Analysis of Steel Plate Shear Wall Performance with Two Wall Openings Modification

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Abstract*—Steel plate shear wall (SPSW) is one kind of steel earthquake resistant building structural stiffener that can dissipate the tremendous amount of quake energy, where the steel plate itself had been developed from years, and still in development. Ideally, SPSW is designed so all of its parts can absorb the energy of lateral force, seismic load for instance, through inelastic deformation. Because of that, the thickness of applied steel plate in a section of a building (a portal in this case) is determined by the shear force of the portal itself. In this research, experiment had been done using multiple applicable methods for the SPSW, where the use of it depends on the architect aspect and necessity. In this experiment, the specimen will be tested with some applicable lateral loading, where in the steel plate itself, there are two openings applied to the web plate. The result of the research shows some behavior changing of the dissipating energy throughout the steel plate, especially along the edge of the openings. Because of that fact, there are some performance degradation in the specimen, compared to the normal steel plate with stiffeners, which is 26.61% reduction of ultimate strength (624.01) kN at perforated specimen, compared to 850.24 kN at non-perforated specimen) and 11.5% reduction of dissipated energy.

***Keywords*—Steel Plate Shear Wall, Opening, Finite Element, Ductile Steel Structure.**

I. Introduction

The use of steel plate shear wall (SPSW) as one of the alternative solutions for building structure is increased from time to time [1]. The advantage from using SPSW is that the SPSW can dissipate massive amount of earthquake force [2]. At the beginning of 80's decade, the regulation of SPSW application was issued. The approach of SPSW application had been divided into two different kinds, which are unstiffened approach and stiffened approach. The approach without stiffener is popular until the early 2000. The US is the country that frequently use this kind of approach for their steel buildings. The common approach that used is at the Vertical Boundary Element (VBE), where it is designed to yield at the panel zone, and at the Horizontal Boundary Element (HBE), where it's designed to experience plastic hinge.

The approach that use stiffeners on SPSW gives some alternative solution form the problems previously mentioned. Additional stiffeners can change the buckling pattern at the steel plate, increasing the possibility of yield on all over the steel plate, before experience any buckle, and increasing the amount of dissipated energy. On the other hand, the disadvantages are that this method will get to cost more money and time [3].

On this research, two wall openings will be implemented on the steel plate element, with the bottom beam perfectly bounded on the ground. The performance of each specimen of steel plate will be compared after the simulation using finite element program.

II. Method

Two specimens modelled in this research, using one-fourth scaled measurement, consist of one steel plate panel, one top beam, one bottom beam perfectly bounded to the ground and two columns on the top of the bottom beam, surrounding the plate as a frame. These specimens were designed based on previous researches [4], [5] and had been checked by the current regulation.

The first specimen is called SSW-1, as shown in Figure. 1a. This specimen is a solid steel plate element with no opening and some stiffeners. The other specimen is called SSW-O, which O stands for the opening, as shown in Figure. 1b. The model looks similar to previous specimen, but with two symmetrical opening on the middle of the plate. Like the previous specimen, stiffeners are installed at the steel plate to divide it unto sub-panels.

The grade of steel that used in these specimens are St.14, which is a low yield strength steel, for the steel plate, St. 37 for the stiffeners and St.52 high strength steel for the beams and columns, detailed in Table 1. The stiffeners' width and thickness are 60 mm and 6 mm respectively, which is designed to prevent buckling on early stages of loading. The width and thickness of the beam flanges are 140 mm and 40 mm respectively, and the height and thickness of beam's web are 250 mm and 20 mm respectively. The thickness of the column flanges are 140 mm and 15 mm respectively, and the height and thickness of the column's web are 60 mm and 20 mm respectively. The connections are modelled as tie-constrain connection.

III. Results and Discussion

In order to measure all the important data, some methods are used in the Finite Element Program. Basically, by checking the displacement at the area of the applied load, compared to the force at certain displacement, the Hysteresis Curve will be gotten.

