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PERFORMANCE OF FRAMED STRUCTURES WITH ADJUSTABLE STEEL PLATE INFILL WALLS

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ABSTRACT

This study focused on the experimental evaluation on the seismic performance of framed structures with adjustable steel plate infill walls. Various combinations of component infill walls were connected by hinged restrainers to fulfill various architectural requirements, such as opening in the wall of the frame system. A series of cyclic loading tests were conducted on frames with various infill wall arrangements. It was observed from the tests that the damage was concentrated on the steel plates, while the frame and the restrainers remained intact. It was also found from the test results that the frame strength was governed by the number, thickness and arrangement of the component steel plates. Further comparisons on the frame performance showed that the adjustable steel plate infill walls significantly enhanced the stiffness, strength and energy dissipation of the framed system, thus justified the effectiveness of the proposed design method.

Keywords: Infill Wall; Strength; Energy Dissipation; Seismic Performance

1. INTRODUCTION

Steel plate shear walls (SPSW) have been proven to possess significant strength and energy dissipation capability thus are commonly used in seismic designs of framed structures (Behbahanifard et al., 2003; Berman and Bruneau, 2003; Chen and Jhang, 2011). SPSW can contribute significant strength enhancement to the structural frames, regardless lateral restraint is provided to the wall or not. The larger unsupported plate dimension of the un-restrained SPSW exhibits significant out-of-plane deformation and lower post-buckling performance when subject to seismic load, which is less desirable in the design. Enhanced performance in the restrained SPSW by adding stiffeners to the plate is a remedy to the wall-frame system. However the higher costs in such construction seem to raise obstacle in the effective application of the design.

In general, the design efficiency of SPSW greatly depends on the adequate connection between the structural members and the plate to develop effective tension field in the thin plate (Civian et al., 2000; Lin and Sugimoto, 2004; Tsai and Popov, 1990). Current designs of SPSW usually require expensive and extensive welding in the connection between the plate and the frame. Furthermore, the welded SPSW incurs closed wall systems that hamper the structural accessibility and design competiveness, such as opening for piping¸ architectural placements and necessity to replace entire plate after the earthquake excitation.

In order to further improve the wall-frame design, a method that using adjustable steel plate infill walls with grid internal connecting members was proposed in this study. This method recommended that the entire SPSW be divided into smaller plate segments. Each segment was bolt-connected by connecting members, and was connected to other segments according to the design requirements. This arrangement not only alleviated the higher welding demand in plate to frame connection, but also allowed flexibility for architectural functions.

To validate the feasibility and seismic performance of the proposed method, a series of cyclic loading tests were conducted on frames with various infill wall arrangements. Structural performance of the test frames, such as strength, deformation capability and energy dissipation capacity was compared to

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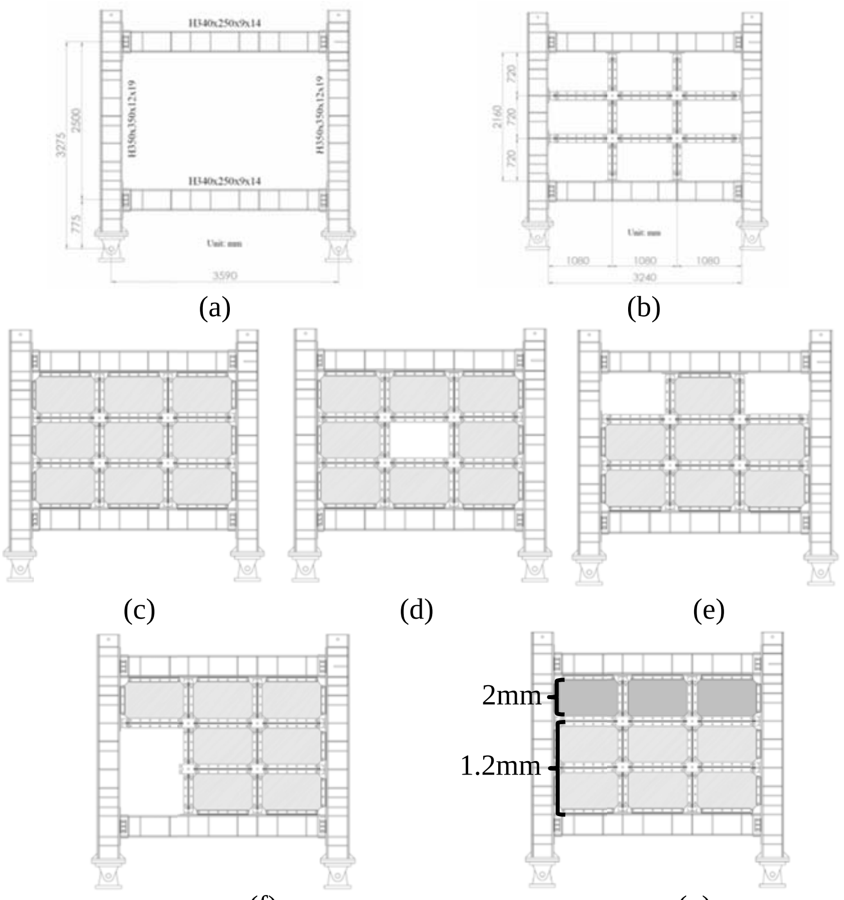
justify the applicability of the design method.

