SUSTAINABLE, RAPID AND AFFORDABLE MASS HOUSING USING ‘GFRG’ PANELS

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Abstract—The construction of building systems using Glass Fibre Reinforced Gypsum (GFRG) panels is a very promising and emerging building technology. Huge housing shortage in countries like India invites innovative solutions that are not only sustainable, affordable and of good quality, but which also facilitate rapid construction. Based on extensive research carried out at IIT Madras for more than a decade, this technology has been demonstrated by constructing around 300 buildings in India. GFRG buildings can completely avoid cement plastering, and uses much less quantities of steel, cement sand and water compared to conventional buildings. GFRG buildings consume much less embodied energy (less carbon footprint) and recycles industrial waste gypsum, contributing to sustainable development. Design and construction aspects of GFRG buildings are presented in this paper.

Index Terms—GFRG Panels, walls, GFRG-RC slabs, affordable mass housing, shear strength, P-M interaction curves.

I. INTRODUCTION

Glass Fibre Reinforced Gypsum (GFRG) panels are new building materials that are suitable for rapid mass-scale building construction. GFRG panels are made essentially of high quality gypsum plaster (beta plaster), reinforced with glass fibre rovings and special additives. This product was originally developed and used since 1990 in Australia by Rapidwall Building Systems [1]. Presently, these panels are manufactured in a few Asian countries like India, China, Saudi Arabia and Oman. In Australia, several buildings had been built using the Rapidwall technology, but the use of the panels were restricted to walls, resisting gravity loads. The floors were made of conventional reinforced concrete slabs. Since 2003, the IITM research team has been engaged in extensive research on extending the use of these panels as structural members for all components of the building, including floor slabs and staircases, thereby it reduces the consumption of Reinforced Concrete (RC) significantly. Furthermore, a detailed design methodology has been developed for the entire building system, including earthquake and wind resistant design. The design and construction of each structural component of the GFRG building system is briefly discussed in this paper.

GFRG panels are qualified for carbon credits by the World Bank under Kyoto protocol [2] and certified as green building material by The United Nations Framework on Climate Change (UNFCC) [3].

II. GFRG PANELS: DIMENSIONS AND MECHANICAL PROPERTIES

GFRG panel are manufactured to a standard size of 12.0 m length, 3.0 m height and 124 mm thick, with modular cavities, as shown in Fig. 1. These cellular cavities are formed between outer skins (flanges), 15 mm thick, and interconnecting ribs, 20 mm thick, at 250 mm spacing. Each one metre length of GFRG panel has four such cavities of size 230 mm length and 94 mm wide, as shown in Fig. 2.

The mechanical properties of GFRG panels, for both empty panels and panels filled with M20 concrete in all cavities are given in Table I, based on tests.
conducted at IIT Madras.

Table I: GFRG Panels: Mechanical properties

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Mechanical Property</th>
<th>Characteristic Value</th>
</tr>
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<tbody>
<tr>
<td>i</td>
<td>Unit weight</td>
<td>0.43 kN/m²</td>
</tr>
<tr>
<td>ii</td>
<td>Uni-axial compressive strength</td>
<td>160 kN/m (empty panel)</td>
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<tr>
<td></td>
<td></td>
<td>1310 kN/m (filled panel)</td>
</tr>
<tr>
<td>iii</td>
<td>Ultimate shear strength</td>
<td>21.6 kN/m (empty panel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61.0 kN/m (filled panel)</td>
</tr>
<tr>
<td>iv</td>
<td>Water absorption</td>
<td>1% in 1 hour, 3.85% in 24 hours*</td>
</tr>
<tr>
<td>v</td>
<td>Fire resistance</td>
<td>2.30 hour rating (empty panel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 hour rating (filled panel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- withstood 900-1000°C</td>
</tr>
<tr>
<td>vi</td>
<td>Coefficient of thermal expansion</td>
<td>12 x 10⁻⁶ mm/mm/°C</td>
</tr>
</tbody>
</table>