For SSW-1, in the 4th cycle of the loading, the specimen experience significant yielding at the side steel panel near the column, at 0.5 mm (0.13% drift) horizontal

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displacement, resulting shear force equals to 53.03 kN (Figure 3a.). In the 8¬th cycle of the loading, first yield at the flange from the bottom of left column occurred, at 9.98 mm displacement (1.04% drift) when the shear force is 410.09 kN (Figure 3b). At the 9th cycle, yield occurred at the top side of the column, leading to plastic hinge forming and the yield of the steel plate at the corner side. At the end of 9th cycle of the loading, the stiffeners received a relatively large amount of shear force compared to the other area (Figure 4a). At the 10th cycle of the loading, excessive buckling happened at the steel plate stiffener at the far side of loading direction (Figure 4b). In cycle 11th, the plate is fully experienced yield at all of the panels (Figure 5). The test was ended after 16 cyclic of loading, resulting an ultimate condition at 15th cycle with 67.79 mm displacement (7.03% drift) and base shear equal 850.24 kN. The specimen condition at ultimate form is shown in Figure 6a, while Figure 6b show the specimen after given all cycle of load.

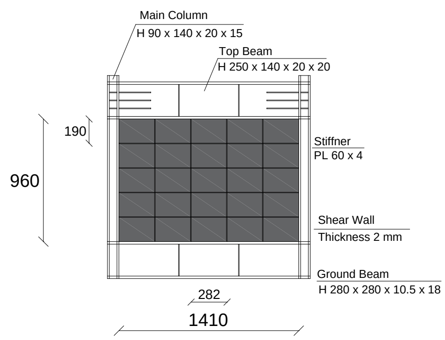

Figure 1a. SSW-1 Specimen.

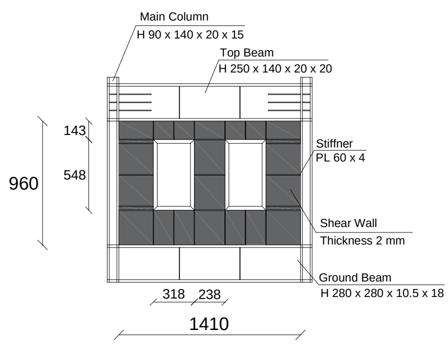

Figure 1b. SSW-O Specimen.

For SSW-O, in the beginning of the 5th cycle, the specimen experienced its first significant yielding at the steel panel near the column, just like the previous specimen, at 1.44 mm (0.26% drift) horizontal displacement. At this displacement, the base shear force is 18.69 kN (Figure 7a.). In the 7¬th cycle of the loading, first yield at the flange from the upper column, left side of the steel plate, occurred, at 7.35 mm displacement (0.78% drift) when the shear force is 67.17 kN (Figure 7b). At this state, the first plastic hinge at the column was formed. Later on, at the same cycle of the loading, yield occurred at the top side of the column, similar place where the first yield of the column occurred. After some cyclic of the loading, unlike the previous specimen, the stiffeners didn't bear significant value of shear stress, but still, at the 8th cycle of the loading, the specimen experience a clear local buckling at the stiffeners, at the bottom side of the specimen (Figure 8). In cycle 12th, the plate is fully experienced yield at all of the panels (Figure 9). After 16 cyclic sets of loading, the test was ended. Before the end of the test, an ultimate condition had been reached at 15st cycle of the loading (Figure 10a) with 59.74 mm displacement (7.03% drift). At this stage, base shear equal 624.01 kN. Figure 10b is the picture of SSW-O at the end of the test.

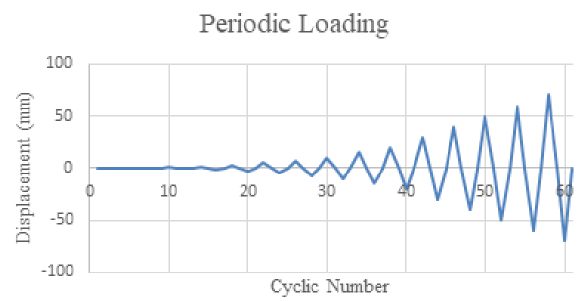

Figure 2. Periodic Loading Applied to Specimen.

