A Review of Research on Building System Using Glass Fiber Reinforced Gypsum Wall Panels

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Abstract – *This review paper summarizes and reviews developments in the field of building systems using glass fiber reinforced gypsum panels. GFRG panels, manufactured in standardized parts or sections ready for rapid assembling and erection as buildings, are ready-made gypsum panels with hollow cavities. This Rapidwall is utilized in residential as well as commercial constructed dwellings. GFRG walls are used both architecturally and structurally as walls and slabs, with no columns and beams needed. It has now found large utilization, even without use of sophisticated codes of structural design, to a great extent because of their environmental friendly behavior. GFRG panels are a composite material consisting of calcined gypsum plaster and glass fiber (a slender filament). When the hollow cavities of GFRG panels are filled with reinforced self-compacting concrete, the bond between the concrete and the GFRG panels yields another composite. As a result, the structural performance of Rapidwall and the related building systems are more sophisticated than that of other conventional building systems. In this paper, we review the important research issues and the state of the art, emphasizing recent significant advances and discussing considerable experimental and theoretical analysis into the structural performance of GFRG walls and providing a structural design procedure for rapidwall building system. It also comprises of the study of response of lengthwise or longitudinal reinforcement on periodic or cyclic shear behavior of GFRG panels and its durability.*

Key Words: Composite material; Rapidwall; Building; Gypsum; Glass fibers; Design; Shear behavior

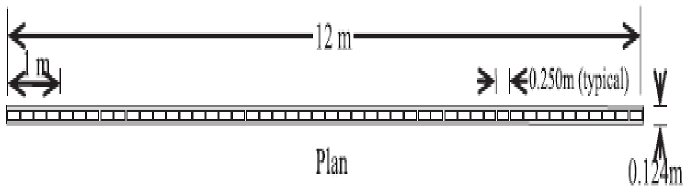
1. INTRODUCTION

Glass fiber reinforced gypsum (GFRG) walls, also known as Rapidwall in the constructed dwelling industry, are new building materials firstly manufactured in Australia in the early 1990s. GFRG panels/Rapidwall are ready-made gypsum panels with hollow cavities and are made of calcined gypsum plaster and reinforced with cut glass fibers (a slender filament). Glass fiber reinforced gypsum (GFRG) panel is a green product ready for quick assembly and erection as buildings. Fundamental analysis and utilization of GFRG panels has been carried in India, Australia, and China. Rapidwall could be used in low buildings as load-bearing walls and in low-rise buildings or as upper storey walls in a high-rise building when filled with self-compacting concrete in the hollow cavities. The application of GFRG wall is finite for its impoverished sideways rigidity even though it is filled with concrete in its hollow cavities. Discovering a unique way to intensify this disadvantage (its sideways rigidity) to make it relevant for the small high-rise residential building is a beneficial choice for analysts.

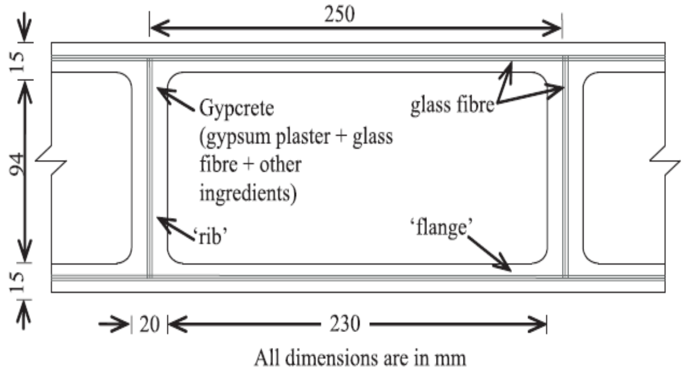
A regular cross-section and enlarged view of a typical GFRG panel is shown in Fig.1. At the time of the manufacturing operation, glass fibers of about 30–35 cm in length are anyway scattered inside the panel surface and in the ribs. The glass fiber amount in the panel is 800 gram per sq. meter of Rapidwall surface area. The physical properties of the ongoing typical GFRG panels are mentioned in Table 1. In building construction, the standard GFRG panels are cut in the manufacturing unit into building element that may possess window and door openings. These elements are then moved to the construction location and hoisted in a similar process as in the construction process of precast concrete panels. The hollow cavities inside the GFRG panel can be properly filled with miscellaneous materials, such as concrete or any insulating material like quarry dust mixed with 5% cement, to serve different aims, such as to escalate the strength or enhance the thermal and sound insulation of the walls. In a Rapidwall building, all or most of the building elements are built using GFRG panels. Therefore, the GFRG panels aid as both architectural partitions and structural load bearing walls.