2. EXPERIMENTAL PROGRAM

Seven semi-rigid frames, including one moment frame, one frame with hinged internal grid connecting members, and five frames with various combinations of component infill walls, as shown in Figure 1, were fabricated for testing. The moment frame and frame with only internal connecting members were used to evaluate the influence of the internal connecting members and infill walls on the structural performance. Identical columns and beams were used for all test frames. They are SN490B H350x350x12x19 and H340x250x9x14, respectively. Story height and span of the test frame were 2500 mm and 3590 mm, respectively. The beam-to-column connections were composed of L130x130x9 top and seat angles and L100x100x10 web angles. The wall of the test frame was divided into nine component wall segments. Two SPHC thin plates with thickness equaling 1.2 mm and 2 mm, respectively, were used to manufacture the component wall segments. Various numbers of component walls were connected by structural tees according to the architectural demands. These combinations yielded different openings in the wall, allowing flexible arrangements for architectural functions. The test specimens were labeled in Table 1. In which, both 1.2 mm and 2 mm plates were used in WF-5, and only 1.2 mm plate was used in other test specimens.



(a) (b)

(c) (d) (e)

(f) (g)

Figure 1. Specimen details: (a)MRF-N; (b)MRF-R; (c)WF-1; (d)WF-2; (e)WF-3; (f)WF-4; (g)WF-5

The column bottoms of each test frame were hinged to the stiffened floor beam that was fastened on the strong floor. Top of the column was attached to a servo-controlled hydraulic actuator that was fixed on a reaction wall. A set of lateral support frame was used to stabilize the test specimen. Figure 2 shows the set-up of the test. Each test frame was subject to cyclic load generated by a series of increasing cyclic displacements. The loading histories were shown in Figure 3. Strain gages were installed on the beams, columns and the infill walls. LVDTs were used to measure the horizontal movements of the top and bottom beams and the diagonal displacements of the frames.

Table 1. Specimen details and responses.

Specimen	**No. of Infill Walls**	**Yield strength (kN)**	**Normalized yield strength**	**Ultimate strength (kN)**	**Normalized ultimate strength**
MRF-N	N.A.	43.6	1	143.1	1
MRF-R	N.A.	49.8	1.14	168.3	1.18
WF-1	9	281	6.44	662.6	4.63
WF-2	8	246.2	5.65	613.9	4.29
WF-3	7	217.5	4.99	510.6	3.57
WF-4	7	211	4.84	535.7	3.74
WF-5	3+6*	306.9	7.04	783.9	5.48

*Note：Three 2-mm-thick infill walls and six 1.2-mm-thick infill walls were used.

