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Simplified Analysis on Steel Frame Infill with FRP Composite Panel

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***Abstract*—**In order to understand the seismic behavior of steel frame structure with infill FRP composite panel, simple models for simulation on the steel frame with the panel systems were developed in this study. To achieve the simple design method of the steel framed structure with the damping panel system, 2-D finite element analysis with the springs and dashpots models was conducted in ABAQUS. Under various applied spring stiffness and dashpot coefficient, the expected hysteretic energy responses of the steel frame with damping panel systems we investigated. Using the proposed simple design method which decides the stiffness and the damping, it is possible to decide the FRP and damping materials on a steel frame system.

***Keywords*—**Interface damping layer, steel frame, seismic, FRP.

I. Introduction

IN recent years, the natural hazards such as minor seismic events have been significantly increased in Korea. With increasing number of seismic events, many of infrastructures in civil engineering have been exposed to rehabilitation. Also, the economic loss can be caused during and after an earthquake. For example, total economic loss including residential buildings and commercial buildings due to the 1994 Northridge earthquake was $25.7 billion to recovery and reconstruct [1]. Therefore, the critical facilities such as hospitals, high tech factories, and emergency facilities must remain functional and operational during a major earthquake.

Many researchers have studied the seismic behavior of critical building structures to improve the seismic qualification using composite material, rather than using damper or bracing system in the structures [2]-[4]. Polymer Matrix Composite panel modeled as a single degree of freedom with equivalent elastic lateral stiffness and viscous damping properties to represent the global behavior of the actual structure validated from the experimental test was developed by [2]. In addition, [5] first applied the carbon fiber to the structure for strengthening and retrofitting of the system and then the FRP material was evaluated by [6], regarding the practical and feasible possibility through experimental tests. Consequently, this paper presented the behavior and energy dissipation of the FRP damping panel of steel frame structures under seismic ground motions. The simplified Finite Element (FE) panel model applied as retrofitting materials was implemented in this study and the FE model was validated from the experimental test.

The primary focus of this study was on developing the optimized design stage for the steel frame with FRP damping panels and this research was to keep in this design stage and standardize the seismic qualification of the structures for the seismic hazard mitigation.

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II. Description of FE Model of Steel Frames

A. Semi-Rigid Steel Frame FE Model

This study used the semi-rigid modeling method developed by [6] for steel frame structures. The joint area between beams and columns was defined by multi linear elastic element with stiffness parameters – K_x, K_y, K_Θ and 5% damping ratio for the steel structures was used in this study. In order to verify the stiffness values of the steel structure, the value should be close to infinite value but this study used the same stiffness both horizontal and vertical value, which was 9.536×10^8 through trial and error method. Fig. 1 shows the configuration of multi-linear elastic elements in steel frame structures under seismic ground motions.

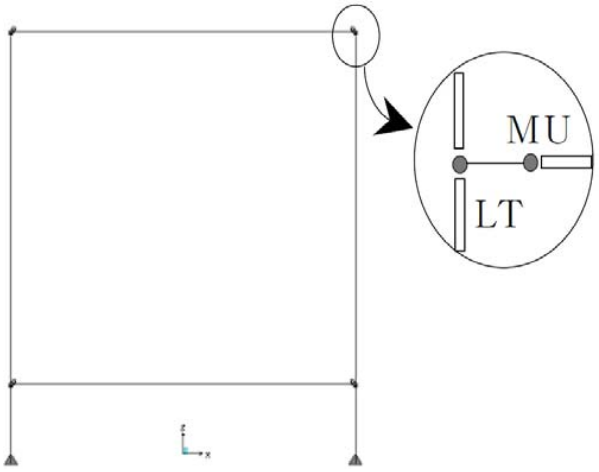


Fig. 1 Steel frame structure with multi linear elastic element [6]

B. FE Model with FRP Damping Panel

The objective of fibers was to provide the composite with their unique structural properties and then fibers were also load-carrying elements. In this study, for the steel frame 2D beam element was applied and springs/dashpots elements in ABAQUS platform were generated in terms of the FRP damping panel. As can be seen in Fig. 2, the simple geometric shape of damping panels was X-shape to consider the

performance at the connection area between the steel frame and the damping panel. In general, this shape can describe the energy dissipation of the structure subjected to seismic ground motions and the FRP damping panel was supported by pin connections to the steel frame. In order to allow smaller rotation at the bottom of the panel, the hinge boundary condition was used.

