World Conference on
Timber Engineering
Oslo 2023

IMPACT OF EXTERIOR SIDING WALLS AND THE CONNECTING METHODS IN WOODEN HOUSES: COMPARATIVE VERIFICATION FOR STRUCTURAL PERFORMANCE WITH DIFFERENT CONNECTION METHODS OF WALL SIDINGS

Kouta Matsumoto [1], Kiyotaka Terui [2], Hideyuki Nasu [3]

ABSTRACT: In recent years, siding has been widely used for the exterior walls of Japanese houses. There are two methods of installation: nailing (hereinafter referred to as "nailed SD") and hooking with metal fittings (hereinafter referred to as "hooked SD"). Previous research [2] shows that nailing bears about 10% of the external force, but it is not clear how much external force is borne by the hooked SD. In this study, we will examine the extent to which a hooked SD bears the external force in terms of wall magnification. The objective was also to elucidate the contribution of the SD itself to the wall magnification. The specimens were subjected to static force tests to extract the structural performance of each load-bearing element. Static force tests revealed the following results compared to the nailed SD, which was the mainstream method at the time. The present mainstream hooked SD was found to have reduced bearing capacity.

KEYWORDS: Wooden Houses, Exterior Materials, Sidings, Static Force Tests, Non-structural Members

1 INTRODUCTION

There are two methods of finishing the exterior walls of wooden houses: wet methods, such as mortar exterior walls, and dry methods, such as siding (hereinafter referred to as "SD"). Wet methods have been commonly used in the past, but in recent years, dry methods have been widely used in order to shorten the construction period and to address the shortage of skilled workers. There are two types of installation methods for ceramic-SD: Nailed SD (Figure 1) and Hooked SD (Figure 2).

In the past, nailed SD was the most common method, but cracks and defects occur around the nails due to inter-story deformation caused by external forces such as earthquakes. However, since hooked SD does not cause major visible damage such as cracks and defects like nailed SD, hooked SD is currently the most common type of SD. However, since hooked SD is a method in which the SD is hooked to the joints, it is considered to have almost no ability to restrain the interstory deformation of the frame against external forces such as seismic forces, and there is concern that the actual bearing capacity may be reduced.

The Architechal Institute of Japan [1] states that 2/3 of external forces such as seismic forces are borne by bearing walls and 1/3 by non-bearing walls such as SD. The same style for [2] states that nailed SDs bear about 10% of the external force. The same style for [3] and other full-scale experiments have also been conducted, but it has not been clarified how much external force is borne by hooked SDs.

Figure 1: *Nailed SD*

Figure 2: *Hooked SD*

2 OBJECTIVE

The purpose of this study is to determine how much external force is borne by a hooked SD in terms of wall modulus by subtracting the structural performance of the bearing wall itself from the structural performance of the bearing wall to which the SD has been applied. The purpose of this study is to clarify the contribution of the SD itself to the wall ratio.

3 SUMMARY OF RESEARCH

3.1 TEST SPECIMEN SUMMARY

In order to extract the structural performance of each load-bearing element, the test specimens were constructed using the Single-sided fascia (Figure 3) and Single-sided plywood (Figure 4) specifications as load-bearing walls, as well as the Nailed SD (Figure 5) and Hooked SD (Figure 6) specifications with the SD fastened to the frame to grasp the structural performance of the different

[1] Kouta Matsumoto, Graduate Nippon Institute of Technology, JAPAN, Email: kouta.matsumoto.1113@gmail.com
[2] Kiyotaka Terui, POLUS R&D Center of Life-Style Co., Ltd. JAPAN, Email: 01452terui-sz@polus.co.jp
[3] Hideyuki Nasu, Prof., PhD. in Eng, Nippon Institute of Technology, JAPAN, Email: hideyuki.nasu@nit.ac.jp

https://doi.org/10.52202/069179-0443

fastening methods for ceramic SD, a dry construction method.

In addition, in order to understand the bearing capacity of the SD when installed in a load-bearing wall, tests were conducted using six specifications: a Single-sided fascia specification with SD fastened to the Single-sided fascia specification and a Single-sided fascia + nailed SD specification (Figure 7), and a Single-sided fascia specification with SD fastened to the Single-sided fascia + hooked SD specification (Figure 8). The test specimens were conventional wooden walls with a core width of 3640 mm for columns and a core distance of 2730 mm for transverse members, with 105 mm square cross sections for columns and foundations, 105 mm x 30 mm for studs, 180 mm x 105 mm for beams, and 90 mm x 45 mm for braces. In order to suppress bending deformation of the beams and pull out of the columns due to up thrusting of the braces, which bear the compressive force, yamagata plates were attached to the top and bottom ends of the middle columns that are connected to the transverse members on the back of the specimens.

