World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:4, No:3, 2010

Elastic Lateral Features of a New Glass Fiber Reinforced Gypsum Wall

Zhengyong Liu, Huiqing Ying

***Abstract*—**GFRG(Glass Fiber Reinforced Gypsum) wall is a green product which can erect a building fast in prefabricated method, but its application to high-rise residential buildings is limited for its poor lateral stiffness. This paper has proposed a modification to GFRG walls structure to increase its lateral stiffness, which aiming to erect small high-rise residential buildings as load-bearing walls. The elastic finite element analysis to it has shown the lateral deformation feature and the distributions of the axial force and the shear force. The analysis results show that the new GFRG reinforced concrete wall can be used for small high-rise residential buildings.

***Keywords*—**GFRG wall; lateral features; elastic analysis; residential building.

I. INTRODUCTION

HOUSING industrialization promotion in China has lighted the researchers' eagerness of finding new ways to erect residential buildings in prefabrication method. The multi-ribbed composite wall [2] put forward by Xi'an University are supposed to be used in small high-rise housing buildings. The research on the dense rib grid beat shearing force rapid-wall [3] (put forward by Guizhou University) shows that it has enough lateral stiffness and is possible to be used in small high-rise residential buildings.

Glass fiber reinforced gypsum (GFRG) wall is a green product which can erect a building fast in prefabricated method. Appeared first in Australia in early 1990s, substantial research and practices on GFRG walls have been carried in Australia and a few Asian countries such as China, Malaysia and India. GFRG walls can be used in low buildings as load-bearing walls and in low-rise buildings or as upper storey walls in high-rise building when filled with concrete in the hollow cores.

The application of GFRG wall is limited for its poor lateral stiffness even though it is filled concrete in its hollow cores. Finding a new way to enhance this disadvantage (its lateral stiffness) to make it suitable for small high-rise residential building is a valuable choice for researchers.

II. MODIFYING GFRG

Whilst GFRG wall have limited application as load-bearing member, modification on it may be adapted for a wide range of multi-storey offices, small high-rise residences and schools etc. To fulfill the demand, Modification to the GFRG wall's structure should be focus on how to increase its lateral stiffness so that it deforms small when bearing the lateral loads.

Considered the GFRG wall's structure and its manufacture, this paper has proposed some adapted to it to increase its lateral stiffness. The first is to enlarge the GFRG wall's hollow cores ensure that the reinforcement cage can be hung in and then fill concrete in-situ to form the reinforced concrete dense columns. The second is to heighten the beam in order to keep the wall work together. The third is to form the large size end columns. Fig. 1 shows the details of GFRG walls filled with concrete (a) and Modifying GFRG M-GFRG reinforced concrete walls (b).

Floor is cast in situ with deep beam and dense columns and end columns together. The GFRG panels works as the form of M-GFRG walls. Deep beam has enough stiffness to keep the columns work as one. Dense columns and end columns are reinforced concrete members. GFRG Form can be ignored when M-GFRG reinforced concrete walls are bearing lateral loads.

III. STRUCTURE ADVANTAGES OF M-GFRG

In building construction, The M-GFRG are transported to the construction site and erected in a similar way to the construction of precast concrete panels. The reinforcement cages are bounded before hanging in the hollow core, and then cast concrete to form dense columns and end columns. This construction technology saves lots of materials and time.

Since the floor and the reinforced concrete walls are cast in-situ together, this structure system of concrete-in-situ is monolithic. Monolithic structures are good in terms of strength, rigid, ductility and energy dissipation, and they have good expression during wind and seismic action, so the building erecting with M-GFRG walls have good prospects in small high-rise residential building.

The bond interfaces between the concrete and the GFRG panel is relatively weak, and the GFRG panel's stiffness is far smaller than the concrete columns', therefore the GFRG panel can be ignored when analyzing and designing.

Z.Y. Liu is with the Building department of Civil engineer college, Tongji University, Shanghai 200092, China, tel: 0086-021-65982428; fax: 0086-021-65982428(e-mail: fcyygsl@163.com).