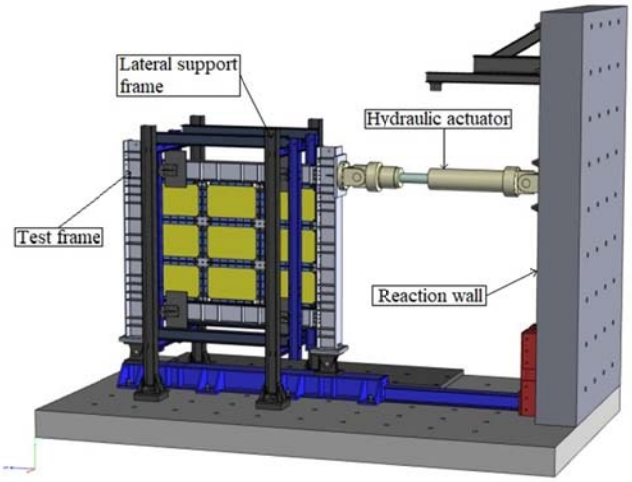


Figure 2. Test set-up

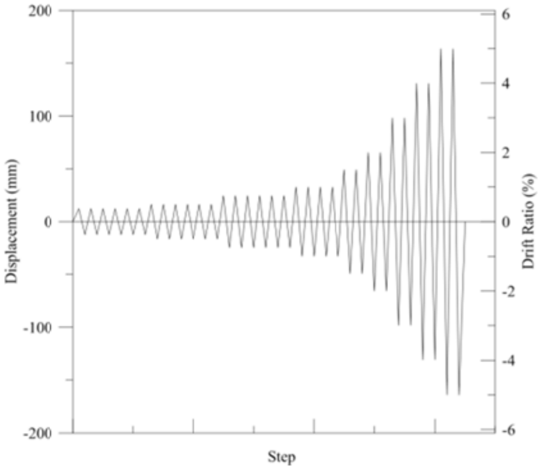


Figure 3. Loading histories

3. HYSTERETIC RESPONSES

The hysteretic curves of the test specimens are shown in Figure 4. It can be observed from the figure that all steel frames exhibited stable behavior throughout the loading histories. As observed from the tests, the damage in frames without infill walls was only found in the top and bottom angles of the semi-rigid connections. For test specimens with various infill walls, the steel plates exhibited inelastic buckling when story drift reached 0.375%. Stable hysteretic loops were observed with minor strength deterioration when the story drifts were increased. Tension field on the steel plate was developed when the drift ratio reached 1.5%.

Significant structural strength was sustained until plate fracture at the perimeters of plate-to-grid-member connection due to fatigue was exhibited, at 3% to 4% drift, depending on the various infill wall arrangements. It was further examined after the tests that the bolt connections between the infill wall and the connecting members remained intact, that validated the feasibility of the proposed connection method. Although various test frames exhibited different strengths, the connection design proposed in this study successfully linked the frames and the infill walls that allowed the system to develop sufficient deformation, i.e. higher than 3% drift. This phenomenon effectively justified the adequacy of the method. The typical failure patterns of test specimens with infill walls are shown in Figure 5.