The typical connections between wall and floor are shown in fig. 2. Connections made are of two types as shown in figure the type one connection is 2(b) and type two connection is 2(c). In the first type, the connection made was of starter bars that are cast in both the lower and upper walls and extend into them by 400 mm. The reinforcement is discontinued in the middle of the GFRG walls and therefore there is no vertical tensile resistance observed in type one connections, i.e., starter bars connection. In the second type of connections, the full length reinforcement was provided through the walls. The lapping of bars was done at the bottom of the walls to ensure continuity. In this paper only shear failure of panel itself is reviewed. The continuity of lengthwise reinforcement at the horizontal joints affects the shear strength of the failure mode.

The continuity of lengthwise reinforcement is necessary when tensile resistance is required in a wall. However, the concrete cores inside the wall panels may crack and become discontinuous, which may affect the shear performance of the wall panels.



(a) Typical cross-section of GFRG panel



(b) Enlarged view of a typical cell of GFRG panel

Fig.1: Typical GFRG panel

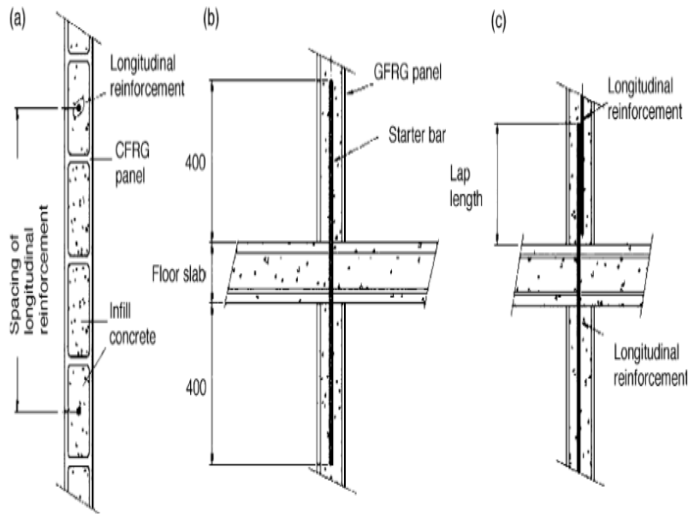


Fig.2: Connections between wall and floor. (a) plan, (b) vertical section of a starter bar connection, (c) vertical section of a continuous reinforcement.

2. GFRG BUILDING STRUCTURE

2.1 Structural Rectitude and Strength

GFRG panels have meaningful axial and shear strength when cavities of the panel are filled with reinforced concrete and therefore are relevant for construction of multi-story buildings. GFRG panel faces very much alike problem as that of concrete shear walls, i.e., concern regarding the adequate connection between the precast units [2].

The usual vertical and horizontal joints between GFRG walls and a slab are shown in Fig. 3(a) and 3(b) respectively.

Yu-Fei Wu, et.al [1, 2, 3] in their research papers had implemented the seismic design principle applied to the GFRG building was of "strong columns, weak beams, and stronger joints", mainly in mainland China.

D. Menon [4] in his research paper elaborated this whole concept of GFRG building system. In which the GFRG panels, which were used by the Australians as for vertical loads, i.e., it takes only gravity loads due to its own self weight, were now for the first time used as slabs, i.e., it now also takes lateral loads subjected to earthquake. GFRG panels with ribs aligned in direction of bending possess flexure, whose strength can be significantly enhanced by providing micro T-beams in each cavity of slab. Joints only provide axial and shear resistances which are unaffected by the discontinuity of GFRG panels. The whole building system proves to form a highly robust structure.