H.Q. Ying is with the Building department of Civil engineer college, Tongji University, Shanghai 200092, China, tel: 0086-021-65982428; fax: 0086-021-65982428(e-mail: tjuyhq@163.com).

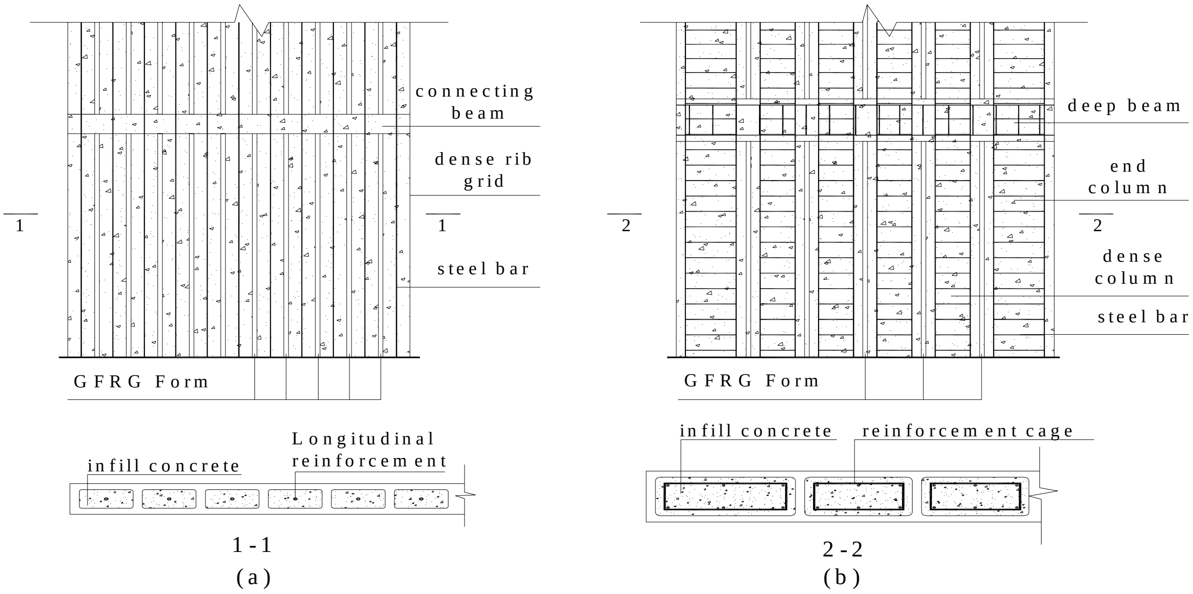


Fig. 1 GFRG wall filled with concrete (a) and M-GFRG reinforced concrete wall (b)

IV. 3-D FINITE ELEMENT MODEL

Analysis of M-GFRG reinforced concrete wall was performed to study the lateral deformation feature and the internal force distribution of M-GFRG wall when bearing lateral loads under normal condition. A small high-rise residential building is often 8to20 stories, 28to50m height. The models created are 12 stories, 35.950m.

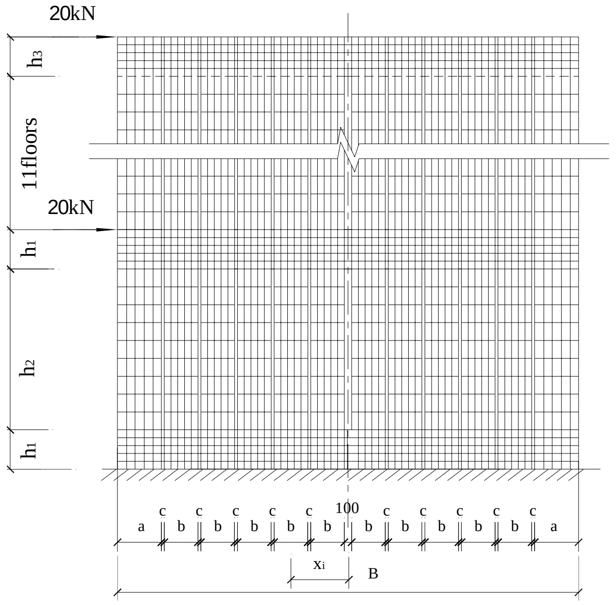


Fig. 2 The schematic diagram of 3-D FEM model (Xi-distance of the column centers to the model center)

