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Effects of Stud Spacing, Sheathing Material and Aspect-ratio on Racking Resistance of Shear Walls*1

Sang Sik, Jang*2†

ABSTRACT

This study was carried out to obtain basic information on racking resistance of shear walls and the factors affecting racking resistance of shear walls. Shear walls constructed by larch lumber nominal 50 mm × 100 mm framing and various sheathing materials were tested by applying monotonic and cyclic load functions. Shear walls with various stud spacing such as 305 mm, 406 mm, and 610 mm were tested under both of monotonic and cyclic loads and shear walls with various aspect (height-width) ratios were tested under cyclic load functions. The effect of hold-down connectors in shear walls was also tested under cyclic load functions. Racking resistance of shear walls has very close linear relation with stud spacing and width of shear walls. The ultimate racking strength of shear walls was reached at around or before the displacement of 20 mm. It was proposed in this study that the minimum racking strength and minimum width for shear wall be 500 kgf and 900 mm, respectively. Load-displacement curves obtained by racking tests under monotonic load functions can be represented by three straight line segments. Under cyclic load functions, envelope curves can be divided into three sections that can be represented by straight lines and the third section showed almost constant or decreasing slope.

Keyword: shear walls, racking resistance, aspect ratio, stud spacing, sheathing material, cyclic load function, monotonic load function

1. INTRODUCTION

Wood frame houses, especially light-frame wood structures, are becoming more and more popular in Korea. In Korea, wood construction was started by import of design and materials from Canada and the United States about 10~15 years ago. Therefore, design principle was also adopted from the Uniform Building Code (UBC) which is the basic building code applied in northwestern area of the United States because there has been no Building Code regulating light-frame wood construction in Korea. Recently, a Code for structural design of wooden structures are being formulated in Korea and the standard for light-framing wood construction is included in that Code.

When considering the loading conditions

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*2 Dept. Forest Products, Chungnam National University, Daejeon 305-764, Korea.
† Corresponding author : Sang Sik Jang (ssjang@hanbat.chungnam.ac.kr)

applied to structures in Korea, wooden houses built currently in Korea are being over-designed because the design principle applied in Northwestern area of the United States is applied in Korea without verification. In Korea, there is no earthquake and less wind than Northwest of the United States. Therefore, the required lateral-force-resisting system can be decreased and less stiff materials can be used to compose shear walls in Korea. This study was initiated to formulate Korea Industrial Standard (KS) for the testing method on shear wall, to verify lateral resistance of shear walls with OSB sheathing and gypsum board and to make recommendation on shear wall construction for the wood building industry in Korea.

Most of light-frame wooden houses employ shear wall as a lateral-force resisting system. Shear wall is one of the most important structural components in light-frame wood buildings. There are a lot of variations including framing member, sheathing material, nail, nailing method, anchoring, openings, etc. in constructing shear walls. Therefore, the exact method applicable to every case of shear wall design is not developed yet. Most of shear wall design is largely dependent on experience. Skaggs and Rose (1996) analyzed the differences between several testing standards on shear walls including ASTM E72, ASTM E 564 and SEAOSC and concluded that cyclic tests closely predict actual shear wall performance. Durham, *et al.* (1998), Karacabeyli and Ceccotti (1996), and Leiva-Aravena (1996) tested various types of shear walls such as various height, width and openings under monotonic and cyclic loads. Johnson and Dolan (1996), Line and Douglas (1996), and White and Dolan (1996) tested perforated shear walls and suggested a design method for shear walls under monotonic and cyclic loads. Gebremedhin (1998) analyzed various testing results and made recommendations for increasing stiffness and strength of diaphragm. Shear walls with various openings and height-width ratio were also tested by pseudo-dynamic method in which loading sequences adopted from actual earthquakes were applied to shear wall specimens (Kamiya, Sugimoto, and Mii, 1996; Kawai, 1998).

In this study, shear walls constructed with various stud spacing, sheathing materials and aspect (height-width) ratio were tested under monotonic and cyclic load functions.

2. MATERIALS and METHOD

Framing materials were selected from nominal 50×100 mm(actual 38×89 mm) larch (*Larix kaemferi Carr.*) lumbers of No. 2 grade. Sheathing materials include 8.7 mm thick plywood of C-D Exterior grade and 11.7 mm thick OSB of rated sheathing grade (Span ratio of 24/16). For lumber, plywood and OSB, moisture contents were 11.6%, 8.7% and 5.7%, respectively, and specific gravities were 0.46, 0.46 and 0.64, respectively, at the time of testing. 6d box nails were used to attach plywood and OSB sheathings to studs and 16d nails were used to connect between studs and plates.

