Design and Performance Evaluation of Hybrid Corrugated-GFRP Infill Panels

WooYoung Jung, HoYoung Son

Abstract**—**This study presented to reduce earthquake damage and emergency rehabilitation of critical structures such as schools, high-tech factories, and hospitals due to strong ground motions associated with climate changes. Regarding recent trend, a strong earthquake causes serious damage to critical structures and then the critical structure might be influenced by sequence aftershocks (or tsunami) due to fault plane adjustments. Therefore, in order to improve seismic performance of critical structures, retrofitted or strengthening study of the structures under aftershocks sequence after emergency rehabilitation of the structures subjected to strong earthquakes is widely carried out. Consequently, this study used composite material for emergency rehabilitation of the structure rather than concrete and steel materials because of high strength and stiffness, lightweight, rapid manufacturing, and dynamic performance. Also, this study was to develop or improve the seismic performance or seismic retrofit of critical structures subjected to strong ground motions and earthquake aftershocks, by utilizing GFRP-Corrugated Infill Panels (GCIP).

Keywords**—**Composite material, GFRP, Infill Panel, Aftershock, Seismic Retrofitting.

I. INTRODUCTION

INFILL panel is the structure for seismic retrofit during and after earthquakes or vibrations, due to lateral forces. Infill panels, part of induced attenuation in the structures, are basically to enhance the strength and stiffness with decrease of weight. In recent years, polymer matrix composite (PMC) materials have received considerable attention for use in civil infrastructure applications ranging from the retrofit and rehabilitation of buildings and bridges to the construction of new structural systems.

Recently, Jung and Aref [1] developed new FRP infill panels. These were applied to steel-frame structures with bolted joints and numerical studies were performed to evaluate the behavior of the new panel. After this study, the construction demand for FRP infill strengthening techniques steadily increased. This study presents a new design concept of infill panel related to previous work in accordance with lightweight and high-strength sandwich GFRP panels and evaluates the performance of the proposed GFRP infill panel.

II. DESIGN OF GFRP-CORRUGATED INFILL PANELS

Corrugated steel plate shear walls is enough to resist the necessary lateral stress of infill structures by corrugated steel plates [2], [3] and the infill walls is typically dominated by buckling load effect of the constraint at right and left side columns [4]. Moreover, prototype light corrugated steel plate shear walls were constructed for seismic retrofit as shown in Figs. 1 and 2.

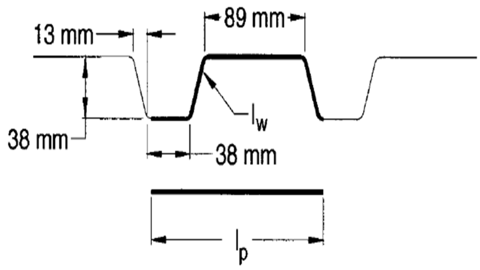

Fig. 1 Corrugated Shape of the Steel Infill [1]

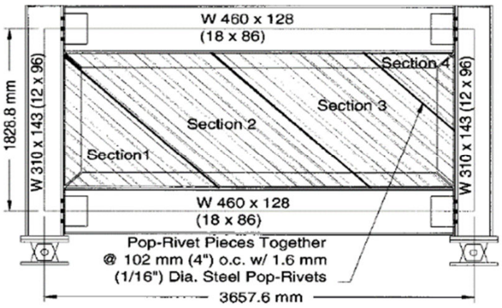

Fig. 2 Configuration of the Corrugated Steel Plate Shear Wall [2]

III. PROTOTYPE CORRUGATED GFRP INFILL PANELS

Current GFRP sandwich infill panels can cause brittle failure by excess of the yield stress and irregular buckling, since the sandwich panel is not strong enough to resist the later force and vibration during and after an earthquake. Therefore, in order to prevent initial failure of the panels, it is necessary to induce the ductile failure of the panels and it is also necessary to select adequate connection type for the boundary frames of the infill plate. Furthermore, corrugated light gauge steel plate shear wall was strong enough to resist the horizontal load in frame structures but a small stiffness relative can result in the deformation of infill panels. Besides, it should continuously reconstruct the infill panels by permanent deformation causing the plastic hinge based on material characteristics. Therefore, it is necessary to select adequate material combination, in order to construct high strength, stiffness, and ductility of the structures.

