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Behaviour of Glass Fibre Reinforced Gypsum panels as Walls: An Update on the Recent Research Developments

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Abstract

The current housing shortage problem in the country, especially among the low-income groups and the necessity to address their shelter needs, led to the introduction of Glass fibre reinforced gypsum (GFRG) panels in India. These panels were originally developed in Australia in 1990 and later introduced in India, China, Hong Kong and other countries. They are light-weight, load-bearing walls used for rapid construction of affordable and eco-friendly houses (individual units to multi-storeyed buildings) and are being used in India for more than a decade. These are prefabricated in controlled-conditions in factories, from gypsum plaster reinforced with glass fibres along with certain special additives and are available in a fixed size of 12 m length, 3 m height and 124 mm thickness. The panels are hollow, with cavities of size, 230 × 94 mm, aligned along the height. These panels can resist axial, in-plane and out-of-plane loads and various studies conducted worldwide established the suitability of the panel for the construction of walls, slabs, staircases and parapet walls. GFRG buildings consist of GFRG panels as walls and slabs (without any beams and columns) and can be constructed up to 5-8 storeys in low to moderate seismic zones, and lesser height in higher seismic zones. Thus to properly understand the structural behaviour of the GFRG building system and to develop a proper design guideline, comprehensive research works were undertaken in India and other countries which includes the study to determine the various material and structural properties of the panel and this paper presents a critical review of the experimental and theoretical investigations on the structural behaviour of GFRG wall panels.

Keywords: GFRG panel, axial load, out-of-plane bending, lateral load behaviour, cyclic load

1. Introduction

The Glass Fibre Reinforced Gypsum (GFRG) panels are light-weight, load-bearing walls used for rapid construction of affordable and eco-friendly houses (individual units to multi-storeyed buildings) and are being used in India for more than a decade. These are prefabricated in controlled-conditions in factories, from gypsum plaster (a by-product from the fertilizer industries) reinforced with glass fibres (chopped) along with certain special additives and are available in a fixed size of 12 m length, 3 m height and 124 mm thickness. The panels are hollow, with cavities of size, 230 × 94 mm (formed between 20 mm thick ribs and 15 mm thick flanges), aligned along the height [1] as in Fig. 1.

These panels were originally developed in Australia in 1990 and later introduced in India, China, Hong Kong and other countries. In a developing country like India, GFRG (with the key advantages of, light-weight construction - advantageous in earthquake-resistant design, sustainable construction - reduced use of steel and concrete, increased carpet area - thin wall panels, improved thermal comfort - saving in operational energy, etc.) is of great significance due to the tremendous need for large-scale affordable housing. These panels can be used for the construction of walls, slabs, staircases and parapet walls.

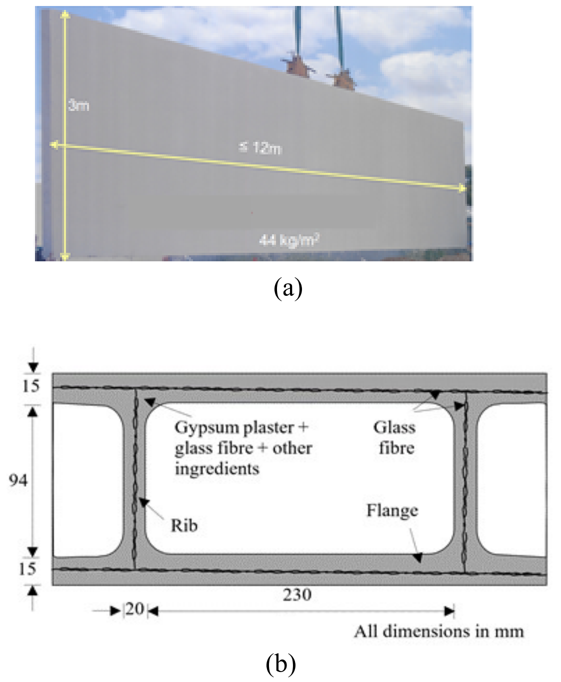

Fig. 1. GFRG panel: (a) Elevation, (b) Cross-section

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The structural behaviour of the GFRG walls and buildings is complex compared to the conventional system. This is due to the development of a composite action as a result of the interaction between GFRG and the concrete when the cavities of the panel are filled with reinforced concrete [2]. Therefore, the well-established conventional structural theories and design procedure do not apply to the GFRG buildings. Thus to properly understand the structural behaviour of the GFRG building system and to develop proper design guideline comprehensive research works has been undertaken, which includes the study to determine the various material and structural properties of the panel. This paper discusses various studies conducted on GFRG wall and slab panels.