* Current GFRG panel’s water absorption is less than 2 percentage weight with improved formulation

III. APPLICATIONS AND ADVANTAGES

GFRG building panels are generally used in the following ways:

a) As load bearing walls in buildings, to resist gravity load;
b) As partition or infill walls in multi-storeyed framed RC structures;
c) As compound walls in combination with minimum quantity of concrete;
d) As shear walls, to resist both gravity load and lateral load from earthquakes and wind; also as walls of lift-well and parapet walls;
e) As floor slabs / roof slabs, pitched roof slabs and also as staircase waist slabs and mid-landing slabs;

GFRG building system has following advantages over conventional building systems:
i) High speed of construction;
ii) More carpet area for the same built-up area: thickness of wall panels is only 124mm;
iii) Less embodied energy and carbon footprint [2]: significant reduction in use of steel, cement, sand and water; recycling of industrial waste gypsum;
iv) Less cost of construction: savings in materials; no cement plastering;
v) Less building weight (panels weigh only 44 kg/m²), thereby reduction in design for seismic forces and savings in foundation, especially in multi-storeyed buildings;
vi) 8 to 10 storeyed buildings can be designed using GFRG panels, without the need of conventional RC beams and columns;
vii) Very good finishes of GFRG buildings: use of factory made panels for all the walls, floors and staircases;
viii) Less CO₂ emission compared to other conventional building materials [2];
ix) Better thermal comfort inside GFRG building compared to conventional buildings.

IV. DESIGN AND CONSTRUCTION OF GFRG BUILDINGS

GFRG buildings are designed as load bearing systems. Hence, all the walls have to be started from the foundation or plinth beam till the terrace. Ideally, the same floor plan has to be replicated for all floors in multi-storey buildings. Buildings can be designed up to ten storeys in low seismic zones, using GFRG panels (and to lesser height in high seismic zones), without conventional columns and beams. In this building system, the foundation is conventional, while the entire structural elements in super structure is constructed using GFRG panels. Limit states design procedures are used for the design of GFRG buildings, considering the ultimate limit state for strength design, as well as serviceability requirements. The partial safety factors for reinforcing steel and the GFRG panel (with and without concrete infill) is taken as γₚ = 1.15 and γₚ₁ = 1.50 respectively, as recommended in IS 456: 2000 [4]. Earthquake resistant design is carried out in compliance with the requirements of international codes (in India IS 1893 (Part 1): 2002), where the response reduction factor (R) is taken as 3.0 for seismic load calculations [1],[5].

Proper preparation of ‘cutting drawings’ (in which the window and door openings are marked) is equally important in addition to structural drawings, for proper construction of the GFRG building. The cutting drawings shall be prepared in such a way that the number of joints and the wastage of cut panels are minimum.

The construction of GFRG building is different from the conventional method. It requires special type of equipment, tools and tackles such as appropriate crane for loading, unloading and erecting the panels, lifting jaws and spreader bar for lifting the panels and adjustable later props for supporting wall panels after erection. The design and construction of important structural elements are summarised in the following sections.

V. DESIGN AND CONSTRUCTION OF FOUNDATION

The conventional type of foundations are used in GFRG building constructions. The foundation is designed base on the safe bearing capacity of soil and soil profile at the particular site and the number of storeys of the structure. Generally, strip footing is used, as the superstructure consists of load bearing walls. Simple masonry spread footings are sufficient for low rise GFRG building, with a network of reinforced concrete (RC) plinth beams on top, above which the GFRG wall panels can be placed. ‘Starter bars’ have to be inserted in the plinth beams, at the
locations (Fig.3), where the cavities of the panel are to be filled with RC, with appropriate lap length in accordance with national codes. This ensures connection of the superstructure with the foundation, spread over the entire wall length over the network of plinth beams. If the foundation is deep, properly designed reinforced concrete pedestals can be used to support RC plinth beams, with small isolated footings (Fig. 3). For taller GFRG buildings, reinforced concrete walls may be provided to support the plinth beams, with appropriate strip or raft footing below.