The numerical analyses didn’t deal with the limit strength of the M-GFRG wall, which related to the lateral deformation feature under normal condition, therefore it was analyzed using FEM program in elastic stage.

Since the function of GFRG panels can be ignored when bearing loads, reinforced concrete finite element of M-GFRG reinforced concrete walls were modeled only. Five three-dimensional finite element models were created. Those models consist of four M-GFRG reinforced concrete walls and one reinforcing concrete shear wall. Fig 2 and Table 1 are the FEM models and their parameters’ values.

The first consideration to models is the comparison of the M-GFRG reinforced concrete walls to the reinforced concrete shear wall, trying to study the ratio of the M-GFRG reinforced concrete walls’ stiffness to solid reinforced concrete wall’s stiffness. The second consideration is the affection of the size of deep beam to the lateral feature. The third is the affection of the size of end columns to the lateral feature.

TABLE I
VALUE OF PARAMETERS OF MODELS (MM)

	a	b	c	h1	h2	h3
M1	600	460	40	450	2500	550
M2	600	460	40	500	2450	550
M3	600	460	40	550	2400	550
M4	700	450	30	550	2400	550
M5	Reinforcing concrete shear wall (solid) B×H=6300×35950, total 12 floors, t (thick) =250.					

V. NUMERICAL RESULTS

A. The lateral-displacement feature

The lateral-displacement curves from the FEM analyses are shown in Fig.3. Table 2 lists the dates for more clarity.

The results show that the inter-story drifts of M-GFRG increate on the lower stories but reverse on the higher stories, which means its lateral-displacement feature is shear-flexural type, comprison to that of reinforcing concrete shear wall (M5), which is flexural type. The max inter-story drift occurred at the 7th floor, just the half height of the walls.

The top displacement of the M2 is the smallest of the four M-GFRG models. Its height of deep beam (500mm) is larger than that of M1 (450mm) and lesser than that of M3 (550mm). This shows that the M-GFRG lateral stiffness varies with the ratio of deep beam stiffness to dense column stiffness. A suitable ratio of deep beam stiffness to dense column stiffness can make M-GRFG more rigid.

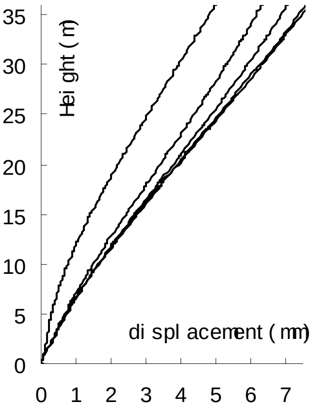


Fig. 3 Lateral-displacement curves
(Left to right: M5, M2, M1, M4, M3)

TABLE II
DATES OF THE INTER-STORY DRIFT AND TOTAL DISPLACEMENT (MM)

Floor number		1	2	3	4	5	6	7	8	9	10	11	12
M1	I-story drift		0.475	0.543	0.592	0.625	0.643	0.649	0.644	0.631	0.614	0.582	0.572
	total disp	0.484	0.959	1.502	2.094	2.719	3.362	4.011	4.655	5.286	5.900	6.482	7.054
M2	I-story drift		0.432	0.493	0.536	0.563	0.578	0.58	0.573	0.559	0.539	0.515	0.503
	total disp	0.453	0.885	1.378	1.914	2.477	3.055	3.635	4.208	4.767	5.306	5.821	6.324
M3	I-story drift		0.48	0.561	0.622	0.666	0.694	0.710	0.714	0.708	0.695	0.678	0.658
	total disp	0.484	0.964	1.525	2.147	2.813	3.507	4.217	4.931	5.639	6.334	7.012	7.670
M4	I-story drift		0.477	0.556	0.617	0.659	0.686	0.702	0.705	0.700	0.686	0.668	0.650
	total disp	0.474	0.951	1.507	2.124	2.783	3.469	4.171	4.876	5.576	6.262	6.930	7.580
M5	I-story drift		0.199	0.285	0.355	0.410	0.452	0.482	0.501	0.514	0.525	0.516	0.537
	total disp	0.205	0.404	0.689	1.044	1.454	1.906	2.388	2.889	3.403	3.928	4.444	4.981