The thickness of SDs was 14 mm for nailed SDs and 15 mm for hooked SDs, and joints were made with joints dedicated to each SD (Figures 9 and 10).

3.2 EXPERIMENTAL SUMMARY

The static in-plane shear static force test was conducted using a force frame tester at the POLUS R&D Center of Life Style with a fixed leg using three repetitive positive-negative alternating cycles of force as described in The same style for [4] (Figure. 11 and 12). The applied force was controlled by displacement, and three push-pull cycles of 1/450, 1/300, 1/200, 1/150, 1/100, 1/75, and 1/50 rad. were performed, and only those that could be applied up to 1/30 rad. were pushed and pulled once. Thereafter, pull-destruction was performed with a target of 1/15 rad. The deformation for each interlaminar deformation angle that was repeated is shown in Table 1.

Table 1: Deformation for each interlaminar deformation angle

Interstitial deformation angle (rad.)	1/450	1/300	1/200	1/150
Amount of deformation (㎜)	6.06	9.10	13.65	18.20
Interstitial deformation angle (rad.)	1/100	1/75	1/50	1/30
Amount of deformation (㎜)	27.30	36.40	54.60	91.00

3.3 EVALUATION METHOD

The SD contribution ratio is calculated by dividing the wall ratio of the wall with SD installed by the wall ratio of the single-sided fascia bearing wall specification; the SD contribution ratio is calculated by dividing the wall ratio of the single-sided fascia bearing wall specification with SD installed by the wall ratio of the single-sided fascia bearing wall specification. The burden ratio was calculated by dividing the contribution ratio by the wall ratio of the single-sided fascia bearing wall specification with SD installed.

