STRAW BONDED SOLID PANELS – THE CONSTRUCTABILITY, THERMAL PERFORMANCE AND STRUCTURAL BEHAVIOUR

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Abstract: Straw bonded solid panels manufactured as boards with a thickness of 58 mm can be used for many applications such as internal partitions, floor boards, acoustic panels, ceiling, etc. However, there have been many issues related to the use of straw panels as a load bearing material for walls. This paper describes the details and results of a full scale load test carried out with straw bonded solid panels to assess the constructability, structural adequacy with short term loads and sustained loads. It also indicates the trends that can be expected with thermal performance.

1. Introduction

In Sri Lanka, the total amount of rice produced is 2.79 million metric tons in year 2009 [1]. This could increase to about 3.83 million metric tons by year 2020. Every ton of rice would produce 0.4 tons of straw. This straw may have many uses. Straw is considered as a very good organic material for restoring the soil quality. It can be used for manufacturing of paper. Many countries uses the readily available wheat straw which is renewable annually, to produce ethanol fuel as a cheap alternative to imported crude oil fuel. The use of straw for manufacturing of solid panels is another application practiced universally. A solid panel is shown in Figure 1. Figure 2 shows the dense arrangement of straw within the panel. The straw is placed in the transverse direction. Therefore, the panel can derive a considerable flexural strength in that direction and hence, it is advisable to support the panel at 1.2 m when used as a structural member carrying loads that can cause flexture.

Figure 1: A DURRA straw panel of 1.2 m width x 2.4 m length

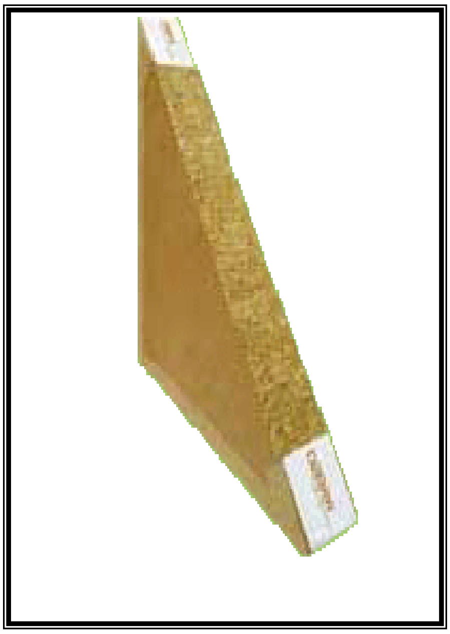

Figure 2: Cross section of a DURRA straw panel with straw arranged in the transverse direction

These panels show promise with cost competitiveness and robustness though it may have few durability related issues that should be addressed. If the data on structural performance is available, it would be possible to overcome durability related issues easily with suitable water proofing system.
Further the design trends of built environments slowly change in style, type, social acceptance, and principals that can be identified roughly based on decade by decade basis. In 70's it was energy efficient design and passive solar energy concepts. In early 80's with the higher cost of energy efficient built environment, it was more about modern designs. In 90's it was a re-interpret of successful older designs into more contemporary modern designs. In the first decade of the 21st century, it appears recycled or green built environment will be given priority (LEED's with U.S. Green Building Council USGBC) [2]. The designs that conserve energy and environmental may be appreciated. In this context, straw is sustainable, recyclable, and biodegradable.
This paper describes a full scale load test carried out using a model to assess the structural capacities and performance especially at ultimate limit state along with few specific issues that may need addressing with respect to constructability.

2. Objectives

The main objective of this research is to determine the structural capacity of straw bonded solid panels when used as load bearing wall panels and in floor systems while addressing the issues related to constructability and thermal performance.

3. Methodology

The following methodology was adopted:

1. The data available on the performance of solid straw panels determined using laboratory experiments were used to make an initial assessment of the performance.

2. A full scale model was created using solid straw panels consisting of load bearing walls and a floor system while addressing issues related to constructability.

3. This model was loaded with representative loading that can be expected in various practical applications to assess the performance.