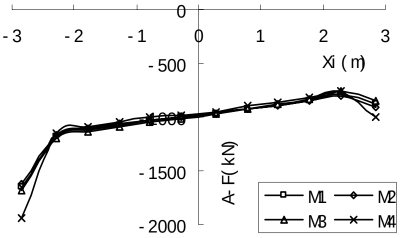
The top displacement of the M-GFRG wall models varied from 7.670mm to 6.324mm. The ratios of top displacement to wall height are 0.0002 to 0.00018. The largest inter-story drift of the M-GFRG wall varied from 0.71mm to 0.58mm. The ratios of the largest inter-story drift to story height are 0.00024 to 0.00020, which is far lower than the China code limit (0.001).

The results show that the lateral stiffness of M2 is smaller than that of M5—Its top total displacement is 1.27 times that of M5, while the top total displacement of M3 (the most flexible) is 1.58 times that of M5. Since M5 is reinforcing concrete shear wall, whose strength and stiffness are enough for high-rise building, M-GFRG is possible to be used for small high-rise residential.

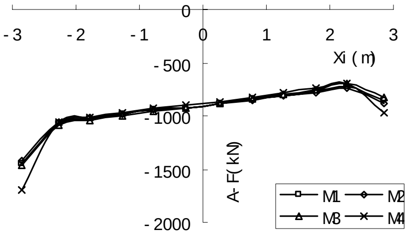
B. Axial force(A-F) distribution of columns

Fig.4. shows the axial force distribution of dense columns and end columns at the middle layer section of the first story (a) and the second story (b).

Results show that the relationship between the axial forces of the dense columns and the distances of the dense column centers to M-GFRG section center (x_i) is similarly linear, which doesn't change with the section elevation. The relationship between the axial force of the end columns and x_i goes beyond the linear, for the reason that their section areas are larger than the dense columns'.



(a-elevation: +1.775m)



(b-elevation: +4.725m)

Fig. 4 Axial force distribution of columns

Results also light that the axial forces of the columns have little relation to the size of the deep beam, but the column section areas can change the curve.

We can easily get the calculation formula of the axial forces from the curves:

$$N_j = \frac{A_j G}{\sum_{i=1}^{n} A_i} + \frac{M \cdot x_i \cdot I_{fj}}{\sum I \cdot \sum_{i=1}^{n+2} x_i^2}$$

G —the structural dead weight

A_j —the wall section area of the *j*th column

$\sum I$ —the section lateral inertia moment

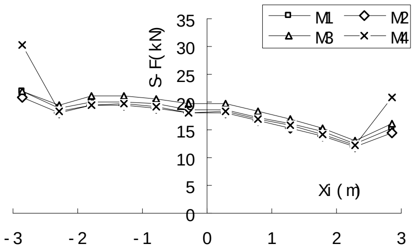
I_{fj} —the additional section lateral inertia moment

M —the section moment.

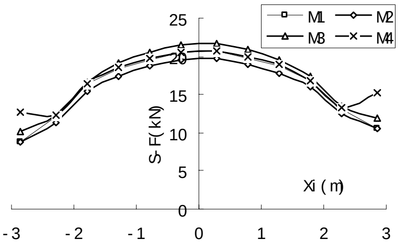
C. Horizontal shear force(S-F) distribution of columns

Fig. 5 shows the horizontal shear stress of the columns of different section elevation (elevation: +1.775m to +34.225m).