2. Material Properties

The physical and mechanical properties of the GFRG panel were obtained based on various tests con-ducted in Australia and China [2–7]. Compression test on GFRG blocks (520×250×120 mm) and tension test on GFRG flanges (as the tension failure is more likely on flanges) were performed at IIT Madras [8], and thus the stress-strain curve under axial tension and compression were determined. The ultimate shear stress was obtained by performing four-point loading test on a specimen of size 1100×270×120 mm [8] and the results are as in Table 1.

The GFRG panels can be used as walls, where the cavities are either left unfilled or filled with plain or reinforced concrete to improve its load-carrying capacity and ductility. GFRG, as a load-bearing structural member is capable of resisting axial load (P), lateral shear (V) and in-plane bending (M_i) and out-of-plane bending (M_o). Various studies conducted on GFRG wall panel are summarised below.

3. Experimental Study

3.1. Axial and eccentric compressive strength

The axial and eccentric compressive strength of unfilled and concrete-filled (plain or reinforced concrete with one 12 mm bar) GFRG panel (1.02 m wide, 2.85 m high and 120 mm thick) was determined experimentally [7], and it was found that all the unfilled panels failed by local crushing near the sup-ports, and no significant out-of-plane bending occurs when subjected to axial load. All the concrete-filled specimens failed by buckling and flexural tensile breaking. For both ends pinned specimen, failure occurred at the mid-span and for one end pinned and other end fixed specimen, failure was near to the pinned support (Fig. 2). Thus it was observed that the failure load depends on eccentricity and the sup-port conditions, and not on the strength of concrete and reinforcing bar in the cavities [2,7]. Similar observations were also made based on the experimental studies conducted at IIT Madras [8]. A signifi-cant increase in the load-carrying capacity was observed when the panels were infilled with concrete and it was also observed that the provision of rebars does not contribute to the strength enhancement.

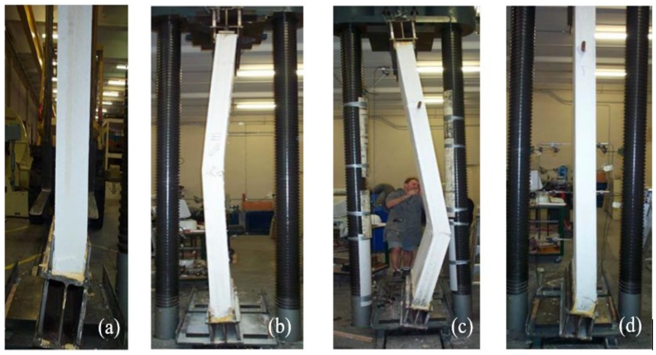

Fig. 2. Failure modes of axially loaded GFRG panel, (a) unfilled panel, (b) both ends pinned concrete-filled panel, (c) and (d) one end pinned and other end fixed concrete-filled panel [9]

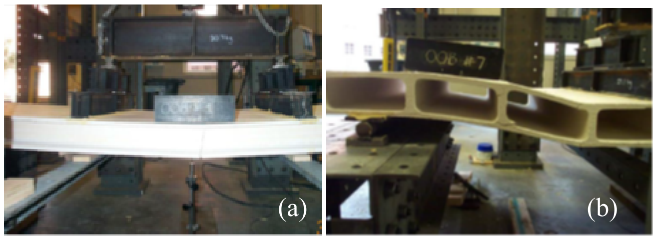

Fig. 3. Failure modes for out-of-plane bending of the panel: (a) Ribs parallel to the span, (b) Ribs perpendicular to the span [9].

3.2 Out-of-plane bending strength

The out-of-plane behaviour of the GFRG panel (predominant when it is used as a slab to resist gravity load or wall to resist wind pressure) with the ribs parallel and perpendicular to the span (Fig. 3) was studied experimentally [9]. In the unfilled and concrete-filled panels with the ribs parallel to the span, tension cracking was observed at the panel bottom confirming flexural failure. For the unfilled panels with ribs perpendicular to the span, failure occurred by the crushing of the web (shear deformation).

3.3 Shear strength

Unfilled and concrete-filled GFRG panels subjected to lateral load was studied experimentally [2,3,7] to determine the failure modes and factors affecting shear strength. Unfilled panels (1.5 m and 2 m wide) develop diagonal cracks initially (Fig. 4(a)) and failure occurs by compression crushing of plaster in the compression zones (Fig. 4(b)). In concrete-filled panels - 1.5 m wide, with starter bar alone, failure occurs by the tensile breaking of the panel just above the starter bar (due to the discontinuity of the bar) (Fig. 4(c)). For concrete-filled panels - 2 m wide, with starter bars alone and 1.5 m wide, with full-length rebars, 45° shear cracks occur before the peak load and longitudinal shear cracks occur at the peak load (Fig. 4(d)). Thus the panels with this type of configuration develop full shear strength.

