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Rapid Affordable Mass Housing using Glass Fibre Reinforced Gypsum (GFRG) Panels

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I. INTRODUCTION

GFRG panels are building panels suitable for affordable mass housing, with the advantages of cost-effectiveness and rapid construction. These panels are made out of gypsum, largely available in India in the form of phospho-gypsum, a waste by-product of the fertilizer industries. These panels are currently manufactured to a size of 12m length, 3m height and 124mm thickness, at FACT, Kochi and RCF, Mumbai.GFRG panels contain cellular cavities between the outer flanges and the inner ribs (refer Fig. 1), which can conveniently be filled with concrete and reinforced with steel bars, if required, to achieve the desired capacity as load-bearing walls.

Buildings built using this technology (without any columns and beams) can go all the way up to 8 to

10 storeys in low to moderate seismic zones, and to lesser height in high seismic zones. The empty cavities in the panels can be used for concealing electrical wiring and other plumbing works. In a typical building, all components, including walls, slabs, staircases, and even parapet walls can be constructed using GFRG. This technology also has the added advantages of sustainability and energy efficiency because of the recycling of a waste product and also due to significantly less consumption of energy intensive or scarce materials, such as cement, steel, sand and water.IIT Madras has been involved in the research and development of this technology for the past twelve years. GFRG was approved as a building material

suitable for construction by BMTPC (Building Materials & Technology Promotion Council, Government of India), and the joint effort by BMTPC & IIT Madras has resulted in the development of a '*GFRG Design Manual*', for the structural design of these buildings.

A. Mechanical Properties

The following table provides some of the important mechanical properties of GFRG building panel (for both unfilled panels and panels filled with concrete), which have been determined from tests conducted at IIT Madras.

TABLE 1. MECHANICAL PROPERTIES OF GFRG BUILDING PANEL

Mechanical Property	**Nominal Value**
Unit weight	44kg/m^2
Modulus of elasticity	7500 N/mm^2
Uni-axial compressive strength, P_{uc} (tests on small sized panels)	160 kN/m (unfilled) 1310 kN/m (filled)
Ultimate shear strength, V_{uc}	21.6 kN/m 61 kN/m (filled)

B. Design Philosophy

The design capacities are based on limit states design procedures, considering the ultimate limit state for strength design,satisfying the serviceability requirements.

The partial safety factors for the GFRG building panel (with and without concrete infill) and reinforcing steel is taken as γ_m **= 1.50** and γ_s **= 1.15** respectively**,** as recommended in IS 456 : 2000.

Earthquake resistant design is carried out in compliance with the requirements of IS 1893 (Part 1) : 2002, where the response reduction factor (*R*) is taken as 3.0 for seismic load calculations.

C. Axial Load Capacity

The axial load capacity of GFRG building panel (under compression) has been assessed taking into consideration possible eccentricities in loading, taking into account the minimum eccentricity values as specified in IS 456: 2000 and IS 1905: 1987. The characteristic values of axial compressive strength of the GFRG building panel, expressed in kN/m, are obtained from compression test results on GFRG building panel for full height panel, subject to various eccentricities of loading (20 mm, 30 mm and 45 mm) and different boundary conditions. For design purposes, the nominal values have been divided by γ_m **= 1.5**. Axial load capacity can be calculated as follows:

$P_{ud} = (68 - 0.9e)$,for unfilled panels, and $P_{ud} = (600 - 13.75e)$,for filled panels,

Out-of-Plane Bending Capacity

D. Unfilled GFRG Panels

Higher bending capacity is obtained when the ribs are oriented parallel to the span, and is as shown in table below:

TABLE 2.OUT-OF-PLANE DESIGN FLEXURAL CAPACITY OF UNFILLED GFRG PANEL

	Ribs parallel to span	**Ribs perpendicular to span**
Design Moment Capacity, M_{ud}	1.4 kNm/m	0.59 kNm/m

E. Filled GFRG Panels

When the cavities are filled with concrete, full composite action of GFRG and concrete cannot be mobilized on account of bond slip at the interface. A conservative estimate of the moment capacity can be arrived at by ignoring the contribution of GFRG and considering the action of the concrete beams occupying the cellular cavities. Accordingly, the design moment capacity is obtained as, M_{ud} = 2.83 kNm/m.

F. Shear Strength

The unit shear strength capacity of the 124 mm thick, 3.0 m high GFRGpanel is given in table below:

TABLE 3.SHEAR STRENGTH OF GFRG PANEL AS VERTICAL WALLS

Application	**Design Shear Capacity, V_{ud} (kN/m)**
Unfilled GFRG panel	14.4
GFRG panel filled with 20 MPa concrete	40.0
GFRG panel partially filled with 20 MPa concrete	14.4 + 25.4η, (η is the ratio of no. of infilled cavities to total no. of cavities)

G. In-plane Bending Capacity

GFRG panels can be used not only as load bearing walls, but also as walls transferring lateral loads, resisting axial force (*P*), lateral in-plane shear force (*V*) and in-plane bending moment (*M*). The design in-plane bending capacity (M_{ud}) and its relationship with the design axial load capacity (P_{ud}) is usually described by means of a P_{ud} - M_{ud} interaction diagram.