With considering the stiffness and ductility of the panels, new hybrid infill panel using light gauge steel plate as a ductile material and GFRP laminate as a skin plate material

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was manufactured. However, the concept of dynamic performance of the panels was similar to the sandwich plate. Also, the schematic design of the hybrid infill panel was described in Fig. 3.

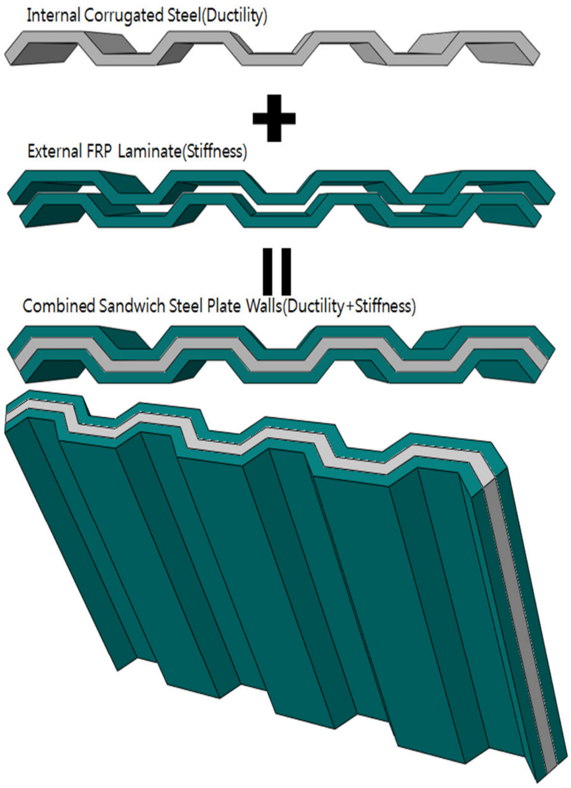


Fig. 3 Combine Sandwich Steel Plate Walls

IV. Performance Evaluation of the Hybrid Infill Panel

A. Experimental Tests

The new hybrid infill panel using light gauge steel plate and GFRP material was designed for quasi-static tests. Fig. 4 was prototype design of the new panel system and the specimen contents was listed in Table I. Also, the test setup of the panel based on current steel design methodology was illustrated in Fig. 5 and the specimen was rescaled about 20 percent down due to the limit of hydraulic actuator mounted between the steel frame and specimen.

In order to evaluate the seismic performance of corrugated-GFRP panel installed in the steel frame structure, the stiffness and energy dissipated capacity for each panel system (BSF and HSF) was observed, respectively. In addition, the guide angle was installed to the panel, due to out-of-plane deformation, as shown in Fig. 6.

In case of the connection of the infill structure, hinge systems at the top and bottom area of the column were applied to allow smaller rotation and for the rigid motion [5]. Regarding the performance of the frame structure, the actuator was connected at the steel rod on the top of column and also for in-plane behavior corresponding to the displacement control from the actuator, guide wheels using four steel rods was installed.

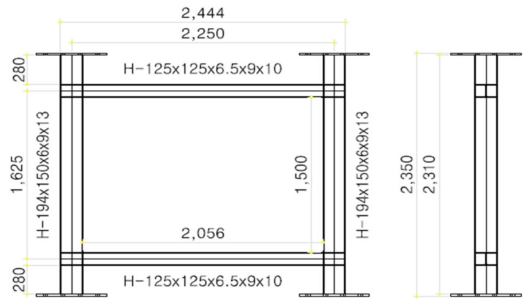


Fig. 4 Configuration of Steel Frame

TABLE I
Specimen Contents

Specimen	Contents
BSF	Steel Frame Only
HSF	Steel Frame + Corrugated Steel Plate-GFRP Panel