The lateral load behaviour of unfilled and concrete-filled GFRG panels (1.02m wide) with one and two rebars

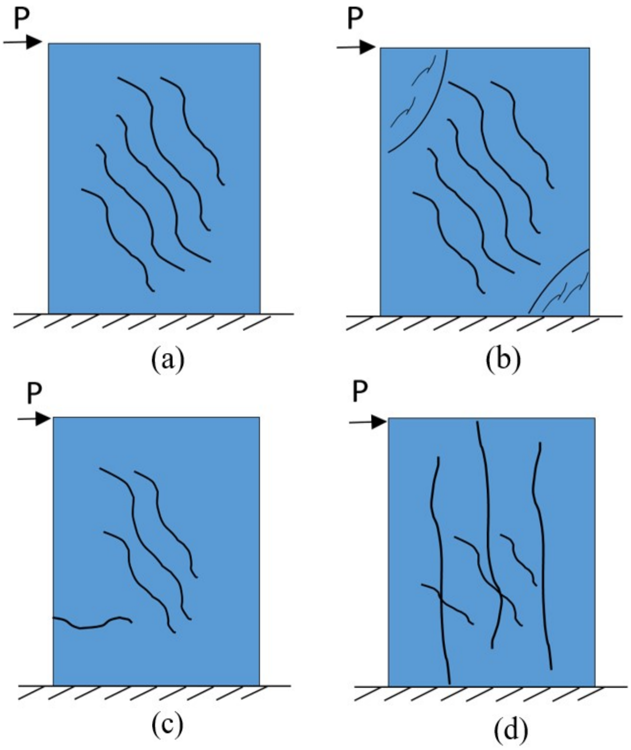

Fig. 4. Various failure modes in a GFRG panel subjected to shear: (a) Diagonal cracking in unfilled panel, (b) End crushing in unfilled panel, (c) Tensile breaking in concrete-filled panels with starter bars, (d) Longitudinal cracking in concrete-filled panels.

was studied [8], and it was observed that panels with one rebar failed in flexure and those with two rebars failed in shear. Cyclic behaviour of RC filled GFRG panels subjected to both in-plane lateral load and constant axial load was studied [10,11], to understand various performance parameters like strength, stiffness, ductility and energy dissipating capacity. 1.02 m wide and 2.02 m wide panels with two rebars in each cavity were studied to investigate the effect of door openings [10], and 3m wide panels were studied to understand the effect of a) two rebars in each cavity and b) provision of tie-beam / tie connection at the wall top [11]. It was observed that the panels exhibited ductile behaviour without any premature failure and thus the RC filled GFRG panels can also be used as shear walls in earth-quake-prone areas. The GFRG-OGS building system is a combination of RC beam-column framed structure (with solid RC slab) in the ground storey and GFRG wall-slab system for the above storeys. The performance evaluation of GFRG-OGS building system, with combined gravity and lateral load was carried out experimentally [12], and it was concluded that the gravity loads are transferred from the walls to the columns by the arching mechanism and thus the beams are subjected to only very less force.

4. Theoretical Study

The ultimate strength of the unfilled, concrete-filled and RC filled GFRG wall panels subjected to axial, eccentric and lateral loads were determined theoretically (using the traditional methods like Euler's theory, Rankine's theory, Reduced modulus theory and Tangent modulus theory for axially loaded specimens, and Secant modulus theory for eccentrically loaded specimens) and from the finite element analysis (FEM) methods [8]. Comparison of the analytical results with the experimental results showed that the traditional methods overestimated the ultimate strength and thus modified methods which incorporate the effect of nonlinearity was proposed and was found to give more accurate results [8,13]. From the lateral load test results, P-M interaction curves were developed, which can be used for the structural design of GFRG shear walls. For laterally loaded panels, an increase in strength was observed due to an increase in reinforcement as well as due to increase in axial load. It was also observed that the lateral load stiffness of the shear wall has two components, in which the flexural component is predominant in narrow walls and shear component is predominant in wide walls [8].

A suitable hysteretic model [14] (as suggested by Ibarra et al. [15]) for the RC filled GFRG panel which considers pinching and cyclic deterioration in the experimental results is identified and calibrated to match the experimental responses up to 80% of the peak load. It was observed that the energy dissipation and pinching parameters obtained for various specimens were the same.