4. The loads were sustained over longer periods to assess the long term creep induced deformation characteristics.

4. The straw bonded solid panels and the usage

These panels are manufactured with a thickness of 58 mm. The Durra technique combines extreme heat and compression in a unique dry extrusion process to form the solid panel core that is encapsulated with a high strength, water resistant, recyclable craft paper liner. No chemical binding agents, glues or resins are added during the panel core production. The width of the panel is generally maintained as (1187mm) 1.2 m. The length could be 2.4 m, 2.7 m, 3.0 m.
The weight of a panel of 2.4 m length and 1.2 m width is about 60 kg. This gives a density of 3.5 kN/ m^3. The surface density is 0.2 kN/m^2. Conventional masonry has a densityof about 20 kN/m^3. The panel shown in Figure 1 has a length of 2.4 m. In the panels, the straw is densely packed in the direction of width as shown in Figure 2. The production process is purely natural and does not use any chemical like formaldehyde. Hence, the panel poses sustainable characteristics such as low embodied energy levels per panel. It is about 5.0 MJ/m^2. It is also biodegradable after its productive life span. If two panels are used side by side, it would give a wall having an embedded energy of 10 MJ/m^2. This can be compared with the embodied energy of a typical brick wall with plaster. It is in the range of 500 - 700 MJ/m^2. Therefore a straw bonded wall with finishes could give much lower embedded energy which being a renewable resource. Another important property of straw bonded panels is the lower conductivity. In tropical climate conditions, the west facing wall could absorb considerable amount of heat especially in two storey houses. A straw bonded double panel of 116 mm thickness can give a U value of about 1.3 W/m^2K. Although U value may not be very significant in houses operated as free running, the significantly lower conductivity in the range of 0.1 W/mK [3] could transfer less heat inwards and hence facilitate much faster rate of structural cooling during the night time. The thermal conductivity of masonry would be about 0.8 W/mK [3]. Therefore, from the thermal performance point of view, walls formed with straw bonded panels could indicate a superior performance. For air conditioned built environments, it can have significant advantages.
Various desirable properties of straw bonded solid panels have been carried at as laboratory experiments (Department of Civil Engineering, University of Moratuwa Ref No CE/GA17/ST/2005/118, and National Building Research Organization NBRO/ENV/26201/2008/147(a) Industrial Technology Institute (ITI) report No CTS-7412, CS-11561). The extensive uses of these panels for many applications have given a significant level of exposure to its uses, strengths and weaknesses. Since, it indicates good promise as a load bearing walling material in addition to its ability to act as a floor panel, a full scale test was carried out to obtain further information on desirable structural characteristics and construction related issues.

5. The constructability

Straw bonded solid panels are manufactured to have a width of 1.2 m. Hence, when one panel is installed, it can cover an area of about 3 m^2. However, one of the key issues would be fixing two panels side by side to form a wall. Although it would be possible to create an effective joint at top and bottom, facilitating effective joint at the intermediate points over the height was a challenge. The generally adopted solution was the use of galvanized steel channels as shown in Figure 3. However, the cost of steel channels could be significant. Easthetically, it may indicate that the house would be different to conventional construction.
In order to improve the joint, two methods are available. One is to use a mechanical connection effected with timber pieces with a polymer modified cement grout. The polymer is expected to have shrinkage compensating characteristics. It can be considered as a wet joint. The other is to have a mechanical connection with staggered panels. This method was found to be economical than the wet joint. It also consumed less labour, less time and also facilitated a robust joint. The use of staggered panels ensured that one Dura panel was continuous when the other was having a joint. This effectively eliminated the chance of forming a crack after the completion of finishes. Thus, majority of the constructability issues could be addressed with the use of staggered double panels connected with mechanical connections.

Figure 3: Panels that have been fixed using galvanized steel channels in a site office

6. The structural behaviour

In order to determine the performance with respect to load bearing characteristics, a full scale model was constructed. The load test has been carried out up to a live load intensity of 5.0 kN/m^2.

6.1. The model

The model for load testing was created using straw based solid panels of 58 mm thickness that is adequately reinforced with another panel to prevent buckling induced failures. In order to apply loading, a floor has been created using straw panels where the timber joists of 125 mm depth x 75 mm width have been used at 1.2 m spacing to support the straw bonded solid panels. Special attention was placed on any local failure that could occur, especially due to the concentrated loads transferred through the timber joists on the straw panel used as a load bearing member. The model is shown in Figures 4 and 5. Figure 4 indicated the external view. Figure 5 indicates the floor system. It also indicates additional supports used prior to load testing to prevent any sudden collapse. Figure 6 indicates the loads applied on the model.