TABLE 1.
MATERIAL SPECIFICATION

Material (German Standard)	f_y (MPa)	f_u (MPa)
St 14	192.4	277.2
St 37	258.3	390.4
St 52	414.9	551.8

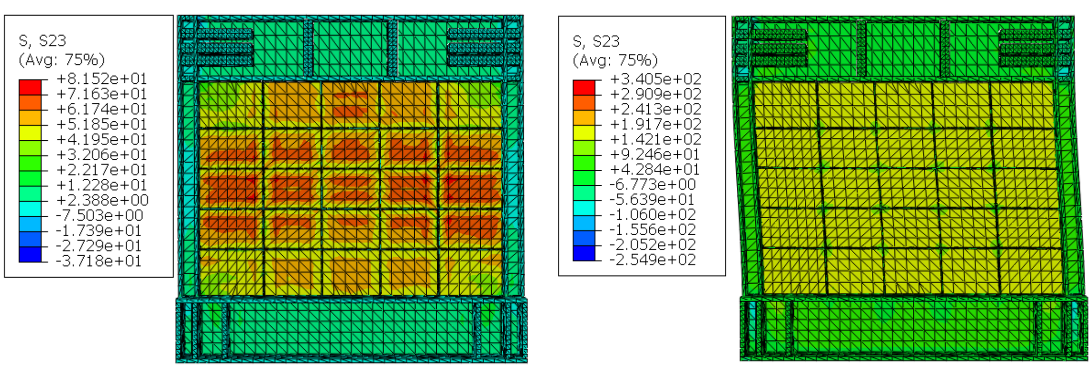

Figure. 3. (Left) First Yield of the Specimen SSW-1 (Right) First yield at the Column.

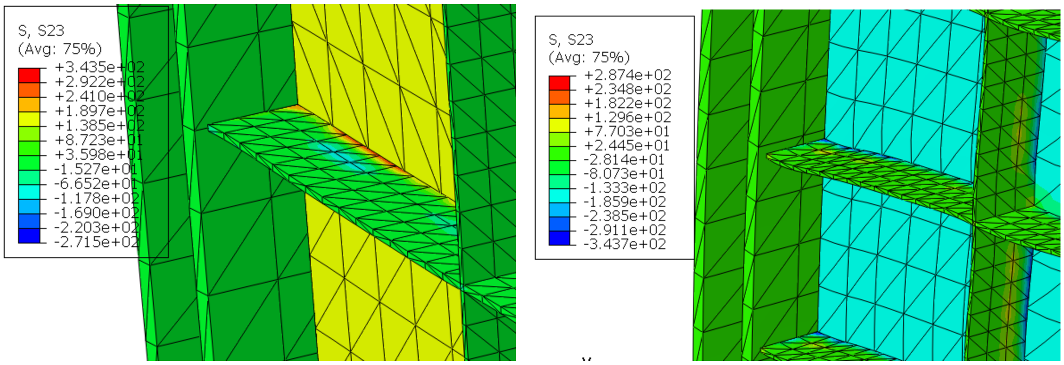

Figure 4. (Left) Stiffeners bear a significant large amount of shear force (Right) Excessive Buckling at Stiffeners