To get basic data for racking resistance of shear walls, 1,220×2,440 mm wall specimens were constructed for plywood and OSB sheathings with 305 mm, 406 mm and 610 mm stud spacing. The specimens were tested by applying monotonically increasing load with load speed of 10 mm/min and cyclic load function given in Fig. 1 with loading rate of 0.5 Hz. Displacement of shear wall was measured at the top and center of the height by LVDT.

To get information about the effect of aspect (height-depth) ratio to racking resistance of shear walls and the minimum required width as a shear wall, specimens of various aspect ratio

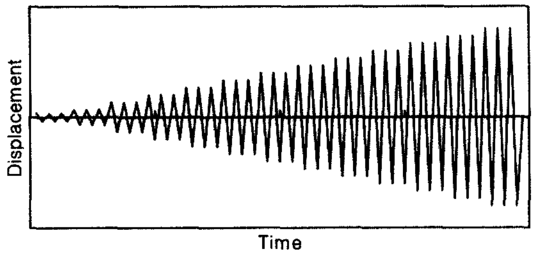

Fig. 1. Cyclic load function employed in this study.

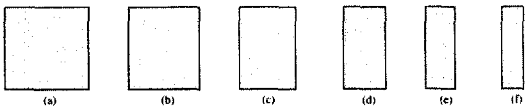

Fig. 2. Shear wall specimens with various height-width ratios: (a) 2,440×2,440, (b) 2,440×2,034, (c) 2,440×1,637, (d) 2,440×1,220, (e) 2,440×813, and (f) 2,440×406 (unit: mm).

as shown in Fig. 2 were constructed with 406 mm stud spacing and OSB sheathing. Specimens in Fig. 2 had 2,440 mm height and 406, 813, 1,220, 1,627, 2,034 and 2,440 mm width, respectively. All the specimens in Fig. 2 were tested by applying cyclic load function given in Fig. 1.

Testing arrangement and method given in KS F 2154 were applied to racking test of shear walls. Hold-down connectors were used at both ends of shear walls specimens, and those in Fig. 2 were also tested without hold-down connectors to check the effect of hold-down connectors on racking resistance of shear walls.

3. RESULTS and DISCUSSION

3.1. Effect of Sheathing Material and Stud Spacing

Typical load-displacement curves obtained from racking tests of shear walls under monotonic load are given in Fig. 3. As shown in Fig. 3, shear wall with OSB sheathing was slightly stronger than that with plywood sheathing under monotonic load. This difference was considered to be caused by the thickness difference between OSB and plywood. Experimental data of racking test for shear wall can be represented by three straight lines as given in Fig. 3. Slope of these straight lines represent stiffness of shear wall, and equation and R^2 (coefficient of determination) for these lines are given in Table 1.

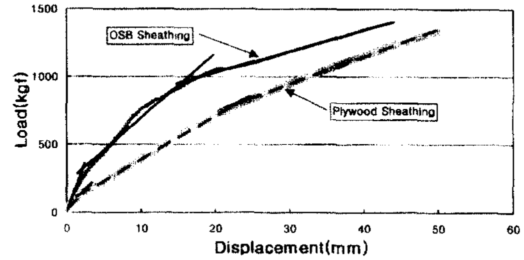

Fig. 3. Racking resistance of shear walls with OSB and plywood sheathing under monotonic load function.

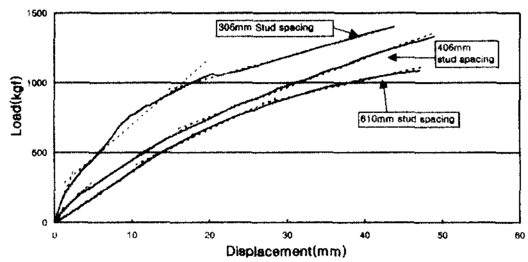

Fig. 4. Racking resistance of shear walls with various stud spacing under monotonic load function.