Based on the experimental and theoretical studies on the lateral load behaviour of unfilled and concrete-filled GFRG panels, factors affecting the shear strength of the GFRG wall panels are summarized as below:

a) Concrete strength: Inspection of the exposed concrete core gave an insight that the longitudinal cracks are due to the tearing of the panel skin alone. Thus the shear strength of the GFRG panel depends only on the strength of the panel and not on the grade of concrete and reinforcement. Thus partial filling of cavities (Fig 5(a)) can be adopted and the number of cavities to be filled depends on the strength requirements [2–4,16]
b) Reinforcement bar: Shear strength of GFRG walls is not affected by the longitudinal rebars. Two types of wall to floor connections are used. In the type-one connection, only starter bars are used and in the type-two connection, longitudinal reinforcements are used along with the starter bars, ensuring the continuity of longitudinal bars along the height of the wall. From the study on the effect of the continuity of longitudinal reinforcement at the wall to floor joint [6], it was observed that type-one connection is acceptable for low rise GFRG buildings where the failure is governed by shear strength and not by the flexural strength. For walls with significant flexural deformation, the continuity of the longitudinal rebars is necessary for the tensile resistance of the wall and the overall stability and integrity of the building [2]. It was also observed that the number of rebars (one or two) in each cavity, do not have a significant effect on the shear strength or stiffness. But the provision of two rebars helps to sustain the load in the post-peak region and thus ensures more ductile behaviour [11].
c) Axial load: The shear resistance of an RC wall increases with axial load, but the shear resistance of a GFRG wall depends on the interface property [3]. If the interface is smooth, then the axial load does not affect the shear

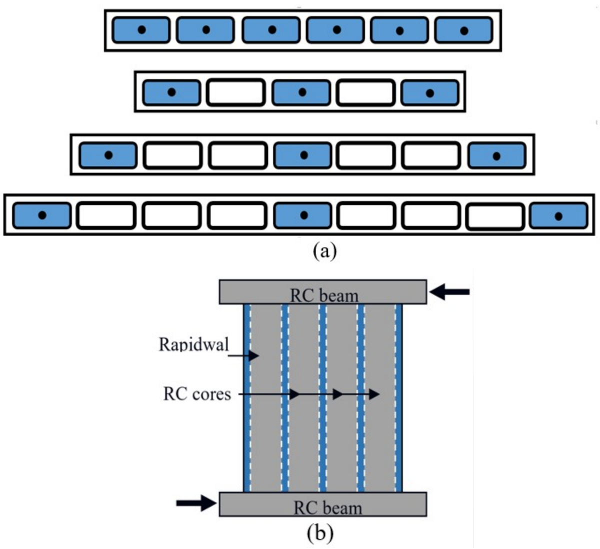

Fig. 5. (a) Various arrangements for filling cavities in a GFRG panel, (b) Concrete-filled GFRG panels with RC beam at top and bottom

resistance, whereas, axial load affects the shear resistance in the case of a rough interface. In actual practice, the effect of axial load on shear strength is usually neglected to have a conservative design.

d) Internal frame action: Internal frame action exists when floor beams are provided and are cast monolithically with the internal RC cores (Fig. 5(b)). Then the total shear strength of the GFRG walls includes the shear resistance of the GFRG panel as well as the lateral resistance of the RC frame.

5. Large Scale Testing

Large-scale shake table tests on full-scale two-storeyed (one storey model plus weight on top) GFRG buildings have been undertaken at Structural Engineering Research Centre (SERC), Chennai with two different plan and three different infill configurations (Fig. 8(a)). Excellent seismic performance and suitability of GFRG buildings up to two storeys in seismic zone V were established from the study [18].

A destructive test was done on a full-scale five-story GFRG building (Fig. 8(b)) at Shandong Construction University, China [20]. Visible structural cracks were not found when a cyclic lateral load equivalent to a zone 8 earthquake in the Chinese seismic code (100 tons) was applied. At small defor-mations, flexural type deformation and at large deformations, a combination of flexural and shear type was observed. The evaluation of the performance of the GFRG building system was done by performing an in-plane cyclic lateral load test on a system unit which represents a typical room of an 8 storeyed GFRG building [21]. System unit comprises of a floor slab with in-plane walls on either side (out of plane strength contribution of the walls are neglected) as in (Fig. 8(c)). This test aimed to evaluate the performance of the connections, system ductility and modes of failure.