A network of RC plinth beams has to be constructed as per the structural design drawings and the top has to be at a perfectly horizontal level. A layer of damp proof course over the RC plinth beam is mandatory in order to avoid the possible absorption of water by glass fibres in the GFRG panels through capillary suction.

VI. DESIGN AND CONSTRUCTION OF GFRG WALLS

The GFRG walls are designed to resist axial force (P) from gravity loads, lateral in-plane shear force (V) and in-plane bending moment (M) from wind and seismic loads. The in-plane bending capacity of the walls depends on its length, the reinforcement provided, as well as the level of axial load and lateral shear. The design in-plane bending capacity (M_{ed}) and its relationship with the design axial load capacity (P_{ed}) is usually described by means of a P_{ed} - M_{ed} interaction diagram. The values of M_{ed} and in-plane shear strength increase with the length of the wall [6]. However, experimental studies of GFRG panels subjected to lateral loading have shown that failure is initiated by vertical cracking caused by shear failure of the GFRG [1],[6],[7]. For all practical purposes, the in-plane bending capacity is limited by the corresponding shear capacity. Longer shear walls tend to attract larger lateral loads and will form vertical shear cracks in the middle region, causing a further redistribution of forces, and possible further vertical shear cracking.

Design interaction curves are developed for various length of GFRG panels (from 1.0m to 3.5m wide panels with an intervals of 0.25m), reinforced with M20 concrete and two reinforcement bars in each cavity [5]. A typical design P-M interaction curve for 2.0 m length panel is given in Fig. 4.

Based on the structural requirements and the design interaction curves, the interval of concrete infilling and size of reinforcement to be provided in walls are decided. The cavities in the GFRG wall panels shall be filled, wherever structurally required, with concrete of grade not less than M20, using aggregate of size less than 12mm. For low rise GFRG buildings (up to three storeys), no need structural requirement to infill all cavities with reinforced concrete, although it is desirable to fill all cavities with plain concrete or quarry dust with cement, in view of public perception of safety against intrusion, and also facilitate nailing, drilling, fastening of non-structural components etc. Reinforcing bars may be provided where required, but in no case, more than three adjoining cavities shall remain unreinforced. Single bar reinforcement of suitable diameter (not less than 8mm), may be used in such low-rise buildings.

The GFRG panels can be installed quickly using cranes (Fig. 5). Lifting jaws and spreader bar are to be used to lift the GFRG panel safely. It is advisable to erect panel without removing door/ window cut pieces from the panel. This will keep the panel in balance and help to locate the centre of gravity of wall panel. Once the panel is brought in position, the plumb and level are to be checked. Adjustable lateral props are used to fix the GFRG wall panels as show in Fig. 5. These props can be removed once the panels are in-filled with concrete and gain sufficient lateral stability.

The slump of concrete shall be 70mm +/- 20mm and water cement ratio shall be 0.50 to 0.55 to in fill of cavities of wall panel. First pour of concrete is to be of maximum 300 mm high from base of cavities. After 2 hrs for allowing initial set of 1st pour of concrete, 2nd pour of concrete up to window sill level shall be done. Simultaneously, the cavities which are not structurally required to be in-filled with concrete shall be in-filled with lean concrete or quarry dust mixed with cement (dry) in stages. All the electrical conduits and plumbing lines can be laid through cavities now. It is mandatory to provide RC embedded lintels over
openings for doors and windows, exceeding 1.2 m in width. 3rd pour of concrete shall be done up to window/door top (2.1m high) and 4th pour up to bottom of horizontal tie beam. This tie beam shall be done on top of walls, all around just below roof slabs.