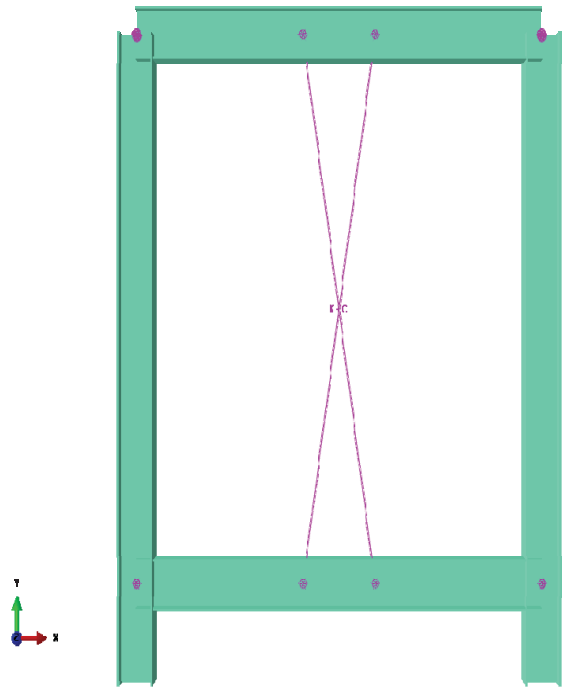
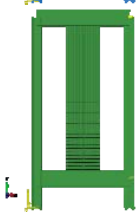
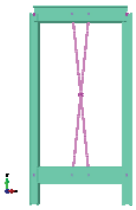
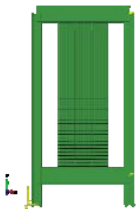
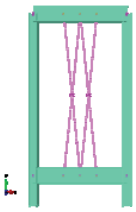
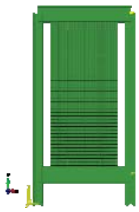
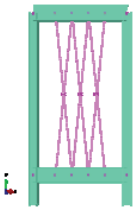


Fig. 2 FRP damping panel FE model

III. Validation of FE Model

This study evaluated the result obtained from idealized FE model conducted in ABAQUS [7], in comparison to linear elastic FRP damping model with height (2.35 (m)) and wide (2.52 (m)) steel frame structure. Also, 2D plane stress was conducted in ABAQUS for the frame structures with FRP panels, and in order to show the effect of energy dissipation of the panels, viscoelastic material was used. The structural system was classified into four different structures: 1) steel frame without the panels; 2) steel frame with two panels; 3) steel frame with three panels; 4) steel frame with four panels. For the analysis, the simple structure modeled with spring and dashpot was applied and then compared the result with FRP damping panel structures. The material properties based on [8] were G_i=0.04128 and 0.064, and τ_i=4.3512, 0.188, and 0.0128 in ABAQUS. For the characteristics of spring and dashpot to illustrate the damping FRP panels, the trial and error method was used in this study. Table I summarized the analysis cases in terms of this study with real FRP model and simple linear elastic model. In addition, the element type of damping FRP panel for the steel frame structure was defined by the plane stress element in ABAQUS.