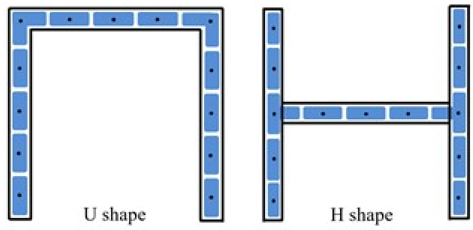

Fig. 6. Shake table test configuration

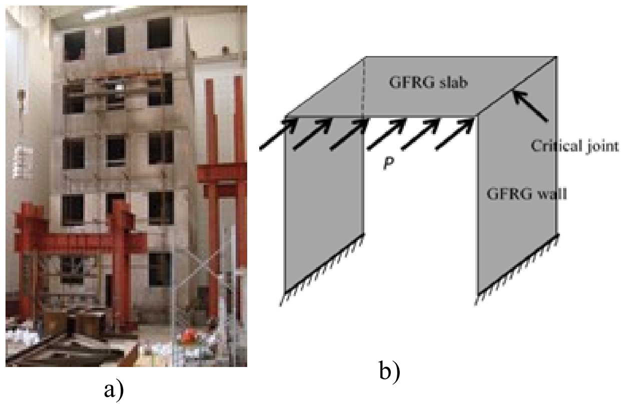

Fig. 7. (a) Five storeyed building under test at China [19], (b) System unit test setup [11].

Some other minor studies were also conducted on these panels. Lintels above the doors and window openings of GFRG walls can be constructed by removing the ribs on the top of openings and filling reinforced concrete into the hollow cavities of the wall. The flexural and shear behaviour of the GFRG composite lintel was studied experimentally [5] and it was found that the conventional flexural design theory for RC beams can be used for GFRG lintels, by considering the concrete cross-section alone and ignoring the GFRG panel.

Durability and sustainability studies [11] – 1) test for the bursting pressure of the panel, 2) expo-sure of the panel towards marine atmosphere, normal and acid rain, 3) biological study on algae and fungal resistance, 4) joint sealant test for doors and windows and 5) studies on indoor thermal perfor-mance, were carried out and the GFRG panel was found to perform well under these extreme exposure conditions. For demonstrating the GFRG technology and the construction of GFRG buildings a two-storey GFRG demonstration building was constructed at IIT Madras [17,21].

6. Conclusions

GFRG panels were used originally in Australia as load-bearing walls to resisting gravity loads and the slabs were made of reinforced concrete. From the studies conducted in India, an earthquake-resistant design procedure for the use of GFRG panels for buildings in different seismic zones of the country was developed. GFRG panels with embedded micro-beams and RC screed can be used as floor/roof slabs and thus the suitability of constructing walls, slabs, staircases, and parapet walls using GFRG is well established. From various studies, the properties obtained are given in Table 1.

Based on these studies at IIT Madras, GFRG has been approved as a building material suitable for construction of buildings in India up to 10 storeys by BMTPC (Building Materials Technology Promotion Council), and the following manuals were published for adoption in practice:

1. GFRG / Rapidwall Building Structural Design Manual [1]
2. Manual on waterproofing of GFRG / Rapidwall Buildings [22]
3. Schedule of Items and Rate analysis for GFRG Construction [23]
4. Manual on Construction of GFRG / Rapidwall Buildings [24]
5. A BIS code on the specifications, design and construction of GFRG buildings [25,26]

These guidelines can be used by architects, structural engineers and construction engineers on the design and construction of GFRG buildings. GFRG panels can also be used advantageously as infills in RC framed buildings without any restriction on the number of storeys and thus ensures faster and economic construction.

Table-1. Mechanical properties of GFRG panel

Property	Nominal value
Unit weight	0.44 kN/m^2
Elastic Modulus	4000 - 7500 MPa
Poisson's ratio	0.15 – 0.23
Uni-axial tensile strength (on flange)	35 kN/m
Uni-axial compressive strength	160 kN/m (unfilled)
	1310 kN/m (filled*)
Ultimate shear strength	21.6 kN/m (unfilled)
	61 kN/m (filled*)
Out of plane bending capacity	2.1 kNm/m (ribs parallel to span)
	0.88 kNm/m (ribs perpendicular to span)
Water absorption	1% in 1 h, 5% in 24 h
	2.3 h rating (unfilled)
Fire resistance	2.3 h rating (unfilled)
	4 h rating (filled*) - withstood 900 –1000 °C
Co-efficient of thermal expansion	12 x 10^{-6} mm/mm/ °C
Thermal resistance	0.36 m^2K/W (unfilled)
Sound transmission class	28 (unfilled)
	45 (filled*)

* filled with M20 concrete

Disclosures

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