab) to avoid cracking of the finish.

The second aspect worth considering is that of the structural behaviour of the test walls. The safe working load limit of 40 kN is approximately 10 kN above the limits set by the Pima and California Codes. These codes may be very conservative and further testing of straw bale walls is warranted to determine 'type' characteristics suitable for inclusion into building codes.

At the ultimate failure load of 73 kN (for the two-storey wall) some interesting comments can be made about straw bale walls. Once this load limit has been reached straw bale walls compress unimpressively, in fact the failure mode was unspectacular. However it does mean that should a straw bale wall be overloaded in residential construction the house owner could reasonably expect to have a slightly 'shortened home', still carrying load.

It is also clear that a cement render based wall will carry slightly more load than an earth render wall (not having any cement component). However the earth based render was easier to apply direct to the straw wall and does not require a layer of chicken mesh to be applied over the wall. This saves both time and cost.

Both tests record a differential settling of the wall(s) (when comparing 'left' and 'right' sides) with the average figure for settlement being used for calculations. Constructing the walls as straight and perpendicular as possible and in plane is definitely an issue of construction quality and 'constructability'.

Care needs to be taken to avoid using bales that may induce some 'rotation' to the wall top plate. Both walls showed some significant rotation of the top plate, however in practice this may be constrained by the action of the roof frame members.

The addition of the slaked lime to the mix design for the final coat (for the earth rendered wall) may or may not be warranted. Some authors argue that this helps workability and has 'self healing' characteristics to guard against any micro-cracking and possible ingress of water. Table 2 in the appendix records some interesting changes to both failure load and ultimate stress of the material with the addition of lime to the mix.

Further work needs to be done on both the composition of the render mix design and the interaction of the straw to render bond to determine exactly how this behaves as a construction material. The bond between the straw and the render was observed to be very strong, particularly at the time of demolition. These tests have shown that this material is suitable for constructing walls for residential purposes from a structural point of view.

6. Appendix:

Table 1: Calculation of bale density and moisture content. (Source M. Faine)

Size of bales and weights as noted						
	length	**width**	**depth**	**kg 26 May**	**kg 6 June**	**kg 9 June**
Bale 1	800	460	360	16.7	15.61	15.63
Bale 2	840	470	350	15.23	14.27	14.29
Bale 3	830	465	360	15.48	14.87	14.82
Bale 4	830	470	360	14.71	13.89	13.9
Bale 5	810	470	360	15.69	14.97	14.93
Bale 6	790	460	360	16.41	15.56	15.53
Bale 7	860	460	360	14.79	14.16	14.09
Bale 8	870	470	360	14.95	14.3	14.2
Bale 9	880	455	350	17.22	16.52	16.32
Bale 10	880	440	360	16.43	15.63	15.48
Bale 11	820	460	360	16.24	15.63	15.52
Bale 12	850	470	360	17.19	16.55	16.47
Averages	**838.33**	**462.50**	**358.33**	**15.92**	**15.16**	**15.10**
Note: Moisture content of straw bales was calculated at 12.11%						
Note: 6 June reading 10:45 a.m. 11.2% R.H. 34.5 deg C						
Note: 9 June reading 12.30 p.m. 10.9% R.H. 34.6 deg C						

Note: random sample of 12 bales taken from the load delivered to the construction laboratory.

Table 2: Test cylinder renders samples failure load and stress calculations (Source M.Faine)

1. Test cylinder load test for earth render **Date** 18/9/02

	wt (kg)	length (mm)	diameter (mm)	**kN**	**MPa**
1	2.51	196	98.8	6.5	0.85
2	2.40	196	98.8	5.8	0.76
3	2.40	198	98.8	6.7	0.87
4	2.43	196	99.5	5.2	0.67
5	2.51	197.2	98.55		
6	2.56	197.95	99.3		
7	2.56	198.6	98.65	1.2	0.16
8	2.31	197.1	99.6	4.2	0.54
9	2.43	197.85	98.55	6.8	0.89
average	**2.46**	**197.19**	**98.95**	**5.20**	**0.68**

2. Test cylinder load test for earth render - with lime **Date** 24/9/02

10	2.196	187.90	98.20	2.20	0.29
11	2.284	191.85	98.30	1.70	0.22
13	2.199	186.65	98.50	1.70	0.22
14	2.169	188.35	97.90	1.10	0.15
15	2.175	185.55	98.25	1.70	0.22
16	2.215	186.90	98.10	1.30	0.17
17	2.288	190.10	98.85	2.40	0.31
18	2.348	195.35	98.10	1.90	0.25
average	**2.234**	**189.08**	**98.28**	**1.75**	**0.23**

Notes:

Standard concrete test cylinders 100mm diameter x 200mm high were used

Test 1 mix design was 3:3:1 for earth:river sand:chaff

Test 2 mix design was 3:3:1:0.6 for earth:fine sand:slaked lime:chaff

Note significant difference for ultimate failure loads, stress (MPa) for lime rich mix