Racking strength of shear walls with different stud spacing under monotonic load is shown in Fig. 4. As shown in Fig. 4, racking strength of shear wall increased as stud spacing decreased. Racking behavior of shear wall under monotonic load can be represented by three straight lines as given in Fig. 4. Equations and R^2 values are given in Table 1.

Typical load-displacement curve obtained from shear wall testing is given in Fig. 5. In

Table 1. Equation and R^2 values for straight lines representing racking resistance of shear walls under monotonic load.

Type of shear wall	Stud spacing (mm)	Regression line	1st line	2nd line	3rd line
Shear wall with plywood sheathing	305	Equation[a]	58.59X + 18.21	32.16X + 69.50	20.58X + 327.81
		R^2	0.981	0.999	0.998
Shear wall with OSB sheathing	305	Equation[a]	150.96X + 5.24	47.67X + 221.25	15.65X + 719.94
		R^2	0.991	0.964	0.996
Shear wall with OSB sheathing	406	Equation[a]	59.59X + 14.13	34.74X + 94.10	20.96X + 337.00
		R^2	0.986	0.998	0.996
Shear wall with OSB sheathing	610	Equation[a]	37.32X 9.45	26.76X + 129.58	12.70X + 512.22
		R^2	0.999	0.991	0.984

[a] Equation obtained on the basis of load in kgf unit and displacement in mm unit. 1 kgf = 9.8 N.

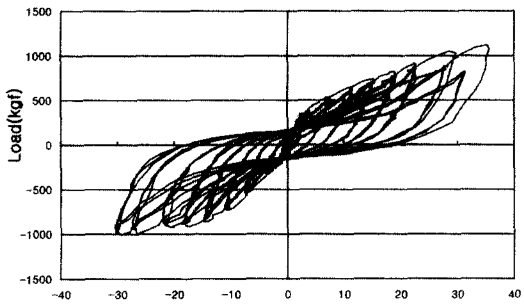

Fig. 5. Typical load-displacement curve obtained from racking tests of shear wall under cyclic load function.

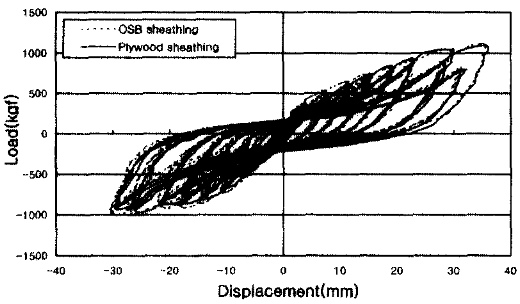

Fig. 6. Load-displacement curves obtained from racking tests of shear walls with OSB and plywood sheathing.

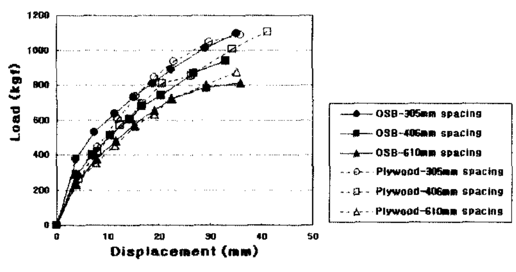

Fig. 7. Average initial envelope curves for shear walls with plywood and OSB sheathing under cyclic load function.

Fig. 5, the curve connecting the maximum point of each cycle is defined as envelope curve and the curves for the first and third cycles are defined as the initial envelope curve (IEC) and the stabilized envelope curve (SEC), respectively. Average of envelop curves of tension and compression sides of load-displacement curve is called average envelop curve (AEC).

Fig. 6 shows load-displacement curve obtained from racking tests of shear walls with OSB and plywood sheathing with 406 mm stud spacing and 6d box nail connections. As shown in Fig. 6, OSB and plywood sheathing show very

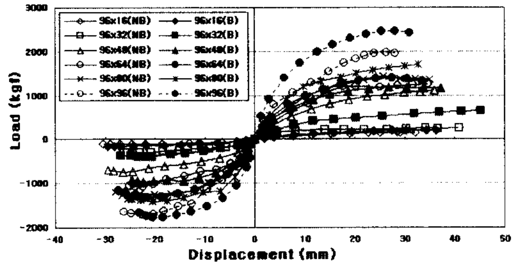

Fig. 8. Initial envelope curves for shear walls with various height-width ratio: In legend, NB means specimens without hold-down connector and B means specimens with hold-down connectors at both ends.

