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The structural behavior and design methodology for a new building system consisting of glass fiber reinforced gypsum panels

Y.-F. Wu *

Department of Building and Construction, City University of Hong Kong, Tat Chee Avenue, Hong Kong

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ABSTRACT

Glass fiber reinforced gypsum (GFRG) walls are prefabricated large gypsum panels with hollow cores. Developed in Australia in the early 1990s and subsequently adopted by other countries, including China and India, this material is used in residential, commercial, and industrial buildings. GFRG walls are used both architecturally and structurally as walls and slabs, with no columns and beams required. They have already found wide application, even without mature structural design codes, largely because of their environmental friendliness. In India, GFRG walls have been approved by the World Bank as being eligible for Carbon Credits under the Kyoto Protocol. GFRG panels are a composite material consisting of gypsum plaster and glass fibers. When the cavities are filled with reinforced concrete, the interaction between the concrete and the GFRG panels produces another composite. As a result, the structural behavior of GFRG walls and the associated building system are more complicated than that of conventional structural systems. This paper presents the results of extensive experimental and theoretical investigations into the structural behavior of GFRG walls, and offers a structural design methodology for GFRG walls and the associated building system.

1. Introduction

Known as Rapidwall in the building industry, glass fiber reinforced gypsum (GFRG) walls were developed in Australia in the early 1990s. GFRG walls are hollow machined panels made of modified gypsum plaster and reinforced with cut glass fiber. A typical panel and GFRG building is shown in Fig. 1. During the manufacturing process, glass fibers of about 300–350 mm in length are randomly distributed inside the panel skins and in the ribs. The fiber volume in the panel is about 0.8 kg per square meter of wall surface area. The physical properties of standard GFRG panels are listed in Table 1.

In building construction, standard large GFRG panels are tailor-cut in the factory into building components that may have window and door openings. These components are then transported to the construction site and erected in a similar way to the construction of precast concrete panels. The cavities (hollow cores) inside the panel can be filled with various materials, such as concrete or insulation materials, to serve different purposes, such as to increase the strength or improve the thermal and sound insulation of the walls. In a GFRG building, most or all the components are constructed with GFRG panels, which means that the walls serve as a combination of architectural partitions and structural walls. Research has shown that GFRG building assemblies have a smaller embodied energy (EE) coefficient and CO_2 gas emission (from the manufacturing of panels to the completion of building construction) than other traditional building construction materials, such as bricks, reinforced concrete, and precast concrete panels [1]. GFRG paneling is thus considered to be a green product that helps to save energy and protect the environment.

GFRG buildings are a new type of construction to which conventional structural theories and design codes are not applicable. Therefore, extensive research work has been undertaken by the author, both in Australia and Hong Kong, to gain a better understanding of the structural behavior of GFRG walls and the associated building system with a view to developing design guidelines. A comprehensive investigation that included about 120 experimental tests and theoretical studies was completed at the University of Adelaide and the University of South Australia in 2002 [2], and structural design theories and guidelines were developed based on this investigation [3–7].

Large-scale experimental tests, similar to those conducted in Australia, have also been undertaken in India at the Indian Institute of Technology Madras [8,9]. The Indian tests also included six full-scale shake table model tests simulating two-story houses [10]. In China, large-scale experimental tests similar to those in Australia and India have been completed at Tianjin University [11–14] and Shandong Construction University [15,16]. A full-scale five-story GFRG building was constructed for a destructive test at Shandong

* Tel.: +852 27844259; fax: +852 27887612.
E-mail address: yfwu00@cityu.edu.hk.

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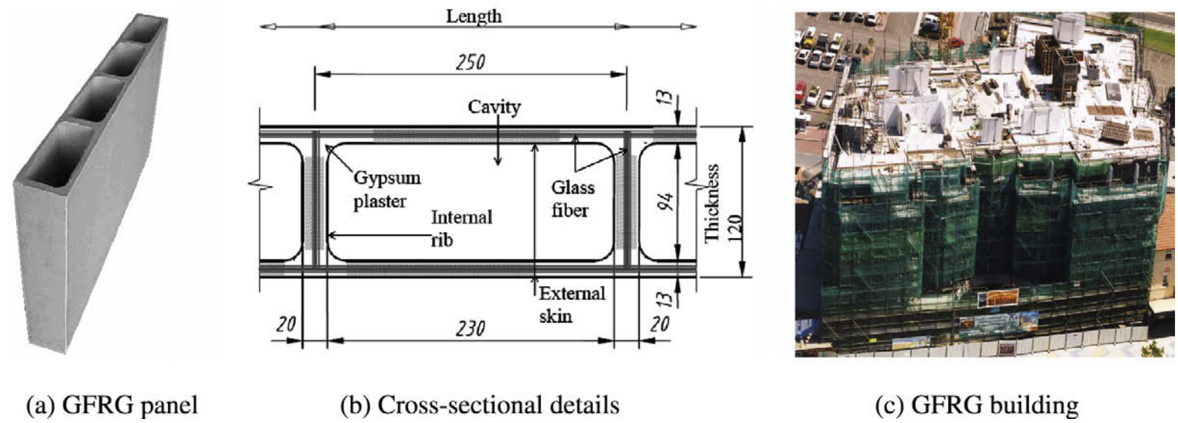

Fig. 1. GFRG panel and building.