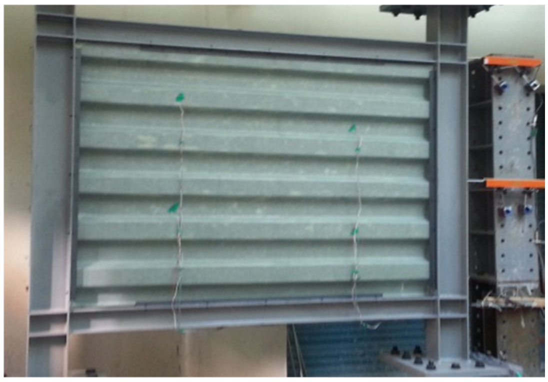


Fig. 5 Test Setup

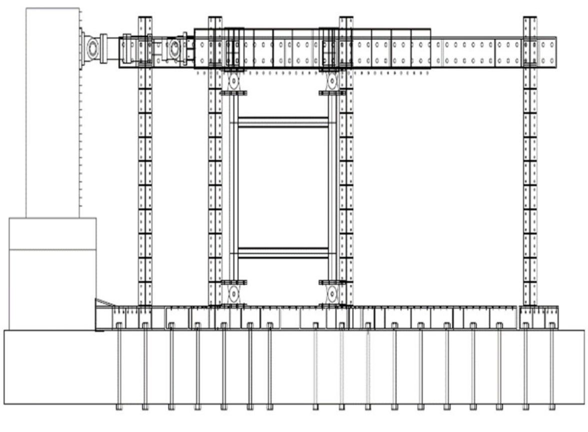


Fig. 6 Test Setup of the Frame Structure with the Guide Angel

Next, in case of loading control, maximum and minimum displacement based on the actuator was ±150mm, respectively. Fig. 7 showed the schematic design of the frame structure with the actuator. The increment of drift ratio was 0.5%, according to cyclic loading protocol [6], as shown in Fig. 8.

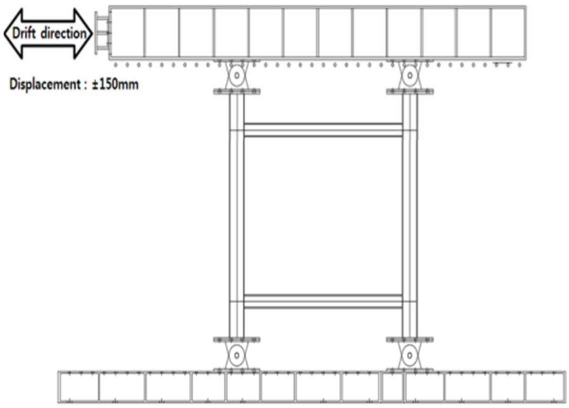


Fig. 7 Schematic Design of the Frame Structure with the Hydraulic Actuator

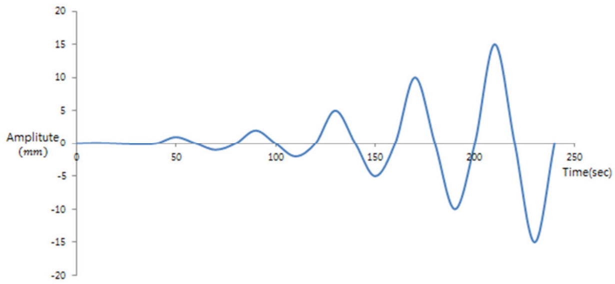
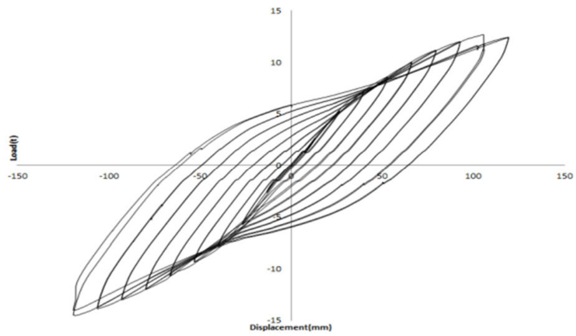
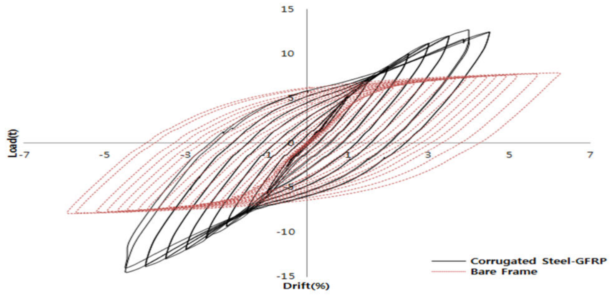


Fig. 8 Applied Load Protocol



(a) Hysteretic Loop of HSF Specimen



(b) Comparison of Hysteretic Loop between BSF and HSF

Fig. 9 Experimental Test Results

B. Experimental Results

Fig. 9 (a) showed the load-displacement relationship of HSF system corresponding to quasi-static tests and Fig. 9 (b) described the experimentally hysteretic loop curve of BSF in comparison to the HSF system.