2.2 Relative Movement and Partial Interactivity

The GFRG hollow cavities are filled with concrete but the bond as if in other conventional building systems is not alike in it. The bond between concrete and GFRG wall surface is neither strong nor reliable. But the beauty is that as long as we put them together and connect them and make them into a unit actually lack of bond is also advantageous because there will be loss of energy. The energy can be dissipated through fraying of surfaces and making the structure a little more flexible. All these things help in earthquake performance of this GFRG building system [3, 4]. This relative movement which occurs when structure deforms shows that GFRG surface and concrete cores are partially interactive instead of fully interactive. This partial interactivity not only causes complications for structural performance but also for structural analysis.

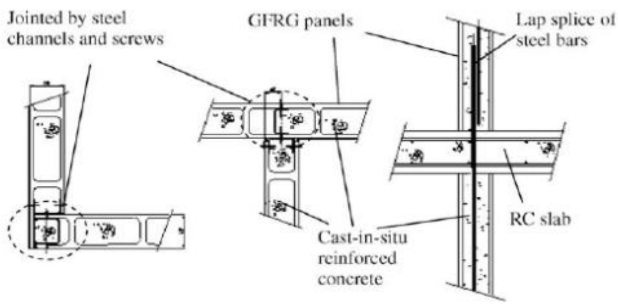


Fig.3: (a) Horizontal Joints (b) Vertical Joints

3. SHEAR STRENGTH OF GFRG WALLS

Yu-Fei Wu, et.al [2, 3] in their research paper observed various properties of GFRG panel. The key results related to shear strength of GFRG walls are listed below:

1. Shear failure mode of GFRG walls was completely different from that of reinforced concrete shear walls. As in RC shear walls the shear failure modes were diagonal tension failure, diagonal compression failure, and shear sliding failure whereas in GFRG panels its different due to the separation of the concrete cores by the internal ribs of the GFRG panel. The typical shear failure mode observed was longitudinal shear in the gypsum plaster as sown in the Fig. 4.
2. The shear strength of the wall was found to be proportional to the length of the wall.
3. Unit shear strength of the wall was found to be near about 50 kN/m. Hence, the shear strength of a GFRG concrete filled wall is simply equal to the unit shear strength multiplied by the length of the wall.
4. Longitudinal reinforcement does not affect shear strength of GFRG wall whereas horizontal reinforcement passing through the concrete cores could significantly increase the resistance of the longitudinal shear and hence increase the shear strength of the wall.

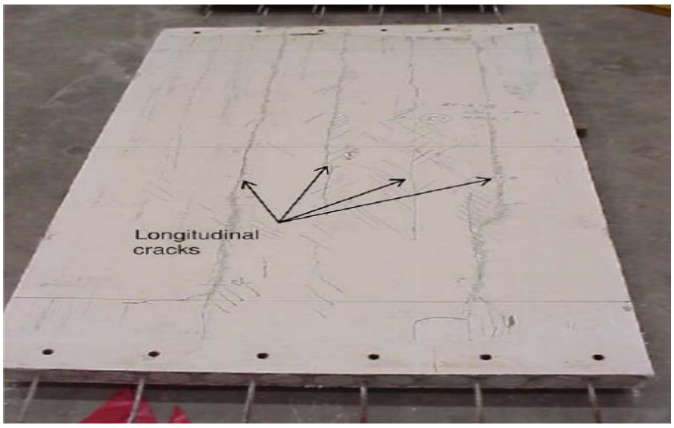


Fig.4: Typical Longitudinal shear failure

D. Menon [4, 5] in his research paper illustrates the test results out of which the unit shear strength of the 124 mm thick and 3.0 m high GFRG panel was as listed below:

1. For unfilled GFRG walls the shear strength as vertical walls was 14.4kN/m.
2. For GFRG panel filled with 20 Mpa concrete was 50kN/m.

Application	Design Shear Capacity, Vud (kN/m)
GFRG unfilled panels	14.4
GFRG filled panels with 20 Mpa concrete	40.0

Table 1: Shear strength of GFRG walls as vertical walls

4. AXIAL STRENGTH OF GFRG WALLS

Axial strength as per **Yu-Fei Wu** [1], after conducting compression tests following conclusions were drawn for axial strength:

1. There was no role of infill concrete and reinforcement bars inside the concrete cores on the compression load test results.
2. Failure load was governed by the eccentricity and the support conditions.