Figure 4: External view of the house model

Figure 5: Floor system of the house model

Figure 6: The model with loads

6.2. The application of loads

The loads were applied on to the floor slab in gradual increments shown Table 1 Since, the timber beams have already been designed for the expected loading, emphasis was placed on making as overall structural assessment for ultimate behavior rather than any serviceability failures. First the slab was loaded up to 2.5 kN/m^2. This is excess of 1.5 kN/mm^2 generally specified for houses [4]. This was to determine the behaviour with respect to adequacy of floor system. Then the load on the floor was increased up to 5 kN/m^2. This was intended to determine the performance of the walls when the upper floor is constructed. Under both these cases, the wall with a thickness of double boards withstood the loads with satisfactory behaviour. After loading the floor successfully up to a live load of 5 kN/m^2, it was retained to determine the long term load carrying characteristics along with assessing any creep induced problems for 60 days.

Table 1: The Loading increments for the loads applied on the floor of the model

Sequence of loading and timing	Loads applied on top of the floor board	Structural deformation observation
24th May 2010 -10:15- 12.45 pm	1,545 Kg	Stable, no deformation
25th May 2010 - 3:24 - 4:43 pm	873 Kg	Stable, no deformation
26th May 2010 -10:00 -11:45 pm	566 Kg	Stable, no deformation
Total Loaded	2,984 Kg	

6.3. The results

The load test carried out on the full scale model clearly indicated the ability of solid straw panels to withstand significant loads either of short term nature or sustained nature. A minor deformation was observed under the concentrated loads transferred through the floor joists as shown in Figure 7. When the floor load was increased up to 5 kN/m^2. However, this local failure occurred at a load that is well in excess of that would occur in a two storey house. It also occurred at a location where only one panel has been used to support the timber beam. Hence, it failure would not have any significance for a two storey house with a properly planned layout.

Figure 7: The localized failure suffered by the straw bonded solid panel

The full scale testing was backed by structural design calculations. Thus, it gave adequate confidence to venture into a new application for two storey houses where walls, slabs and roof could be constructed with solid straw panels to create a very robust structural system that could safely withstand any expected loads. The plan of the two storey house is given in Figure 8.

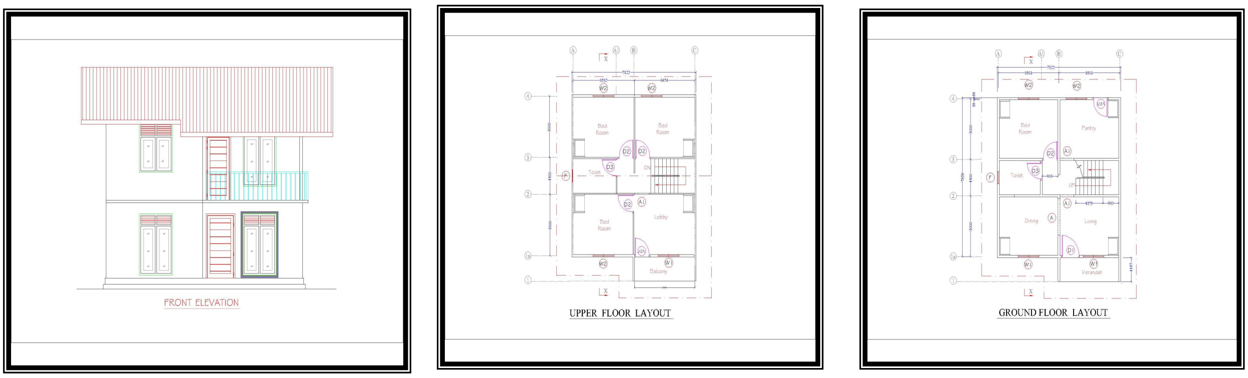

Figure 8: Plans of a two storey house

7. Conclusion

In order to determine the structural performance of a system of floors and load bearing walls constructed with solid straw panels, a load test was carried out on a full scale model. This load testing aimed primarily at determining the behavior at ultimate conditions shed light on many important issues that would need the attention of the structural engineer. With the confidence gained with this testing, the construction of a proto – type house has been undertaken and build as the project office for the engineers at the construction site of John Keels Chaaya Bay hotel at Beruwala Sri Lanka with the aim of gathering further information and experience on real time performance. Figures 9 and 10 are showing a proto –type building under construction at Chaaya Bay hotel at Beruwala.

Figure 9: Side view of the two storey house under construction at Chaaya Bay hotel at Beruwala

Figure 10: Front elevation of the two storey house under construction at Chaaya Bay hotel at Beruwala

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