In case of HSF specimen, I the stiffness and energy absorption at 0.5% drift ratio was 187.3kN/mm and 5051.3kN/mm, respectively. Also, the dynamic properties of HSF based on each drift ratio was obtained following: 1) the stiffness (194.3kN/mm) and energy absorption (28927.4kN/mm) at 1% drift, 2) 177.8kN/mm stiffness and 137159.7kN/mm energy absorption at 1.5% drift, and 3) the stiffness (155.9kN/mm) and energy absorption (323565.4kN/mm) at 2% drift. In addition, the comparison with respect to the stiffness and energy of the specimens at each drift ratio was listed in Table II.

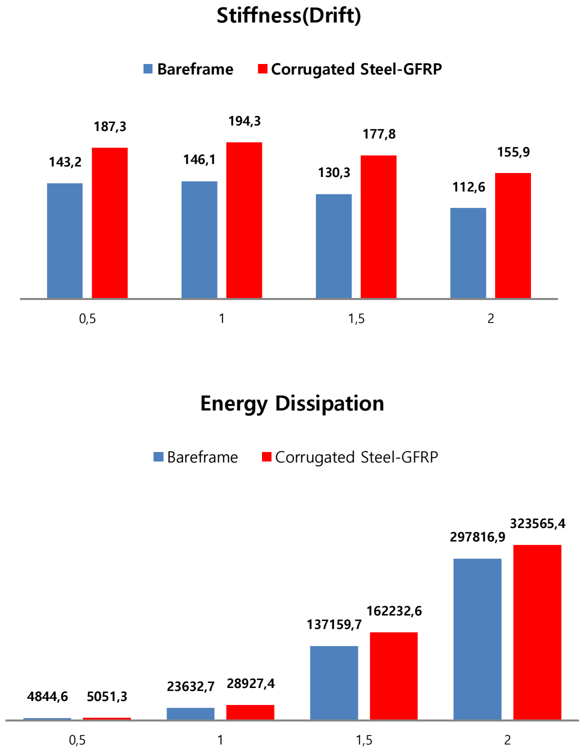


Fig. 10 Comparison of Bare Frame and Corrugated Steel Plate-GFRP Infill Panel

TABLE II
COMPARISON OF THE STIFFNESS AND ENERGY DISSIPATION OF HSF AND BSF

Drift	Stiffness (=H.S.F/B.S.F)	Energy Dissipation (=H.S.F/B.S.F)
0.5%	1.3	1.05
1.0%	1.3	1.2
1.5%	1.35	0.8
2.0%	1.38	1.08

V. CONCLUSIONS

This study presented the seismic retrofit of steel frame structures using corrugated-GFRP infill panel. The specimen design of the frames was rescaled for the quasi-static loading and the conclusion of this study obtained from the experimental tests was as following:

1) Corrugated-GFRP infill panel specimen was shown to carry out for the improvement of the frame structure with increasing the stiffness, energy, ductility and other dynamic properties. For example, the stiffness and energy was 1.3 times and 1.03 times more, respectively.
2) It was interesting to find that increased stiffness and energy of the corrugated-GFRP panel was due to combination of the panel system in accordance with the stiffness of GFRP and ductile material of corrugated steel plate.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST) (No. 2011-0028531).

REFERENCES

[1] Jung, WY and Aref, A. "Energy-Dissipating Polymer Matrix Composite-infill Wall System for Seismic Retrofitting" J. Struct. Eng., 129(4), 2003b, 440-448
[2] Berman, J.W., and Bruneau, M. "Experimental investigation of light-gauge steel plate shear walls for the seismic retrofit of building." Tech. Report. No. MCEER-03-001, Multidisciplinary Center for Earthquake Engineering Research, Univ. at Buffalo, N.Y, 2003a.
[3] Berman, J.W., and Bruneau, M. "Plastic analysis and design of steel plate shear walls." J. Struct. Eng., 129(11), 2003b, 1148-1156
[4] W.Y. Jung, "Seismic Retrofitting Strategies of Semi-rigid frames Using Polymer Matrix Composite Materials." Ph.D. Dissertation, the State University of New York at Buffalo, USA, 2003.
[5] F.C. Rodrigues, A.C., Saldanha. "Non-linear Analysis Steel Frames with Semi-rigid connections", 1998.
[6] Astaneh-Asl, A., ""Seismic Behavior and Design of Steel Shear Walls –- SEONC Seminar"", 2001 SEOANC Seminar, Structural Engineers Assoc. of Northern California, San Francisco, CA, 2001.