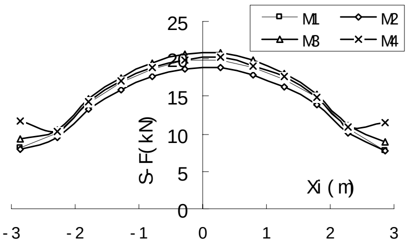
Fig. 5(a) comes from the middle layer section of the first story of the M-GFRG walls, their horizontal shear force of dense columns varied similarly to a line. The curves show that the shear force is nearly distributed by the columns' stiffness at the wall bottom story. This variation pattern is largely decided by the fixing bottom. The horizontal shear force of end columns varied in different way, the reason of which is their larger section areas.



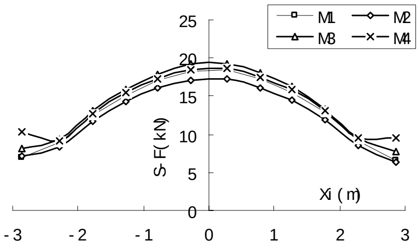
(a-elevation: +1.775m)



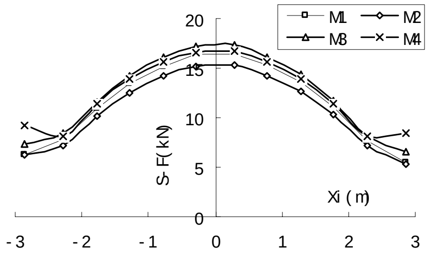
(b-elevation: +4.725m)



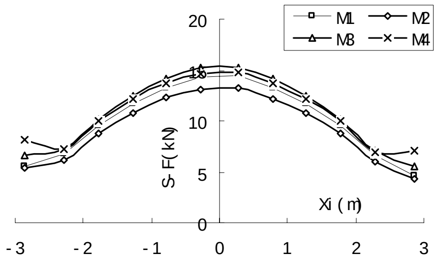
(c-elevation: +7.675m)



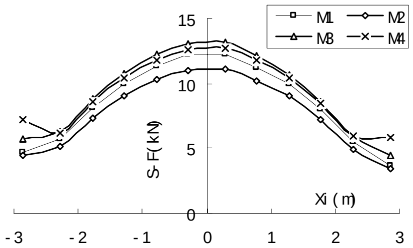
(d-elevation: +10.625m)



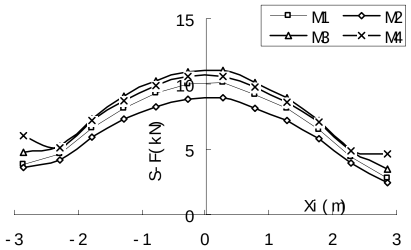
(e-elevation: +13.575m)



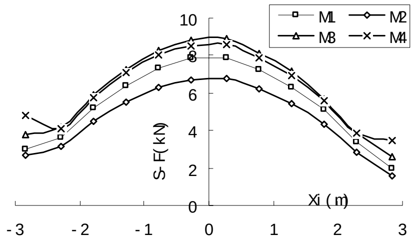
(f-elevation: +16.525m)



(g-elevation: +19.475m)

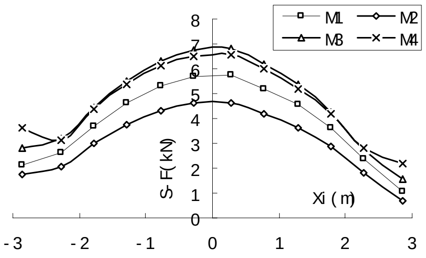


(h-elevation: +22.425m)

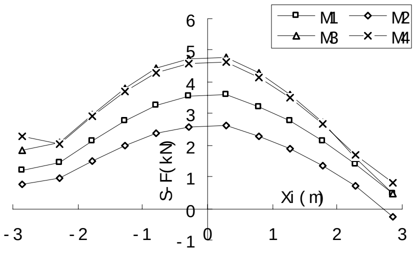


(i- elevation: +25.375m)