D. Menon [4] in his research work observed that the axial load of the GFRG panels is governed by the assumed eccentricities in loading. The GFRG panel was tested for various eccentricities in loading, i.e., (20 mm, 30 mm, and 45 mm) for different boundary conditions. The axial load capacity calculated was as follows:

1. For unfilled panels the axial load capacity was calculated as: P_{ud} = (68 – 0.9e), and

2. For filled panels the axial load capacity was calculated as: P_{ud} = (600 – 13.75e).

5. OUT-OF-PLANE BENDING CAPACITY

5.1 Unfilled GFRG Panels

D. Menon. [4] in his research found that when the ribs of GFRG panels are aligned in the direction parallel to the span higher bending capacity is obtained:

	Ribs parallel to span	Ribs perpendicular to the span
Design Moment Capacity, Mud	1.4 kNm/m	0.59 kNm/m

Table 2: Out-of-plane design flexural capacity of unfilled GFRG panel

5.2 Filled GFRG Panels

D. Menon. [4] in his research found that the design bending moment capacity obtained was 2.83 kNm/m ignoring the offerings of GFRG panel and considering the action of concrete core beams occupied by hollow cavities.

6. IN-PLANE BENDING CAPACITY

D. Menon. [4] GFRG panels, which was used by the Australians as for vertical loads, i.e., it takes only gravity loads due to its own self weight, was now used as slabs for the first time ever, i.e., it now also takes lateral loads subjected to earthquake. GFRG panels with ribs aligned in direction of bending possess flexure, whose strength could be significantly enhanced by providing micro T-beams in each cavity of slabs. The design in plane bending capacity

(Mud) and its relationship with the design axial load capacity (Pud) is usually described by means of a Pud - Mud interaction diagram. A design Pud and Mud interaction diagram for 1.25 m wide GFRG panel with two bars in each cavity having M20 grade concrete is shown in Fig. 5.

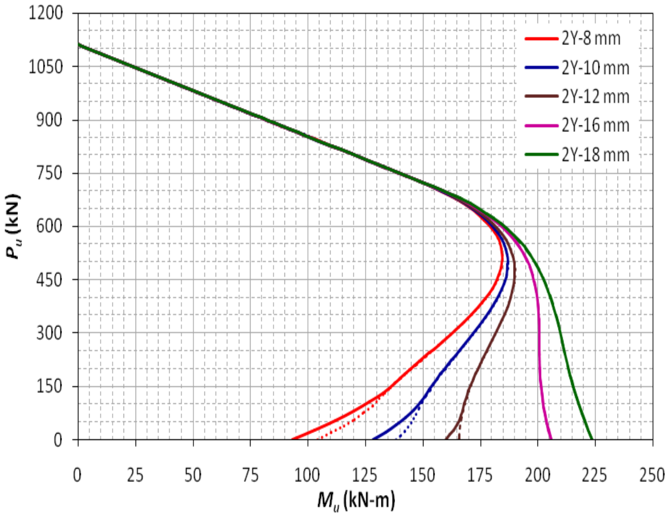


Fig.5: Pud and Mud interaction diagram for 1.25 m wide GFRG panel

7. Response of lengthwise reinforcement on periodic shear behavior

Yu-Fei Wu et.al [1, 3], in his research mentioned the purpose of this study was therefore to analyze the suitability and performance of the type one connection, i.e., starter bar connection. The problem which arose was complicated due to the composite nature of GFRG walls and the additional composite action between the concrete cores and the GFRG wall surfaces. The procedures of periodic shear testing and the results were mentioned in this paper.

Shear test specimens used are shown in the fig. 6(a) and 6(b). Both the type-one and type-two connections were tested for a 1520 mm walls. However, only the type-one connection was tested for 2020 mm wide specimen. All the hollow cavities of the GFRG panel filled with self compacting concrete. The reinforcement used was 12 mm diameter bars in the specimens and yield strength of the bar was 530 Mpa. The concrete strength for each type of the specimens as observed are provided in the table 3.

