ICSBE2016-256

COST EFFECTIVE BUILDING SYSTEMS FOR RAPID CONSTRUCTION IN TROPICAL CLIMATES

M.T.R. Jayasinghe*, K.K.G.K.D. Kariyawasam, C. Jayasinghe

Department of Civil Engineering; University of Moratuwa-Sri Lanka
**E-Mail: thishan@uom.lk*

Abstract: Over usage of natural resources for construction of buildings has caused many environmental problems. Hence mainstream requirements of building projects such as cost effectiveness and rapid construction should be achieved while ensuring that the impact on the environment is also minimum. In this context, it is beneficial to use recyclable or renewable materials as building elements. This paper describes a successful adoption of the combination of such systems in a rapid building construction project in Sri Lanka. The building envelope consists of two and three storied steel portal frames, walling system based on compressed straw panels, upper floor with precast concrete slab panels supported on a steel framework, ceiling made from compressed straw panels. The successful application of these systems indicates the possibility to adopt them in the future for rapid, cost effective and sustainable building construction.

Keywords: Straw panels, pre-cast, alternative materials, rapid construction, low cost construction

1. Introduction

One of the key contributing parameters for the total cost of a building is the labour component [1]. Therefore, the adoption of precast components, which could be manufactured under factory conditions and can be fitted with a minimum labour component at site, is suitable and cost effective [2]. Wall panels made out of compressed straw can be introduced as such a versatile material. Similarly, adoption of pre-stressed concrete can minimize the usage of reinforcement and concrete [3]. In the two storey buildings presented in the case study, the upper floor slab slabs were out of pre-tensioned concrete panels which resulted in a rapid construction. In the case of columns and beams, the use of hot rolled steel I beams made out of S275 or S355 steel [4] was explored to minimize the construction duration .

Further, the application of renewable materials such as straw in an effective manner has been highlighted along with the use of recyclable material such as hot rolled steel to minimize the construction duration. Another aspect highlighted is the minimization of the concrete volume required with the use of optimum sections made possible due to the effective use of pre-stressing technology. The use of precast panels as slabs reduced the construction time and labour requirement while eliminating the need for any shuttering. The pre-stressing slabs have been made continuous to control the vibration induced in thin slab panels.

This rapid construction technique was applied for 4 newly constructed buildings at the Negombo Base Hospital, Sri Lanka, where an urgent need for space was arisen due to an evacuation order placed on the existing main building owing to its deterioration.

2. Objectives

The objectives of this research are the following:

1. Developing a methodology for the introduction of innovative and cost effective building materials.
2. Application of such technology for large scale buildings and assess the possible challenges in the form of acceptance and confidence.

Fig. 01: Three completed buildings and fourth building under construction

3. Methodology

1. The research and development carried out for alternative building materials has been collected and the best combinations for rapid construction have been selected.
2. The alternative materials and building systems which were developed have been assessed for its feasibility in large scale projects.
3. The construction process and the methodology in the large scale buildings was recorded in daily basis to indicate the special techniques that should be adopted to ensure successful implementation of these alternative cost effective and durable building materials.

4. Alternative building materials and methods selected

Following alternative building materials and methods are adopted:

1. The use of compressed straw based panels as a walling material ceiling material.
2. The introduction of precast slab panels to behave as continuous panels thus assuring more robust behaviour that can dampen the vibrations induced by human activities.
3. The use of steel zinc alum galvanized sheets as an external walling material in conjunction with straw panels to give robust walling system that can resist earthquake and cyclone induced extreme forces.
4. A rapid construction method for the foundation that consists of a cellular raft combined with individual pad footings.

5. The details of the foundation

Since the soil condition was extremely weak at the site, it was decided to utilize a pad footing combined with cellular raft in this project to assure that the chances for any differential settlement is eliminated. One of the problems with weak soil is the collapse of soil when the excavation is carried out for pad footings. This problem was overcome by having a 300 mm thick laterite earth compacted fill laid over the existing soil as shown in Fig. 02. The pad footings have been placed on compacted quarry dust filling which allowed the pad footings to be cast above the water table.

Fig. 02: A pad foundation and the laterite earth compacted filling

The presence of thick, strong and dry layer of laterite soil prevented the chances for soil collapsing when the mechanical excavator was used for the excavation of pits of 1. 2 m x 1.2 m. Once the concrete of the pad footings and stub column is hardened, the soil has been filled up to the soffit level of the ground slab after fixing a shuttering around the column.

Cellular raft foundation could be cost effective and robust provided it could be cast with minimum amount of labour and almost eliminating the shuttering. To minimize the construction time, the excavations for the trenches needed for the ground beams was carried out using the bucket of a mechanical excavator. Once the excavation of such trenches is complete, thick polythene was laid in the trenches to act as the shuttering [5]. The reinforcement is laid for the beams after removing the shuttering placed around the columns. For the ground slab, thick polythene was laid on the compacted earth fill and 2 layers of prefabricated mesh of 6 mm diameter at 150mm centres can be laid as top and bottom reinforcement of the slab. Additional reinforcement also can be provided in the middle strips of the slabs if necessary. A timber shuttering was used only to mark the outer periphery of the cellular raft. Concrete of C30 strength was pumped over the whole floor starting from one corner by using a pump car and a large foundation of 15 m x 42 m could be completed in 2-3 days. The use of this method minimized the labour requirement and also reduced the cost. This cellular raft foundation combined with pad footings was not only cost effective but was robust and can minimize the chances for any differential settlements.

