PRELIMINARY TEST RESULTS STRAW BALE WALLS.

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1. Introduction.

At the request of Mr. John Glassford of Huff'n'Puff Constructions, the Building Research Centre undertook testing of walls constructed from cement rendered straw bale walls. The method of construction has a history in the Western regions of the U.S.A. where building authorities in New Mexico and Arizona have provisionally approved straw bale houses. The testing was undertaken with a view to determining the structural properties of the walls for applications in domestic construction. Other aspects of the material such as water-tightness fire performance and resistance to pest infiltration are not addressed in this document.

The BRC tested specimen walls were constructed by Huff'n'Puff Constructions at the Centre's Randwick Laboratory. The method of building included pre-compression using the Fibrehouse system from Linda Chapman and Bob Platts of Fibrehouse Limited of Ottawa Canada. We achieved an average of 125 mm. of compression on 2.7 metres high walls 3.6 metres long. The bales were made from rice straw and were very average in density and quality. We wanted a typical bale that anyone could buy from a produce agent. These bales were two stringers approximately 900mm. long by 450 mm. wide by 400 mm. high. Their moisture content was well below 10 % and could not be measured on our probe.

These tests were carried out by staff of the Building Research Centre of the University of New South Wales in Sydney New South Wales under the direction of John Carrick BE. M Eng Sci, Laboratory Manager. The work was done between August of 1997 and January of 1998, and was supported by New South Wales Environmental Protection Agency.

The straw bale wall specimens were subject to vertical load, transverse wind load and racking loads as would be encountered in domestic applications. The test procedures were drawn from those of the American standard, ASTM E72 80 which, describes compressive, transverse and racking load tests for building panel systems. Two rendered straw bale specimens were also subjected to longer-term dead load tests with a view to assessing the material's creep characteristics.

The results were interpreted in the light of the expected loads that must be withstood in single and two storey domestic applications.

2. Procedure

2.1 Specimens: Three wall specimens (designated A, B and c) each measuring approximately 3600mm long x 2800mm high x 450mm wide were made up by the client on steel base plates supplied by the Centre. Straw bales were layed seven bales high in stretcher bond on timber bottom plate assemblies placed on the steel bases – steel spikes retained the bales in place during the laying operation. Steel wire ties were employed to compress the straw bales in conjunction with the Fibrehouse pre-compression method. (Described under a separate paper). The method involved squeezing the top plate down towards the bottom, as it would be tightened down to a concrete slab on site.

The downward deflection of the top plate achieved in this operation varied between 100 and 200 mm. Galvanised chicken wire mesh made up from 1 mm dia. wire was stretched into place over the walls' surfaces before a sand and cement render was applied to a depth of about 30mm.

Bales of rice straw measuring 450 x 400 x 900 mm were used to construct all the specimens. The cement render used was 8 parts of yellow bricklayer's sand to 2 parts of off-white cement to 1 part of the rendering additive, 'Plastermaster'. Walls A and B were rendered on the 14,15.08.97, wall C was rendered on the 19,21.08.97.

Two creep specimens were made up by stacking three bales, squeezing between top and bottom plates and rendering as before. When finished, the creep specimens measured about 950mm long x 500mm wide x 1200mm high excluding top and bottom plates. One of the creep specimens, C1 was made using rice straw, the other, C2 used wheat straw.

2.2 Test regime: Each wall specimen in turn was mounted in the centre's wind rig where test loads were applied. A vertical downward acting uniformly distributed line load (UDLL) was applied to the top edge, a transverse wind pressure was then gradually applied to the front surface of two walls by evacuating the space behind after which a horizontal concentrated racking force was applied to the top left hand corner. All specimen walls were tested to ultimate by increasing the vertical load.

2.2.1 Vertical Load: The vertical test UDLL represented an upper bound that would be expected from loads encountered in a typical two storey domestic application – factored for strength according to the requirements of AS1170.1. The vertical test load was gradually applied via a spreader beam along the top plate, which was loaded by two identical hydraulic rams reacting against an overhead frame. The rams were fed in parallel from a common pressure source. The test set-up is similar to that of ASTM E&@ except that at 3.6 metres, the specimen wall is approximately three times as long as a typical 1.2m single panel described by that standard.

An electronic load cell monitored force in one of the rams–the force in the other jack was assumed to be the same. As increments of load were applied, four potentiometer type stroke transducers assessed the vertical deflection between the top and bottom plates. Signals for load and deflection were logged on a data acquisition system and written to file.

One pre-compressed straw bale assembly was vertically loaded before being rendered and loaded again after the render had been applied and cured.

2.2.2 Transverse Load: Air pressure simulating wind load was incrementally applied to the front surface by evacuating the space behind. The top plate and the bottom edge were restrained. The procedure is similar to the vertical chamber method specified in ASTM E&@. The transverse test pressure adopted was 2 kPa, which corresponds to a wind speed of approximately 58m/s.

Deflection transducers were set up in a similar fashion to procedure for the vertical load test to monitor in the specimen's net lateral deflection at mid height.