TABLE I
The Element Types of FE Model: FRP Model and Simple Model

Case	Real model	Simple model	Number of Panel
Case1		-	0
Case2			2
Case3			3
Case4			4
Material model & Element type	Viscoelastic Prony series (G_s=0.04128, 0.064, 0.8) τ_i=4.3512, 0.188, 0.0128 Plane stress element	Dashpot coefficient SPRINGS/ DASHPOTS element	

Consequently, the performance of steel frame structure for case 1 showed perfect linear elastic behavior under cyclic loading condition, as can be seen in Fig. 3. However, Figs. 4-6 described the energy dissipation of damping FRP panel of steel structures and with increasing number of damping panels, the energy dissipation was significantly increased based on force-displacement relationship. In particular, the behavior of simple spring/dashpot FE model under cyclic loading condition was coincided with the FRP damping panel modeled by plane stress elements in ABAQUS. Finally, the simple spring/dashpot model for damping panels in steel frame structures can reduce the computational efforts and contribute the modeling method for the FRP panel structures.

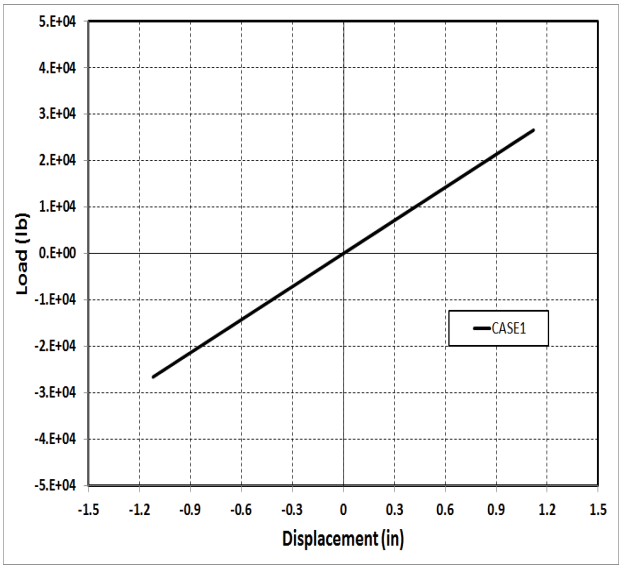


Fig. 3 Force-displacement relationship: case 1

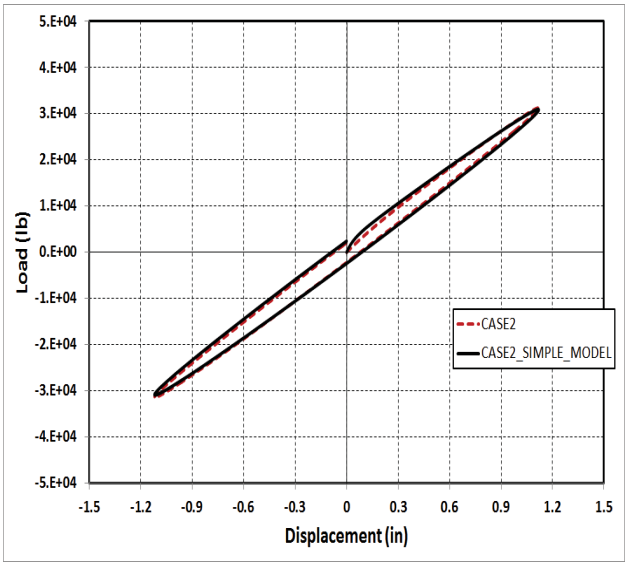


Fig. 4 Force-displacement relationship: case 2

IV. Performance Evaluation of the FRP Panels

In order to understand the seismic performance of steel frame structure with the damping panels, the El-Centro earthquake was applied in this study. Fig. 7 illustrated the displacement history with time domain with respect to number of damping panels. As a result, the displacement to the steel frame structure strengthening with damping FRP panels was significantly reduced, in comparison to the steel frame without retrofitting the FRP panels.

The maximum reduced ratio of the displacement was about 44 percent for the steel frame structure.