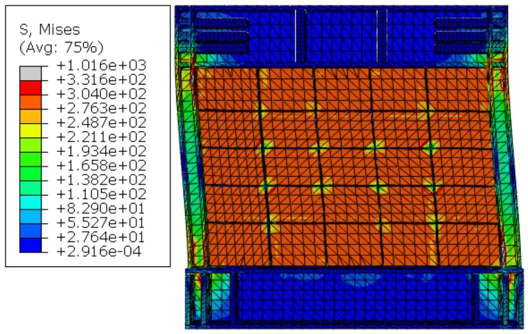

Figure 5. Condition at Fully Yield Panels

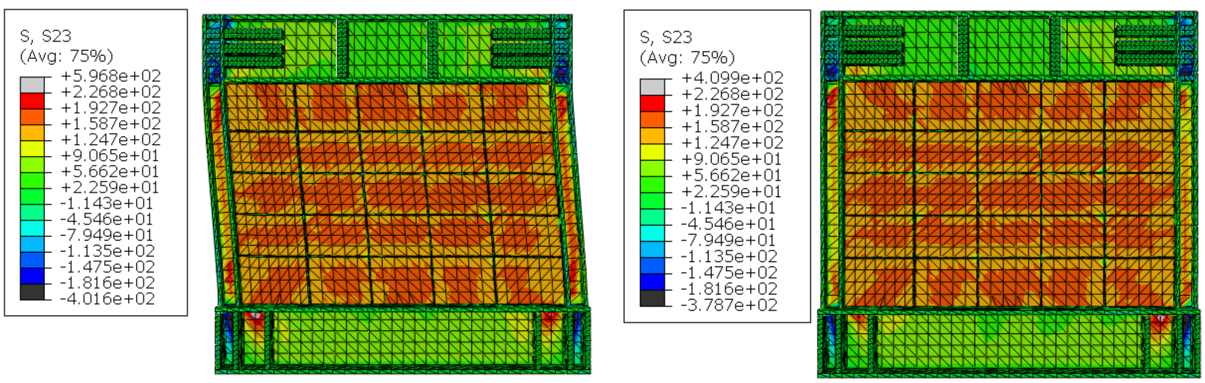

Figure 6. (Left) Specimen at Ultimate Condition (Right) Specimen at the End of the Test

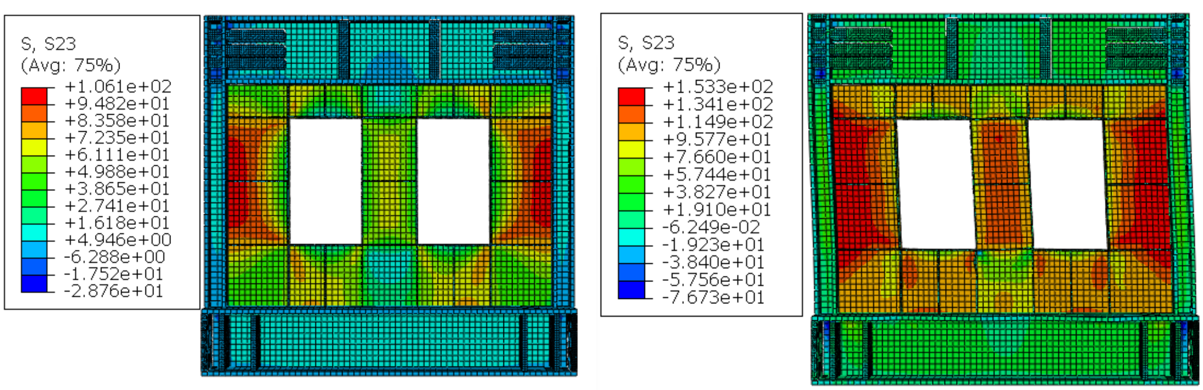

Figure 7. (Left) First Yield of the Specimen SSW-1 (Right) First yield at the Column

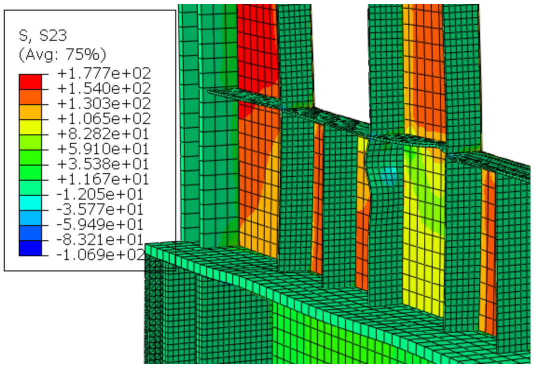

Figure 8. Local Buckling on the Stiffeners at Bottom Side of Steel Plate.