2.2.3 Racking Load: The racking procedure of ASTM E72 was followed whereby the specimen was restrained against translation at the bottom left corner, restrained against rotation about the bottom left corner by a vertical stop at the top right and subject to a horizontal concentrated load at the top right corner. The test racking loads were those of ASTM E 72; 3.5, 7.0 and 10.0 kN. Deflection transducers were set up to monitor in the specimen's deflection under racking.

2.2.4 Creep: The rendered, three bale high creep specimens were mounted on pedestals and loaded via a central steel rod passed through the middle which was attached to a lever and dead weights to reach 13kN. similar dead weights were applied to the second specimen.

The creep deflection over the 1200mm height was monitored in the centre of the back and front faces of each specimen by dial indicators and gauge rods. The test were commenced in November 1997-readings of creep deflection under constant load were taken at closer intervals initially to build up a picture of the specimen's creep behaviour. The tests were discontinued in February 1998.

3/. Results:

The results of tests carried out on wall specimens are summarised in Table 3.1. Figures 3.1 to 3.3 show load deflection curves for walls tested under vertical load, racking load and transverse wind pressure. The curves for vertical load plot the force exerted by one of two identical rams against deflection-the total force experienced by the wall is double the number plotted. Figure 3.4 shows a plot of creep deflection over time for the two creep specimens.

All three walls were loaded to failure by vertical load. In all cases an ultimate load was reached and a gradual displacement of the top plate into the render around the top course of straw bales ensued. The failure mechanism was progressive and predictable.

3.1 Vertical Load Results: Comparison of the vertical load/deflection curves for an un-rendered and rendered walls indicates that the walls become much stiffer with the addition of the render. The results suggest that it is the two 38mm thick render layers that are offering most of the resistance to vertical load.

The ultimate vertical loads on the three rendered walls varied from 20 to 24 kN/m expressed as uniformly distributed line loads. All three rendered walls showed a decrease in stiffness at loads about 30kN per jack or 11kN/m. The ultimate of about 35 kN per jack ensued after about 5mm of deflection.

Table 3.1 Summary of Tests and Results.

Test Type	*Max. Load Total (UDLL)*	*deflection (mm)*	*Comments*
Vertical	15kN (4.2kN/m)	66.0	Preliminary, on un-rendered wall C
Vertical	10kN	0.4	Preliminary, on rendered wall C
Racking	10kN	2.3	Racking load on wall C
Vertical	77kN (21.4kN/m)	4.5	Ultimate on wall C
Transverse	2.1kPa	5.5	Wall B, transverse by air pressure
Vertical	60kN (16.7kN/m)	6.0	Vertical on wall B
Racking	10kN	2.4	Wall B, racking
Vertical	74kN (20.6kN/m)		Ultimate vertical load on wall B
Transverse	2.5kPa	7.5	Wall A, transverse by wind pressure
Vertical	60kN (16.7kN/m)	5.0	Vertical on wall A
Vertical	80kN (23.6kN/m)	7.5	Ultimate vertical load on wall A

3.2 Racking Load: In both the racking tests carried out, the 10kN horizontal load at the top corner produced small deflections of slightly more than 2mm. The material's performance under racking load would be considered acceptable.

3.3 Transverse Load: The maximum static air pressure of 2.5kPa that was applied represents a significant wind of over 60m/s. Both walls tested showed small deflections of around 7mm. The walls would be considered acceptable for structural behaviour under wind load.

3.4 Creep Performance: The specimens three bales high have responded to the long-term load with a creep deflection of just over a millimetre. Over a full height wall a creep of about 3mm could be expected for a load resulting from a second storey wall above. While the tests show that most of the deflection is likely to occur within the first months after plastering and application of the dead loads, details, which allow for such movement will have to be used at joints in the structure such as junctions of walls and ceilings.

4 Conclusions:

The results suggest that rendered straw bale walls resist load as a sandwich panel in which the exterior render skins, reinforced with chicken wire, are the main load carrying elements-the thickness and quality of the render would need to be assured in practise. Under vertical load, the straw provides lateral restraint to the reinforced cement-render panels loaded in membrane compression. The failure mechanism is by local crushing of the top plate structure into the render skins and is predictable. It is important that the top plate detail be arranged to transfer loads into the wall's render panels rather than into the less stiff straw.

The creep specimens were loaded by a force that would be experienced in a wall of a two storey domestic house with timber floors of about 6 metre spans with a tiled roof. The creep deflections are significant and the results suggest that some intermediate load bearing elements within the lower walls would be appropriate if the construction is to be used for load bearing walls greater than a single storey.

Were the domestic construction to be confined to a single main storey with perhaps a loft space and a light metal roof, then these tests indicate that the material could be used in a design that would be acceptable for load bearing construction.

The results are summarised above and as soon as we get the time we will have the paper written and published, with photos, graphs and tables. We also hope to start moisture penetration tests as soon as we can afford it. We need moisture tests for the Building Code of Australia. In the mean time we will make sure that the designs of any straw bale houses that we build incorporate generous eaves and or verandahs. I hope that the above results are of some use to you.

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