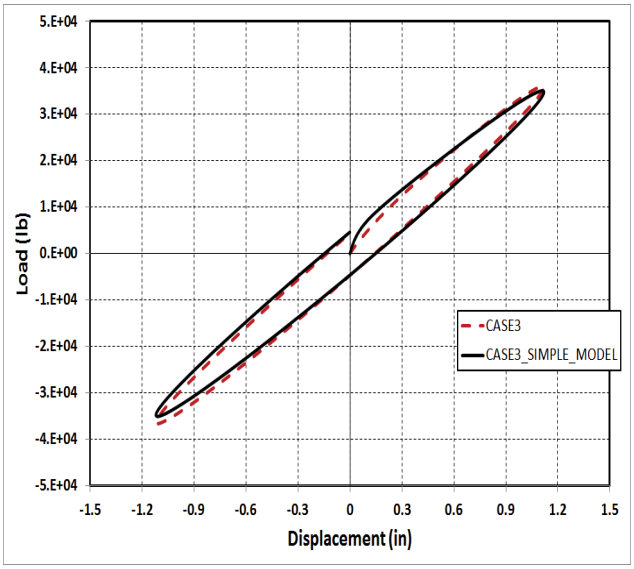


Fig. 5 Force-displacement relationship: case 3

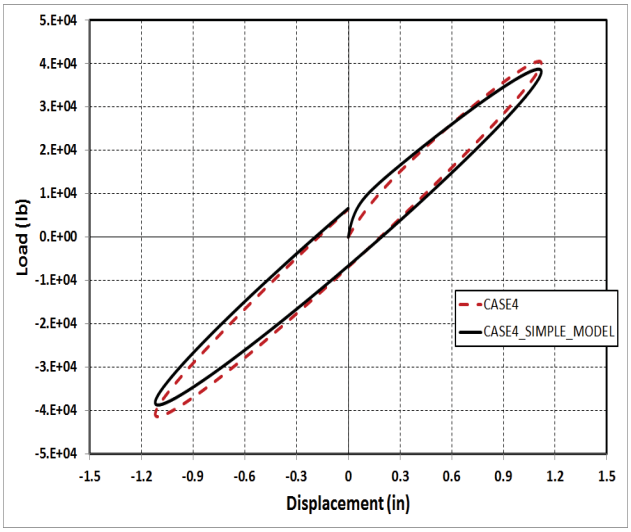


Fig. 6 Force-displacement relationship: case 4

V. Conclusion

This study developed the FE model of steel frame structures with and without damping panels and proposed the simple spring/dashpot model with respect to steel frames with FRP damping panels using ABAQUS. Finally, with increasing number of FRP panels, the performance of frame structures was improved with energy dissipation. Moreover, the seismic performance of steel frame structures with the damping panels was significantly improved during loading and reloading. Further this research can provide the fundamental modeling concept using spring/dashpot model to simplify the FRP damping panels in the frame structures.

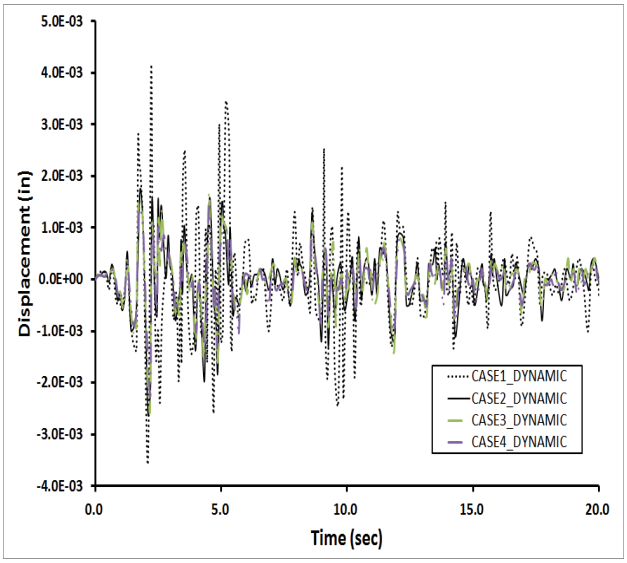


Fig. 7 Comparison of time history of the structures

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