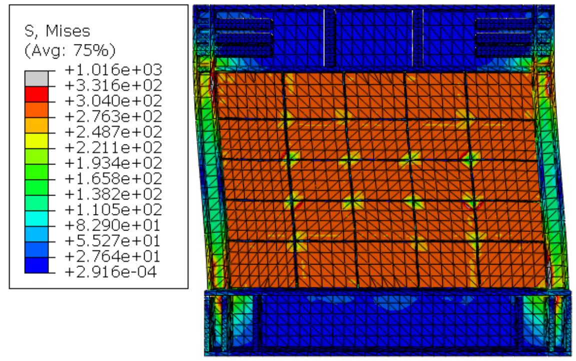

Figure 9. Specimen when Experienced Yield on All Steel Plate Panels

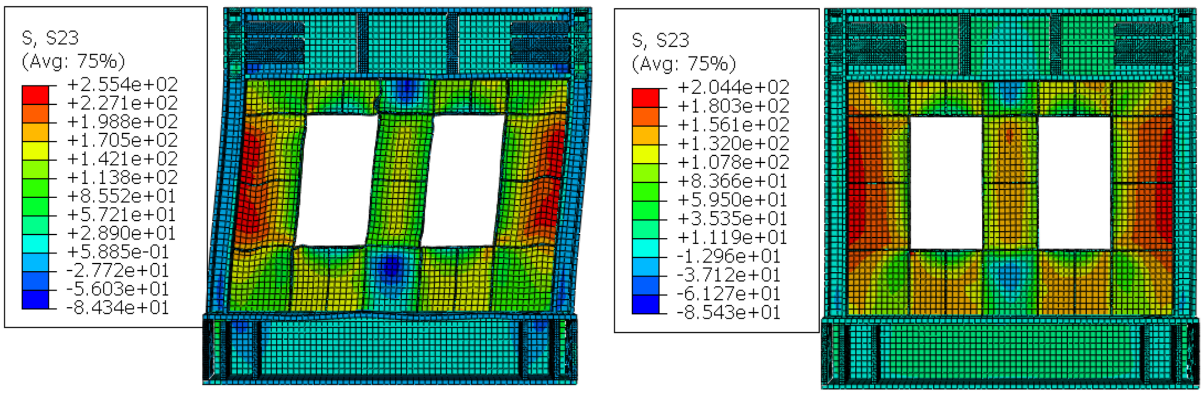

Figure 10. (Left) Specimen at Ultimate Condition (Right) Specimen at the End of Test.