Construction University [17], and an in-situ, non-destructive dynamic test was conducted on a recently built six-story GFRG building in Tianjin [12]. These Chinese tests were part of a combined Australian-Chinese test program aiming to develop Chinese design guidelines for GFRG construction.

This paper reports experimental and theoretical studies on GFRG walls and associated structural system undertaken by the author in Australia and Hong Kong since 2002. It should be noted that the experimental results for the axial and shear testing of GFRG walls have been published separately, but for completeness the results of the two tests are briefly introduced in this paper.

2. GFRG building system

2.1. Structural integrity and robustness

With infill reinforced concrete in their cavities, GFRG walls have significant axial and shear strength, and are suitable for the construction of multi-story buildings. GFRG buildings are similar to constructions with precast concrete wall panels. As the main structural issue for construction with precast concrete wall panels is making adequate connections between the precast units, it is believed that GFRG buildings suffer a similar problem.

The typical horizontal joints between two GFRG walls and the vertical joint between the walls and a slab are shown in Fig. 2a and b, respectively. It is clear that the joints are significantly weaker than the wall itself, and it is this inherent weakness of the joints that has caused serious concern about the seismic performance of GFRG buildings, as the seismic design principle of "strong columns, weak beams, and stronger joints" is usually applied to GFRG buildings, especially in mainland China.

In fact, the GFRG structural system is very different from the conventional rigid frame structural system that must abide by the "strong columns, weak beams, and stronger joints" principle. Indeed, in the typical structural form of GFRG buildings, as illustrated in Fig. 3, the horizontal joints and the out-of-plane resistance of the vertical joints can be completely ignored. Obviously, the structural system is stable and sound as long as the walls and joints have sufficient in-plane axial, flexural, and shear strength. Although the GFRG panels stop at the floor joints, which reduces the out-of-plane flexural resistance of the walls, this reduction in strength does not affect the overall stability of the system, as the whole structure relies only on the in-plane resistance of the walls. The joints only provide axial and shear resistances, which are virtually unaffected by the discontinuity of the GFRG panels. The infill concrete cores inside the GFRG panels and the slabs are monolithically cast in-situ, as with reinforced concrete constructions. Furthermore, the continuous reinforcement bars inside the concrete cores of the GFRG walls and slabs form a strong, closely spaced, and continuous tie system like a net, which avoids the weak connections found in constructions with precast concrete walls and forms a highly robust structure. The typical failure mode of progressive collapse for precast wall constructions is unlikely to occur in GFRG buildings, as long as the reinforcing bars inside the concrete cores of the GFRG walls satisfy the requirement of the minimum tie strength specified by the relevant reinforced concrete design codes.

Several strong earthquakes in the past have demonstrated that the in-field seismic performance of properly designed precast con-

Table 1
Physical and mechanical properties of GFRG panels.

Property name	Value	Note
Unit weight	40 kg/m^2	
Thermal expansion coefficient	12×10^{-6} mm/mm/°C	
Water absorption	<5%	By weight after 24 h immersion
Thermal resistance	0.36 m^2 K/W	Unfilled panel
	1.63 m^2 K/W	With 35 kg/m^3 and R2.5 rockwool batts infill and standard texture finishing
Sound transmission coefficient (STC)	28	Unfilled panel
	45	Concrete-filled panel
Fire resistance level (FRL)	>3 h	For structural adequacy
Young's modulus	3–5 GPa	
Compressive strength	167 kN/m	
Tensile strength	36 kN/m	

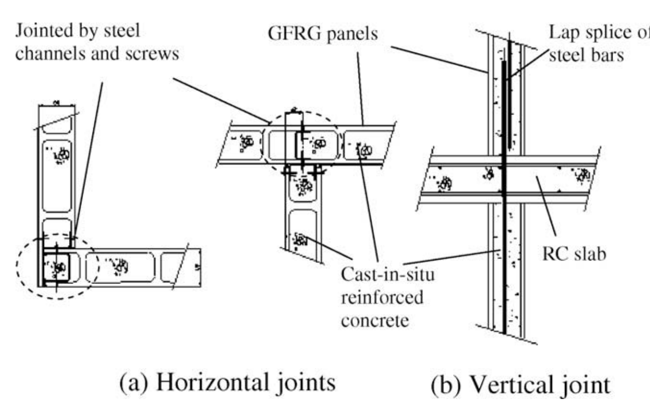

Fig. 2. Typical joints.