6. The use of strong and innovative wall cladding system

The two-storey building under consideration (Fig. 03) has a length of 42m and a width of 15m. Two such buildings had to be completed within one month to facilitate occupation within a short period. To meet this target, the foundations have been constructed rapidly as described above. In order to minimize the construction duration to meet the above target, hot-rolled sections have been selected to form the two-storey portal frame. Fig. 03 shows the two-storey portal frame where the span at the first floor level was limited to 7.5 m by having a column at the centre. This column allowed the use of 400 x 200 x 56.6 kg/m hot rolled section as a beam to support the pre-cast concrete slabs of the upper floor.

For the walls, it was decided to use a frame as shown in Fig. 04 consisting of galvanized cold-formed C channels of 2mm thickness and 100 mm width. The external cladding was mounted directly on this steel framework. The interior was out of 58 mm thick compressed straw panels (Durra). This gave an overall thickness of about 120 mm for the external wall.

Fig. 03: Two storey portal frame structure

Fig. 04: The steel frame used for mounting the wall cladding

The compressed straw panels are provided with a heavy-duty craft paper as shown in Fig. 05. It is a very good thermal and acoustic insulation material. Since the building was intended to be a hospital building, where the walls could be washed from time to time, an additional protection was given to the straw panels by using fibre based cement sheets (asbestos free) which is generally known as flexi sheets. The flexi sheet does not absorb much water and when provided with water based emulsion paints or enamel paints or water proofing in-situ formed membranes, can give an ideal interior surface. Since the panels of size 1.2m x 2.4m are mounted on the steel frame, it formed a strong wall that has an aesthetically pleasing finish. The boards were connected to the steel frame by using screws.

Fig. 05: Completed wall with flexi board mounted compressed straw panels

One of the key needs with these new systems is paying attention to the detail. In this context the mere usage of zinc alum sheets and flexi sheet mounted durra panels alone would not be sufficient. Therefore, all the joints between the steel frames, the windows, etc. that can allow some moisture into walls have been carefully sealed with high quality silicon sealers to assure that Durra panel walls will remain as dry as possible hence assuring a longer life span for the straw panels. It should be noted that the straw panels are manufactured by using naturally forming paddy straw that is found in abundance in Sri Lanka. The straw processed at 1000C with stream to squeeze out natural enzymes to form a very dense but still light weight and fire resistant building material that comes as 1.2mx 2.4m sheets of 50mm and 58 mm thicknesses covered by water resistant craft paper. Hence these straw panels can be considered as a material with almost zero carbon footprint and hence an ideal material for sustainable construction when it is strengthened in both axial loads and flexure. Fig. 05 shows a completed wall that has given an attractive interior with a good finish.

7. The innovative ceiling systems with enhanced cyclone resistance

The roof of the rapidly constructed building consisted of zinc alum sheets. These sheets have been mounted on 150mmx 65mm x 16mm C channels arranged on the portal frames spaced at 6m intervals. The C channels have been arranged at 1.2 m intervals. This facilitated the use of 1.2m x1.2 m straw panels as a ceiling that can be supported on the lower flange of the C channel. A 65mm x 25mm L angle was used to assure proper support for Durra panels. These have been covered with recycled thick polythene to ensure that moisture will not attack the craft paper of durra panels. Durra panels were tested for strength according to ASTM D 2164 -83[6]. The special feature of Durra panels is its strength in flexure [7]. In addition it can provide a very significant level of thermal insulation and acoustic insulation thus the combination of C channels and durra panels supported on extra L angles formed an ideal ceiling (Fig. 06) that could be completed in less than 2 days for these massive buildings.

Fig. 06: Innovative ceiling system

The very high thermal resistance of durra panels assured very low heat flow inwards and hence this massive building with high headroom were able to provide a free running space using the cross ventilation provided by the large number of sliding windows that facilitated ample ventilation during both day time and night time.

8. The concrete floors

The use of cellular raft foundation combined with isolated pad footings formed an ideal solution for the ground slab. The upper floor slab consisted of 90mm thick pre-tensioned panels of 1.0m width. In order to fix these panels to the portal frame 3 numbers of 25 mm diameter GI tubes have been kept at the ends of the panel to facilitate reaching the steel girders. This is to weld steel reinforcement to the girder for additional fixing of the panel. Once the pre-cast panel was placed on the steel frame, a 10mm reinforcement was welded to the steel girders using each hole created by the 25 mm diameter GI tubes and then the reinforcement was bent to fix the panel firmly to the steel frame. This will assure that the concrete panels will not fall from the steel frame in case of an earthquake. Once fixed properly, the gap between two adjacent panels at the ends have been sealed with non-shrinking construction grout thus forming a continuous concrete over the steel beams. Additional reinforcement was placed to provide continuity. Then a 40mm screed was placed on the pre- cast concrete panels. Prior to placing the screed, a vehicle jack of 5 ton capacity was used to assure that all the concrete soffits will have the same deflection (camber) so that a smooth soft could be obtained for the pre-tensioned slabs. This was achieved by placing an adjustable jack under the precast panels (Fig. 06) so that adjacent panels will have the same deflection. These props have been kept until the screed concrete gained adequate strength. This assured that part of the dead load also carried as a continuous load.