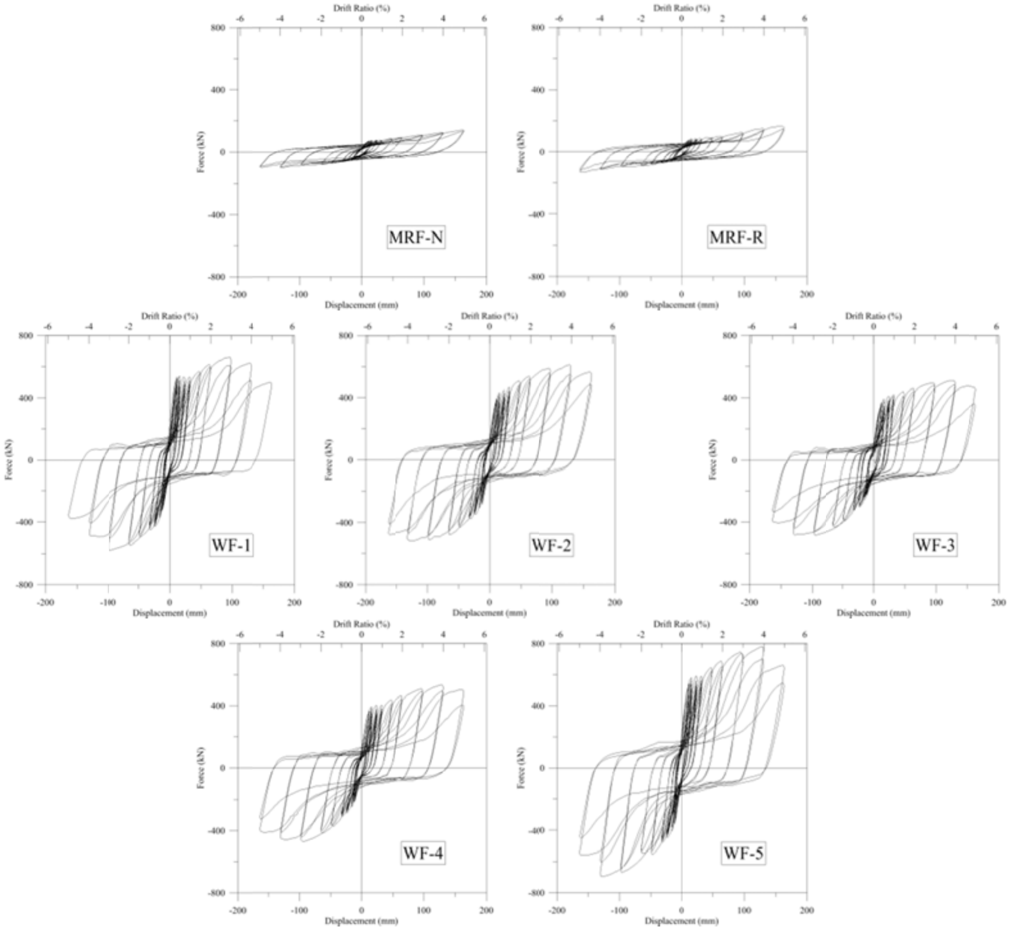


Figure 4. Hysteretic curves of the test specimens

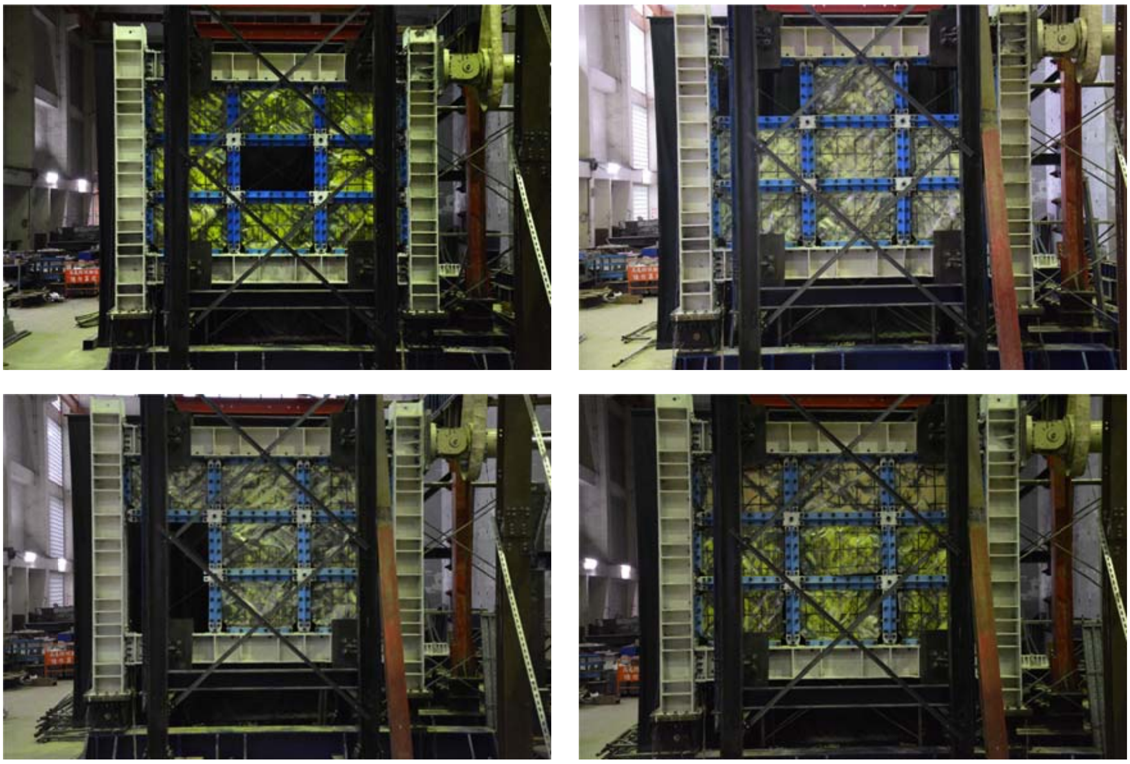


Figure 5. Typical failure patterns of the test specimens

4. STRENGTH IMPROVEMENT

The backbone curves of the test frames were compared in Figure 6. It can be found from the figure that the strength of frames with infill walls was significantly enhanced, and the influence of grid internal connecting members to the structural strength was minor. This phenomenon indicated that the major strength contribution in this design was achieved by the infill walls, instead of the grid connecting members. This mechanism simplified the complicated welded connection between the shear wall and structural frame in traditional design, allowing easier replacements of the buckled infill wall plates. Table 1 also lists the strength of the test specimens. Significant strength gains over moment frames, ranging from 3.57 to 5.48, for frames with infill walls were achieved.

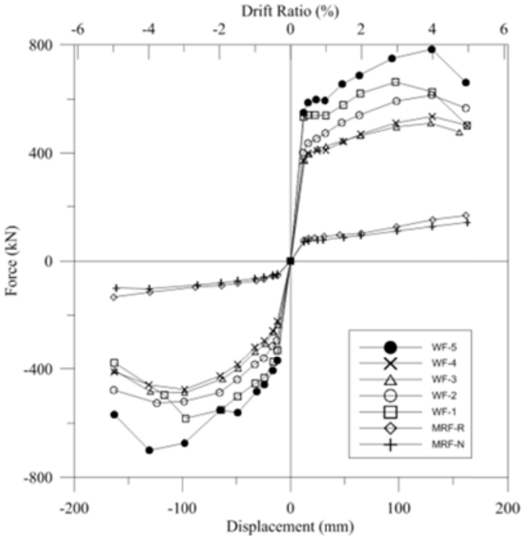


Figure 6. Comparison of backbone curves for the test specimens

5. ENERGY DISSIPATION

To further evaluate the contribution of infill wall to the structural performance, the energy dissipation, calculated by the cumulative area of the hysteretic loops, of the test specimens was compared. Figure 7 shows the cumulative energy dissipation for the