The requirement of the shear test setup was to prevent flexural failure before the shear failure occurs. The test setup is shown in fig.7. Unique features of the test setup were that: (1) the specimens were tested horizontally 1 m above the ground instead of vertically to avoid flexural failure of the GFRG panel, (2) the top and bottom steel beams were able to transfer load uniformly into the panel without crushing the gypsum plaster, and (3) the axial load could be adjusted and axial load effect on shear strength could be measured.

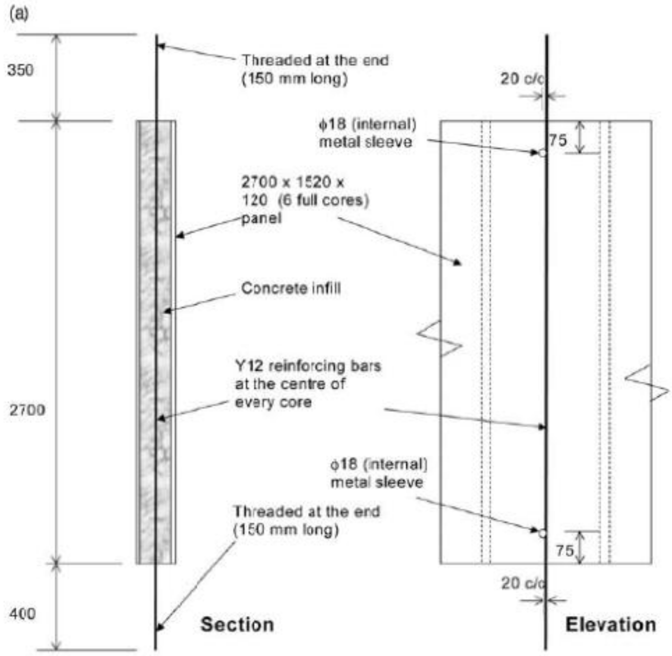


Fig.6 (a): Specimen with full length bars

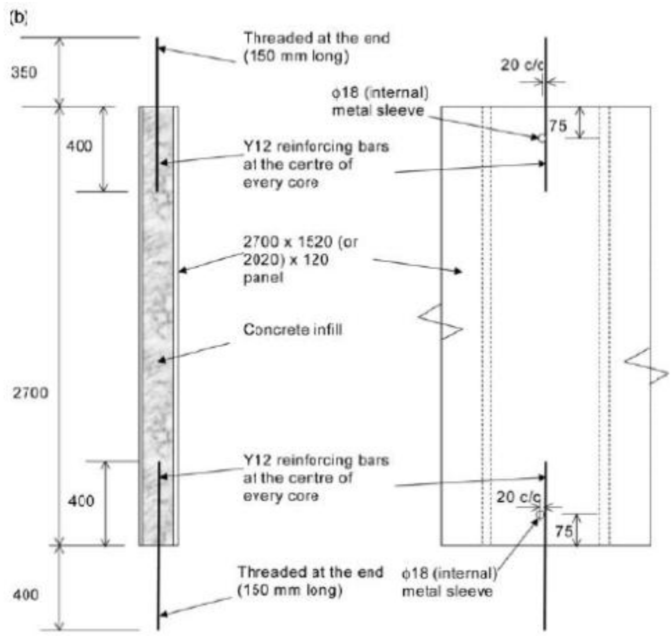
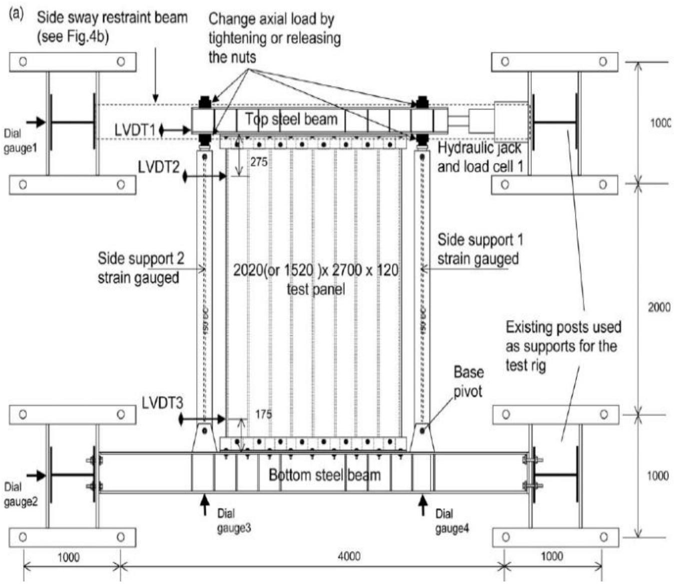