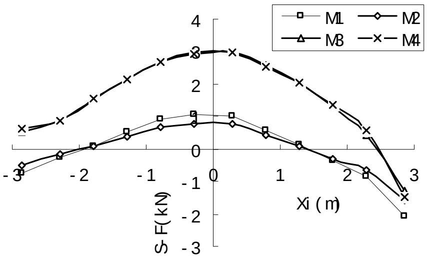
(ii-



(j-elevation: +28.325m)



(k-elevation: +31.275m)



(l-elevation: +34.225m)
Fig. 5 the horizontal shear force distribution of columns

Fig. 5(b)~(l) come from the other stories, their horizontal shear force of dense columns varied similarly to a quadratic curve which means that the distribution of the shear force is linear relation to x_i^2 which is totally different from that of the bottom story.

Take the anti-shear strength of the M-GFRG walls into consideration; the most important section is the middle layer section of the bottom story for structure inner force calculation and design. The axial forces calculation formula of the bottom story section can be formulated as follow:

$$V_j = \alpha \frac{VI_j}{\sum_i^n I_i}$$

I_j —the *j*th column inertia moment

α —the shear effect coefficient

V_j —the *j*th column shear force

VI. Summary and Conclusion

This paper presented a new GFRG wall, named M-GFRG wall, which intended to erect small high-rise residential. Considerations on M-GFRG walls show that they can erect building fast like GFRG wall in prefabricated method. The following conclusions of its lateral deformation feature are derived from the elastic FEM analysis.

A. The lateral stiffness of M-GFRG wall is a little smaller than that of reinforcing concrete shear wall, but it still is enough rigid for the small high-rise building.

B. The inter-story drifts of M-GFRG increate at the lower stories but reverse at the higher stories; its lateral-displacement feature is shear-flexural type. The largest inter-story drift occurred at the half height of walls.

C. The relationship between the axial forces and the distances of the dense column centers to M-GFRG section center (xi) is similarly linear.

D. The horizontal shear force distribution of dense columns is different from the bottom story to the higher stories. The bottom shear force is distributed by the columns' stiffness. This variation pattern is largely affected by the fixing bottom. The shear force of the higher stories are distributed by the distances to the wall center (xi) which similar to the solid section wall.

The elastic analysis shows that the M-GFRG wall is possible to be used in the small high-rise residential. But it still needs more theory analysis and experiment research for engineer application.

References

[1] Yu-Fei Wu, *The effect of longitudinal reinforcement on the cyclic shear behavior of glass fiber reinforced gypsum wall panels: tests* Engineering Structures 26 (2004) 1633–1646

[2] Chen Ping, Zhao Dong, Yao Qianfeng. *A study on the bearing capacity of the Multi-ribbed composite wall*. Journal of Xi'an university of Arch and Tech. vol.34 No.1 26-29

[3] HUAN G Shou yun, *Two Kinds of New Environmental Protection Walls of Shaping of Gypsum-the Structure and Mechanics Characteristic of the Rapid-wall are Compared*, Journal Of Guizhou University of Technology, China, 2006.8

[4] Kang Liu, Yu-Fei Wu, Xin-Liang Jiang, *Shear strength of concrete filled glass fiber reinforced gypsum walls*, Materials and Structures, AUS, 2007

[5] LU Xi-lin, JIN Guofang, WU Xiaohan, *theory and application of nonlinear finite element of reinforced concrete [M]*, Shanghai: Tongji University Press, 1997

[6] Wu YF, Dare MP (2004) *Axial and shear behavior of glass fiber reinforced gypsum wall panels: test.* J Compos Constr ASCE 8(6):569–678

[7] R. J. Vidmar. (1992, August). *On the use of atmospheric plasmas as electromagnetic reflectors. IEEE Trans. Plasma Sci.* [Online]. *21(3).* pp. 876—880. Available: http: //www.halcyon.com/pub/journals/ 21ps03