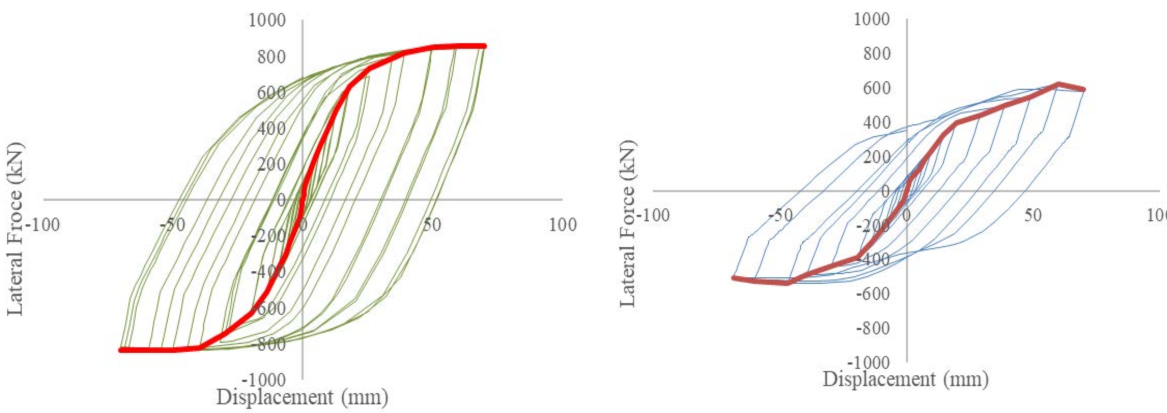

Figure 11. (Left) SSW-1 Hysteresis Curve (Right) SSW-O Hysteresis Curve.

In the unperforated specimen (SSW-1), the first yield occurred at the early stages of the loading. It's a known fact, because the material that used in the steel plate is a low-yield steel (LYS). It's a common knowledge too, that LYS are quicker to experience buckling than to reach its potential yield point. But, in this specimen, the steel plate can reach its yield point because of the stiffeners. The stiffeners set in this specimen is effectively prevent the local buckling on the plate. As can be seen in Figure 3, the yield started at the sides of the plate, and went all the way to top side through the middle section. Even on the later stage of the loading, when there were buckling at some point from the stiffeners and plastic hinge formed at the column, the base shear still went up, until the end of the loading series. The hysteresis curve of this specimen can be seen in Figure 11a.

In the perforated specimen (SSW-O), the specimen experienced its first yield a bit quicker than the previous specimen. It's understandable because the openings gave a clear difference between them. Many parts of the plate experienced buckle before reach the yield point, for instance, the panel between the openings, at the top and bottom side. Even after given the set of loading, these panels received the least amount of shear force, compared to the other section. In the other hand, the panels at the outer side of the openings immediately reach the yield point. Since this point, these sections received the largest amount of shear force by turn. After the test is done, these panels still hold the residual force, as can be seen in Figure 10b. In Figure 11b, hysteresis curve of SSW-O specimen is shown.

By comparing these two specimens, it can be seen that there are several differences caused by additional properties (opening) at the steel plate. As for the dissipated energy comparison, it can be seen in Figure 12. It is clear that additional opening may cause smaller amount of dissipated energy, because at the later stage of loading, the hysteresis curve of the perforated specimen become smaller.

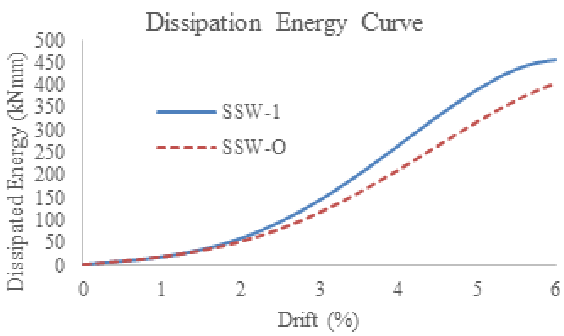

Figure 12. Dissipated Energy Comparison

IV. Conclusion

Based on the test result, following conclusion can be drawn:

1. Plastic hinge was formed at the outer flange of the column, on the top side of both specimens. The wall openings have small to none effect of this occurrence.
2. There is several buckling on stiffeners near the column at first specimen. But on the perforated specimen, buckling mainly happened at the stiffeners near the bottom beam, between the two openings. Clearly the openings were taking the cause of this phenomenon.
3. The effect of the openings on the ultimate strength and dissipated energy are significantly large. It can be seen from the curve, the ultimate strength for SSW-1 and SSW-O are 850.24 kN and 624.01 kN respectively. It means, the ultimate strength decreases down by 26.61%. Meanwhile, the dissipated energy decreases down by 11.5%, as can be seen on Figure.12.
4. Higher ultimate strength and dissipated energy mean good performance. But, considering the advantage of perforated SPSW with only mentioned decreases, it is important to know that the prize to building structural point of view, it is affordable.

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