Design interaction curves of such panels fully infilled with reinforced concrete (with two reinforcement bars in each cavity) for 1.0m to 3.5m with intervals of 0.25mhave been developed. A typical P-M interaction curve is as shown in Fig. 2.

H. Design of Floor / Roof Slab

As GFRG panels with ribs aligned in direction of bending possess flexure, such panels can be used as flexural slab, whose strength can be significantly enhanced by embedding 'concealed beams', filled with reinforced concrete (Fig. 3). Unfilled GFRG panels can be used as pitched roofs for single storey small span buildings.The ribs are to be oriented along the shorter span, supported on GFRG wall panels. For convenience in design, the contribution of GFRG towards the flexural strength can be ignored and the GFRG can be treated as lost formwork. Reinforced concrete concealed beams are to be provided by filling cavities at regular intervals (typically every third cavity) and provided with reinforcement suitably designed, with a screed concrete of thickness not less than 50 mm. One way slab action may be assumed for strength and deflection check, considering T-beam action of the embedded beams. In the screed concrete, suitable welded wire fabric shall be provided. The design of reinforcement in the micro beams shall conform to the requirements of IS 456: 2000.

I. Demonstration of technology

Inorder to demonstrate this technology, a two-storeyed GFRG demo building was built inside the IIT Madras campus is shown in Fig.4. This building, constructed within a span of 30 days housing a total area of 1981 sq.ft., has 4 flats, two having a carpet area of 269 sq.ft meant for the EWS (economically weaker section), and the other two with 497sq.ft carpet area each meant for the LIG. The saving in cost was almost 35%, when compared to conventional construction.

References

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[3] GFRG/RAPIDWALL Building Structural Design Manual, prepared by Structural Engineering Division, Department of Civil Engineering, IIT Madras, 2012.

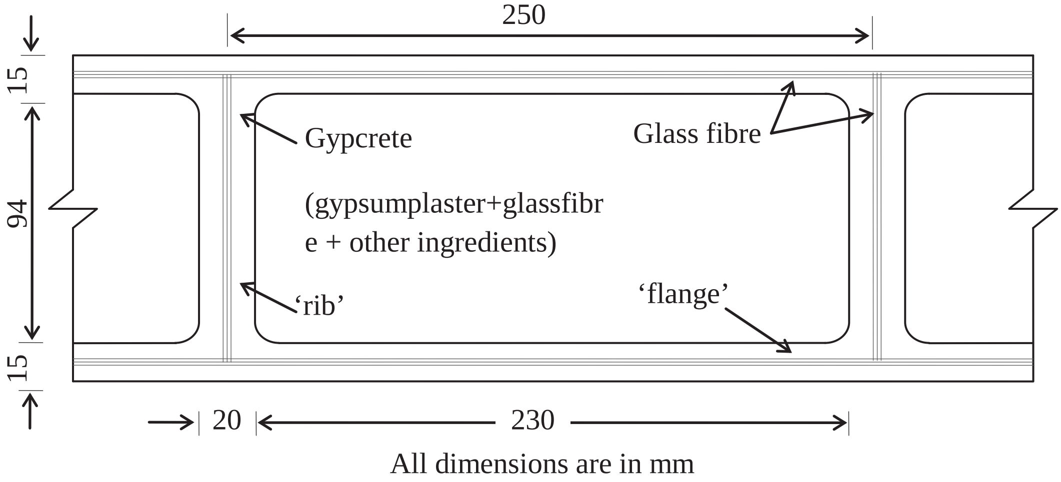

Fig. 1. Enlarged view of a typical cell of GFRG panel

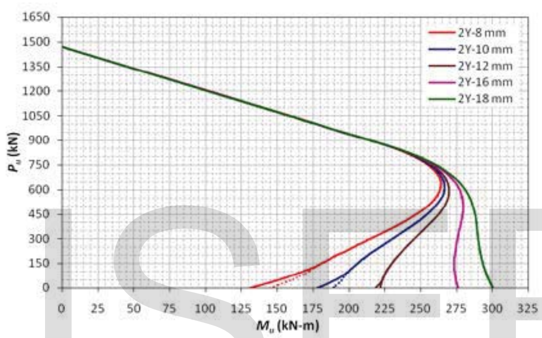

Fig. 2.Design P_u-M_u plots for 1.50 m wide GFRG panel with M25 concrete infill

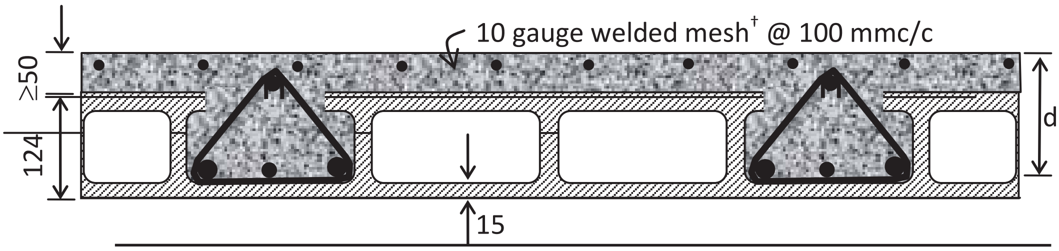

Fig. 3.Typical cross-section of panel with micro beams

Fig. 4. GFRG demo building at IIT Madras campus