**Fig. 5** Wall panel being installed using crane, wall panels supported by lateral props

**Fig. 6** Insertion of reinforcement and concreting of lintel cum sunshade (cast-in-situ), concreting of wall panels

**VII. DESIGN AND CONSTRUCTION OF GFRG – RC FLOOR/ROOF SLAB**

GFRG panels, with ribs aligned in the direction of bending, can be designed as a one-way slab system, with the cavities suitably reinforced, as shown in Fig.7. GFRG-RC slab systems can be used efficiently in floor slabs and roof slabs. The ribs should be oriented along the shorter span, supported on GFRG wall panels. RC concealed beams, provided by filling cavities at regular intervals (typically, every third cavity or every alternate cavity, if required) and suitably reinforced, combined with a screed concrete of thickness not less than 50 mm, as shown in Fig.7, provide a flanged-beam action. For roof slab, minimum thickness of screed to be 60mm. One way slab action is assumed for deflection and strength check, considering T beam action of the embedded beams. The screed concrete shall be reinforced with suitable welded wire fabric (of required gauge and spacing), to avoid thermal and shrinkage cracks. Suitable cover blocks at 750mm spacing on both directions to be provided to keep weld mesh reinforcement in correct level. The design of reinforcement in the concealed beams shall conform to the requirements of national codes.

**Fig. 7** Typical cross-section of GFRG-RC slab (with concealed RC beams)

For installation of slab panels, provide a suitable support system (acrospans) with adjustable vertical props. The acrospans are aligned perpendicular to the ribs direction. The panels are then lifted horizontally means of by means of spreader bars attached with soft slings. Place the floor slab panels in position over the support system, with a minimum of 40 mm bearing on all supporting walls.

**Fig. 8** Placing of roof panels over support system

**Fig. 9** Concreting of roof slab panels

The top skin/ flange of the panel shall be cut open, typically at every third cavity (as per the drawing), by leaving minimum 25 mm flange on either side protruded to serve as the key to concealed RC “T” beam. The reinforcement cage of concealed reinforced concrete beams, tied and prepared in advance, are placed inside the open cavities. Simultaneously, service cables and pipes are also laid. Side shuttering are provided throughout the perimeter of the floor slab before concreting. Roll a welded mesh (Fe 250) of 10 gauges at a spacing of 100 mm x 100 mm over the entire slab and with 25 mm effective cover from the slab top. After this, concreting can be done with minimum grade of M25 and maximum size of
aggregate is 12 mm.

VIII. STAIRCASE

GFRG panels can be used for the construction of staircase waist slabs. All the top flanges of panels shall be cut open and reinforcement cage is to be inserted. This can be concreted after providing appropriate support. The steps can be constructed with either concrete or bricks as shown in Fig. 10.

IX. GFRG BUILDINGS IN ASIAN COUNTRIES

A 2-storeyed GFRG building was constructed inside IIT Madras campus to demonstrate GFRG technology developed. The total built-up area of this building is 1981 sq.ft, shown Fig. 11. This model house apartment, houses four flats (two for the Economically Weaker Section of carpet area of 269 sqft each and two for the Lower Income Group of carpet area of 497 sqft each), which can be replicated for mass housing, horizontally and vertically. The entire building was completed in 30 days. The use of prefabricated light weight GFRG panels for the entire building system facilitated substantial reduction in building self-weight, construction time and workforce requirement. So far, more than 300 buildings are constructed in India, most of them are individual residential buildings. This panels can be used not only for residential buildings, but also for industrial and institutional buildings. This building system gains popularity in few Asian counties also like in Oman, China, Saudi Arabia, etc. Buildings from few Asian countries are shown in Fig. 12.

SUMMARY

GFRG panels can be effectively used for the entire superstructure of a buildings, including all walls, slabs, staircases, parapets, etc. This building system has many advantages over conventional buildings. GFRG buildings have the potential to meet the challenge of providing rapid affordable mass housing. This is an eco-friendly and sustainable building system, making use of recycled industrial waste gypsum or natural gypsum and minimising the use of cement, steel, sand, water and labour input. This technology is now gaining acceptance in India and other Asian countries.

REFERENCES