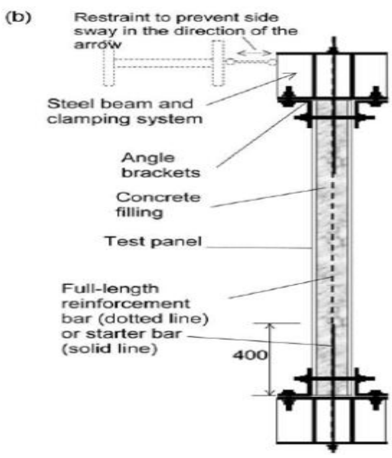
Fig.6 (b): Specimen with starter bars

Specimen number	Dimensions b X h (mm)	Connection type	Concrete strength (N/mm²)
1	1520 x 2700	Starter bars	17
2	1520 x 2700	Starter bars	17
3	1520 x 2700	Full bars	20
4	1520 x 2700	Full bars	20
5	2020 x 2700	Starter bars	27

Table 3: Details of the test specimen



(a) Plan view



(b) Cross-sections

Fig.7: Shear test setup

One common observation made in all the five shear tests was that visible 45° diagonal shear cracks developed before peak load was reached. All the diagonal cracks were tensile cracks as they closed back at unloading and opened up with further loading. The cracks were visible and they disappeared when the panel was unloaded. It was also observed for flexural performance continuity of reinforcement is important [3]. The shear cracks developed in the panel is shown in fig.8.