test specimens. It can be found that the enhancement in energy dissipation for frames with infill walls was approximately 3.58 to 5.05 times of that without infill wall. It should be noted that the energy dissipation efficiency was significantly increased when the story drift reached 1.5%. This can be attributed to the development of effective tension field in the wall plate at that deformation. This phenomenon further validated the effectiveness of the proposed connection method.

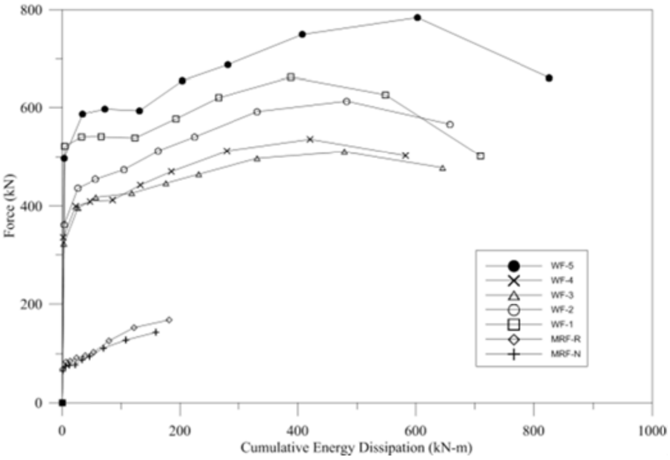


Figure 7 Comparison of energy dissipation for the test specimens.

6. CONCLUSIONS

This study proposed a new method for the infill wall system design. A series of cyclic loading tests on steel frames with various combinations of segmental infill walls were conducted. It was observed from the tests that effective tension field was successfully developed in the proposed system and the damage was only concentrated at the steel plates, while the frame and the grid connecting members remained intact. Further examinations on the bolt connections at the infill walls indicated the adequacy of the connection strength that avoided potential failure in the boundary. Significant enhancements in strength and energy dissipation validated the applicability of the proposed design method.

7. ACKNOWLEDGMENTS

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