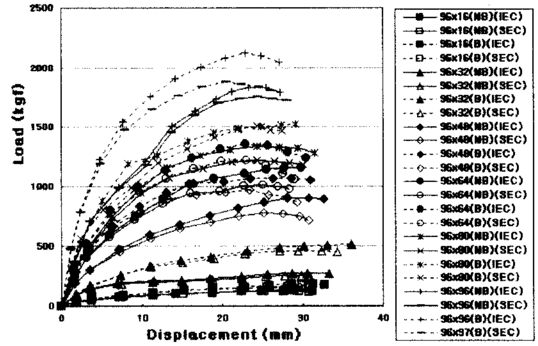

Fig. 9. Average envelope curves for shear walls with various height-width ratio.

similar racking resistance. Fig. 7 shows average initial envelope curves (AIEC) for shear walls with OSB and plywood sheathing and various stud spacing such as 305, 406 and 610 mm. OSB and plywood sheathing showed very similar envelope curves, and the slope of envelope curve increased as stud spacing decreased.

3.2. Effect of Height-width Ratio

Initial envelope curves (IEC) for shear wall specimens with various height-width ratio are given in Fig. 8 for tension and compression sides. These specimens were tested for both of with hold-down connectors at both ends of specimens and without hold-down connector to check the effect of hold-down connectors on racking resistance. Stabilized envelope curves (SEC) for the same specimens were similar to Fig. 8 but showed slightly lower values. As shown in Fig. 8, racking resistance of shear walls increased when hold-down connectors were used. Actually, hold-down connectors are required to simulate the vertical load applied to shear walls from the upper structures in the actual environment.

The average envelope curves can be used to represent racking resistance of shear walls at the given loading cycle. Average IEC and average SEC are given in Fig. 9 for shear walls with various height-width ratio. As height-width ratio increased, racking resistance of shear walls increased and hold-down connectors also contributed in increasing the racking resistance. Most of envelope curves showed the maximum at around 20 mm displacement. Therefore, it may be possible to say that the ultimate strength of shear wall is the maximum load or the load corresponding to 20 mm displacement even though more comprehensive testing is required to make conclusion.

The ultimate strength for each specimen as a function of wall width is given in Fig. 10. As shown in Fig. 10, the ultimate strength of shear walls showed a linear relation with width of walls. Therefore, it can be concluded that the ultimate strength of shear wall is linearly proportional to the width of shear wall. The R^2 values for the ultimate strength values and wall widths were all greater than 0.97. Therefore, the linear equation can be used to estimate the ultimate racking strength of shear walls.

If we can determine the required minimum racking strength for shear walls, the minimum required width of shear wall can be calculated from the equations in Fig. 10. For example, if the required minimum racking is 500 kgf for shear wall, then around 955 mm can be

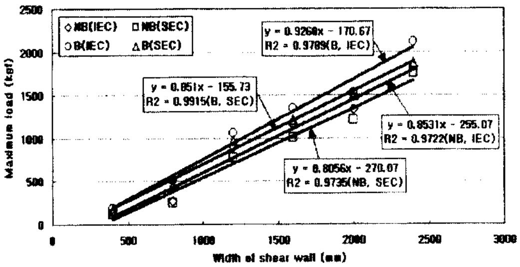

Fig. 10. Ultimate racking strength of shear walls with various height-width ratio.

obtained as the minimum width for shear walls from the equation for NB (SEC) (stabilized envelope curve for specimens with no hold-down connector). This value is similar to the minimum required shear wall width of 900 mm set in the Standard Code for the design of wood structures that was recently formulated in our country.

4. CONCLUSION

To get basic information on racking resistance of shear walls, shear wall specimens with larch lumber framing, plywood and OSB sheathings and various height-width ratios were tested under monotonic and fully reversed cyclic load functions. Shear walls with OSB and plywood sheathing showed similar racking resistance to each other under monotonic and cyclic load functions. Racking resistance of shear walls increased as stud spacing decreased. Experimental data obtained from racking tests under monotonic load can be represented by three straight lines.

Under cyclic load function, envelop curves can be divided into three sections, and the ultimate racking resistance was appeared between second and third section at which the displacement equal to or less than 20 mm. Racking resistance of shear wall showed linear relationship with the width of shear wall. It looks reasonable to set the minimum required strength of shear wall as 500 kgf and to set the minimum required width of shear wall as 900 mm.

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