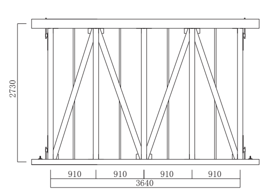

Figure 3: *Single-sided fascia specifications*

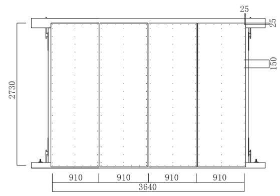

Figure 4: *Single-sided plywood specification*

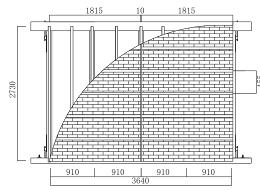

Figure 5: *Nailed SD specification*

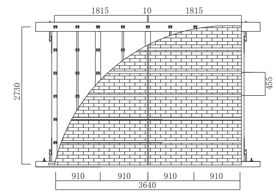

Figure 6: *Hooked SD specification*

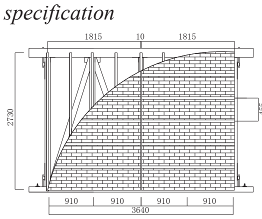

Figure 7: *Single-sided fascia + nailed SD specification*

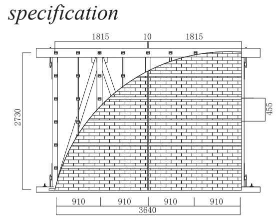

Figure 8: *Single-sided fascia + hooked SD specification*

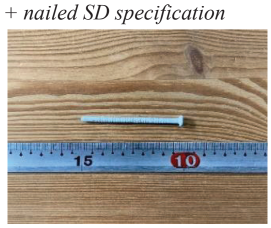

Figure 9: *Dedicated fittings (stainless steel nails)*

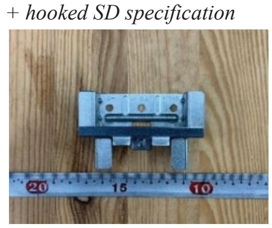

Figure 10: *Dedicated fittings (hooks)*

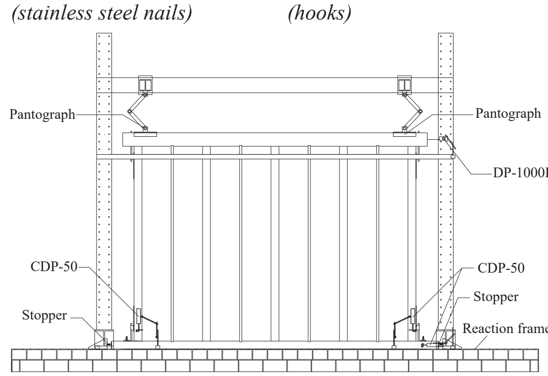

Figure 11: *Test object installation status*

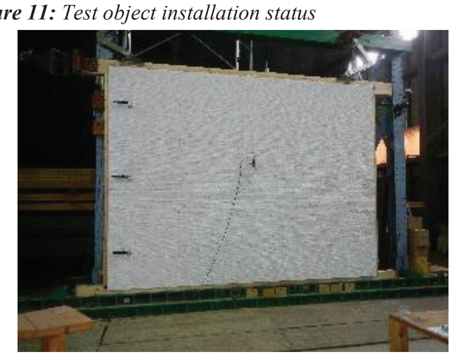

Figure 12: *Actual test unit installation (SD wall)*

https://doi.org/10.52202/069179-0443

4 EXPERIMENTAL RESULTS

The relationship between load and horizontal displacement for each specification is shown in Figures 13~16, and the Pa determinants and calculated wall factors for each specification are shown in Table 2. The wall magnification of the Single-sided fascia specification was 2.18 times compared to the assumed wall magnification (2.00 times), which is almost equivalent. The wall factors for walls with SDs constructed using different fastening methods were 1.14 times for the Nailed SD specification and 0.28 times for the Hooked SD specification. In addition, the wall-to-wall ratio of the Single-sided fascia + nailed SD specification, in which SD was fastened to the Single-sided fascia wall, was 4.08x, which was much higher than the value obtained by adding the wall-to-wall ratios of the Single-sided fascia and nailed SD specifications (3.32x). The value of 2.39 times for the Single-sided fascia + hooked SD specification was almost equal to 2.46 times, which is the value obtained by adding the wall factors for the one-sided rebar and hooked SD specifications. The single-sided plywood specification showed a wall factor of 2.50 times, the same as the assumed wall factor.

The nailing SD itself was converted to a wall factor of 1.90 times and the burden ratio was 46.5%, while the hooking SD itself was converted to a wall factor of 0.21 times and the burden ratio was 8.7%.

Table 2: *The Pa determinants for each specification and the calculated Wall ratio*

	Py(kN)	2/3Pmax(kN)	Pr(kN)	(0.2/Ds)×Pu(kN)	Wall facto
Single reinforcement specification	16.16	18.99	19.44	15.61	2.18
Single-sided plywood specification	17.87	22.50	26.27	18.48	2.50
Nailed SD specification	12.16	15.59	8.68	8.19	1.14
Hooked SD specification	4.62	5.83	2.16	2.00	0.28
Single-sided fascia + nailed SD specification	29.15	36.35	30.23	30.36	4.08
Single-sided fascia + hooked SD specification	20.54	22.18	21.19	17.11	2.39

※Paint sections are Pa determinants

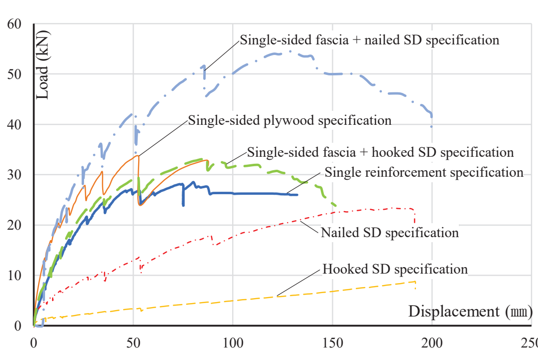

Figure 13: *The relationship between load and horizontal displacement*

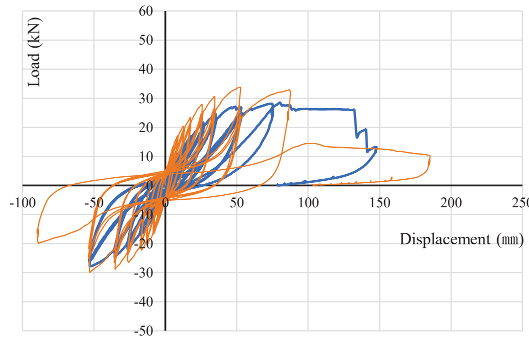

Figure 14: *Relation between load and horizontal displacement of load-bearing walls*

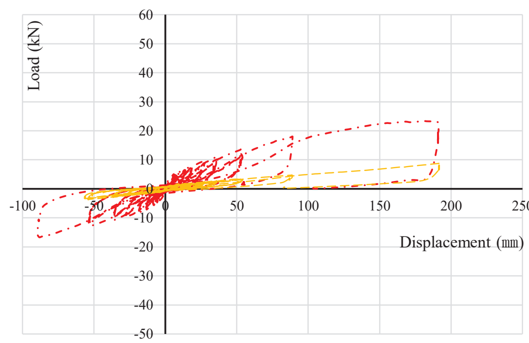

Figure 15: *Relationship between load and horizontal displacement of SD walls with different fastening methods*