Fig. 07: The concrete slab system

For electrical wiring, it was possible to place 20mm conduits over the concrete slab panels and then place the 6mm welded mesh above it. Thus, the amount of reinforcement need in the concrete slab was minimized substantially while gaining a final slab thickness of only 140mm for a span of 6.0 m.

In order to assure continuity, 10mm diameter bars have been placed at 150mm centres over the steel beam extending 2.0m to the span on either side as shown in Fig.07. This reinforcement provided the hogging action needed to behave as a continuous slab. This behaviour is essential to reduce the vibration tendency of the thin slab. The 90mm thick precast panels constructed this way gave very good service while assuring that the floor will have adequate strength.

Fig. 07: Slab system with reinforcement

9. The need for attention to detail with alternative building materials

In a rapidly constructed building system, it is essential to deal with panels rather than individual bricks or blocks. The materials used also could be different such as the use of straw panels instead of bricks and blocks. Therefore, durability and constructability related issues will need extra alteration. The following points could be highlighted:

1. The straw panels used for the ceiling and the walls have very good thermal properties and strength. However, it is to be protected from moisture since moisture could make straw to soften. Therefore, when straw panels are used for a ceiling, it is advisable to cover it individually with polythene to assure additional protection.
2. The side facing the interior of the building could be kept with craft paper or it could be covered with a flexi sheet. In this building, the more durable flexi-sheet mounted panels have been used. The advantage is that once painted, the surface exposed will give a uniform appearance which can be better than the appearance that can be obtained with craft paper.
3. The straw panels for the walls also needed adequate protection. This was achieved by using flexi-sheet mounted straw panels for the walls to give an overall protection on the front side.
4. At the windows, the opening was provided with an additional U-channel made with 0.75 mm Zinc- Alum sheets. This is to assure that the interior of the wall with a cavity will not be accessible for any moisture. When the panels have been made with a steel structure, there can be many minor gaps that can allow ingress of moisture inwards. All such surfaces have been sealed with silicone sealer to ensure that the ingress of moisture is totally prevented wherever it could occur.
5. The concrete used for the precast panels was Grade 50. In order to assure a sufficient durability, a cement with 15% fly ash was used to enhance the imperviousness of the surface zones thus ensuring a better resistance to attacks by elements such as chlorides and sulphates.

The above discussion indicates that the rapidly constructed buildings that will have the components provided as panels instead of individual units will need special attention especially when rapidly renewable materials like straw panels have been used with recyclable materials like steel that was used to form in low carbon footprint building.

10. Conclusion

Rapidly constructed buildings would need the supply of components as precast or prefabricated items. The provision of such components for rapid assembly will need attention to details to realize a building of acceptable quality. The case study demonstrated in this paper presents the successful application of straw based compressed wall and ceiling panels, precast concrete slab panels and steel framework for a rapid construction of high quality buildings.

The cellular raft foundation introduced with least amount of shuttering has reduced the labour requirement and material cost. The use of hot rolled steel sections as a two/three storied portal frame, Durra panelled walls and the innovative slab system has lowered the time spent on construction while assuring cost effectiveness. However, each of these elements need high level of attention to detail for the successful construction.

References

[1]. Cunningham, T. (2013). *Factors Affecting The Cost of Building Work - An Overview.* Dublin : Dublin Institute of Technology.

[2]. Chan, T. (2011). Comparison of precast construction costs – case studies in Australia and Malaysia. *Procs 27th Annual ARCOM Conference* (pp. 3-12). Bristol,UK: Association of Researchers in Construction Management.

[3]. Hewson, N. (2003). *Prestressed Concrete Bridges: Design and Construction.* London,UK: Thomas Telford Publishing.

[4]. BS EN 10025 : part 2. (2004). *Technical delivery conditions for non-alloy structural steels.* European standards.

[5]. Abdelgader, H., West, M., & Górski, J. (2008). State-of-the-art report on fabric formwork. In Proceedings of the International Conference on Construction and Building Technology, Kuala Lumpur, Malaysia.

[6]. Jayasinghe C., "Testing of dura panels for strength properties", Report submitted to International Construction Consortium (pvt) Ltd., 2006.

[7]. Jayakody, S., Kondadeniya, M., & Jayasinghe, M. T. R. Straw bonded solid panels as a walling material – A two storey house with "Dura", *International Conference on Sustainable Built Environment*, (pp. 115-123). Kandy,Sri Lanka, 2010.