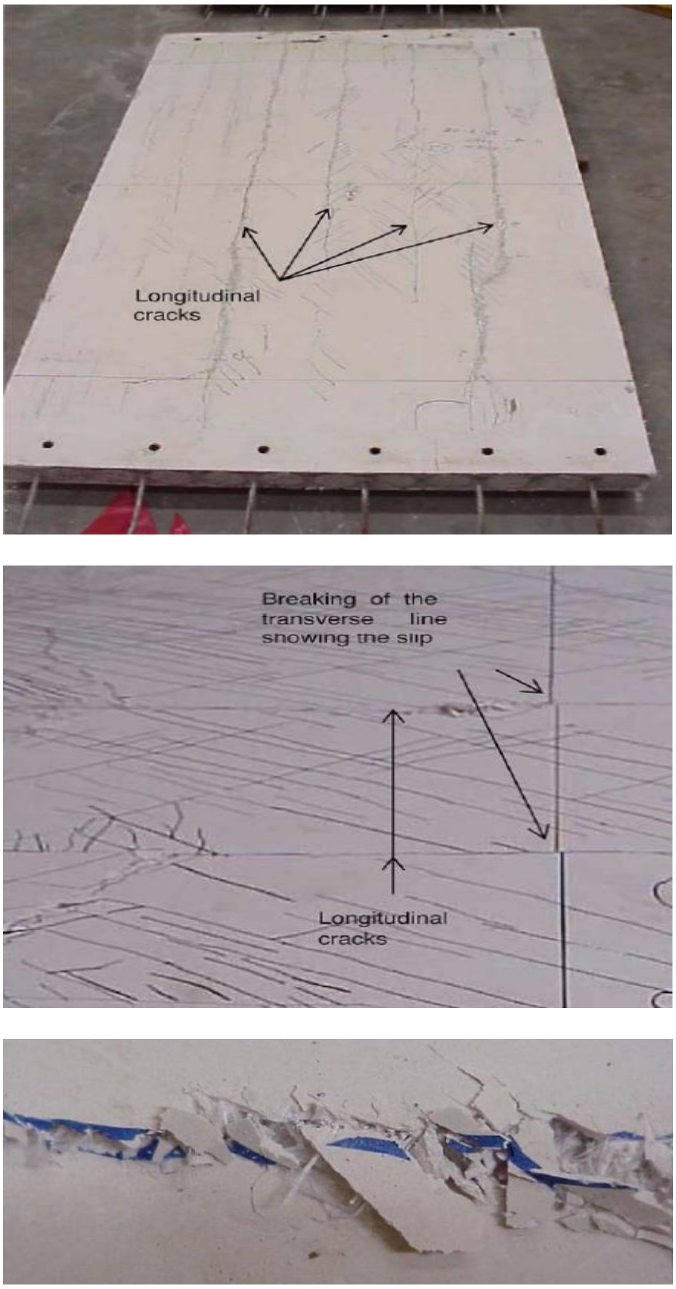


Fig.8: Longitudinal cracks

The positive and negative peak points are given in table 4. For the specimen 1 and 2, the positive peak strength was higher than that of negative, the average been higher than 19%. For the specimen 3 and 4, positive peak strength was lower than negative and average been 8% lower than negative.

However, the average negative peak strength with starter bars was 20% lower than that of full length bars. So it was observed that the full length bars had no effect on positive peak strength of bars but only increased the negative peak strength of the walls.

	Positive peak strength (kN)	Negative peak strength (kN)
Specimen 1	82.0	-65.5
Specimen 2	92.0	-81.0
Average of 1 & 2	87.0	-73.3
Specimen 3	89.5	-93.5
Specimen 4	78.9	-88.3
Average of 3 & 4	84.2	-90.9
Specimen 5	143.0	-127.5

Table 4: Summary of test results

7. DESIGN PROCEDURE FOR GFRG BUILDING SYSTEM

Yu-Fei Wu [2], in his research paper proposed a design procedure for GFRG building system supporting lateral loads which are listed below:

1. Base shear method is used when seismic loads are applicable and modification factor (R_f) is selected by treating the GFRG filled walls as RC shear walls.
2. Total shear force is divided among each wall in proportion to its stiffness.
3. Shear strength of walls is checked for all load cases to assure that a shear failure does not happen.
4. Lateral bending check is not an issue for GFRG building provided that the height/breadth ratio in any direction is less than two. It is not recommended to construct building taller than 8 storey.

D. Menon, A.M. Prasad. [5] in their review to developments in field of GFRG building system proposed their design philosophy. The design capacities were based on limit states design procedure. It should also satisfy serviceability requirements. The design must account for the partial safety factors for loads and also various combinations of loads acting simultaneously on the structure, as per IS 456: 2000. The partial safety factor for the GFRG building panel (with and without concrete infill) shall be taken as m = 1.50 and in the case of reinforcing steel, the partial safety factor shall be taken as s = 1.15, as recommended in IS 456:2000. Earthquake resistant design shall be carried out in compliance with the requirements of IS 1893 (Part 1): 2002, where the important and difficult task is the determination of the response reduction factor (R). GFRG walls are composite members with partial interaction and hence, it is reasonable to treat buildings constructed with GFRG walls as reinforced concrete shear wall structures and to adopt the 'R' values as 3.0 (IS 1893 (Part 1) :2002) for seismic load calculations.

8. CONCLUSIONS

This paper has introduced GFRG panels/Rapidwall and related building system with also analyzing its structural performance. All the experimental and theoretical values set in motion by the authors since 2004 have been bestowed from the structural elements and overall building's response point of view.

The accurate calculations of the tests were not possible due to the relative movement between the concrete cores and GFRG wall surface. Based on the experimental results a design procedure for the building system has been proposed.

The lengthwise reinforcement has no significant effect on shear response of concrete filled GFRG panels. Therefore, panels with starter bars as reinforcement could be used for which shear failure controls the design. Axial load has a similar effect on the shear strength of the walls. As a result, the type –one connection (starter bar) is acceptable for GFRG wall building if failure is due to shear strength of the wall.

However, these conclusions are only valid for shear prevailing wall panels. They are not valid for the walls with flexural deformations, for which the continuity of reinforcement is substantial.

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