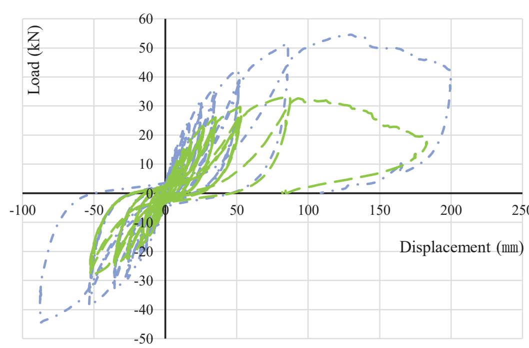

Figure 16: *Relation between load and horizontal displacement of SD walls with different fastening methods when SD is installed in a Single-sided fascia bearing wall.*

5 COMPARISON AND DISCUSSION

5.1 SINGLE-SIDED FASCIA SPECIFICATION AND SINGLE-SIDED FASCIA ＋ NAILED SD SPECIFICATION

The load-horizontal curves are shown in Figure 17 and a comparison of test results in Table 3. The Single-sided fascia + nailed SD specification improved the overall structural performance compared to the Single-sided fascia specification. The yield load and ultimate bearing capacity increased by about 80%, and the maximum bearing capacity and toughness values increased by about 90%. The reason for this improvement is thought to be that nailing the SDs restrained the entire wall, as if it were a face plate load-bearing wall. The nailed SDs were also

https://doi.org/10.52202/069179-0443

considered to be a factor in the increase in the overall restraint of the wall due to the use of the furring strips for ventilation as joints. These factors are thought to have increased the bearing capacity by suppressing bending deformation of the beams and pulling out (Figure 18 and Figure 19) of the columns due to the beams pushing up against the fascia, which bears the compressive force.

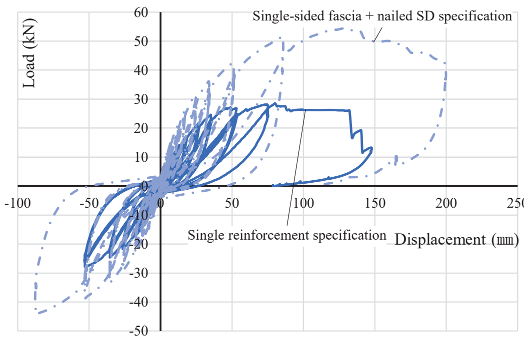

Figure 17: *Relationship between load and horizontal displacement for single-sided fascia specification and single-sided fascia + SD with nails specification*

Table 3: *Test results and ratios for Single reinforcement specification and Single-sided fascia + nailed SD specification*

Structural performance	unit	Single reinforcement specification	Single-sided fascia + nailed SD specification	Ratio※
K	kN/㎜	0.98	1.36	138.7%
Pmax	kN	28.49	54.53	191.4%
E	kN・㎜	3104.95	8466.70	272.6%
Ds		0.33	0.31	93.93%
Pu	kN	26.09	47.63	182.5%
Py	kN	16.16	29.15	180.3%
2/3Pmax	kN	18.99	36.35	191.4%
Pr(1/120rad.)	kN	19.44	30.23	155.5%
(0.2/Ds)×Pu	kN	15.61	30.36	194.4%

※Calculated based on Single Reinforcement Specification

Figure 18: *Bending deformation of beams*

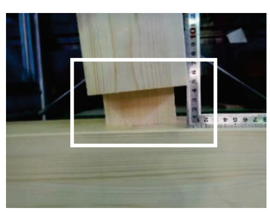

Figure 19: *Pillar pull out*

5.2 SINGLE-SIDED FASCIA SPECIFICATION AND SINGLE-SIDED FASCIA ＋ HOOKED SD SPECIFICATION

A comparison of test results is shown in Table 4 and Figure 20. The Single-sided fascia + hooked SD specification showed a slight improvement in structural performance, except for initial stiffness, compared to the Single-sided fascia specification, but only the initial stiffness was almost the same. From this, we consider that the influence of the hooked SD is almost negligible until 0.4Pmax, when the value of the initial stiffness is determined. The yield load increased by about 30%, and the maximum and ultimate bearing capacity increased by about 20%. The damage check revealed that the joints had scratches where the metal fittings interfered with each other (Figure 21 and 22). This caused a restraining force on the SD, and the resistance force of the SD was transmitted to the frame via the metal fittings.

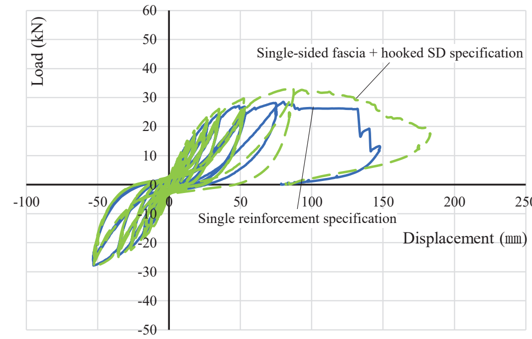

Figure 20: *Relation between load and horizontal displacement for single-sided facia specification and single-sided facia +hooked SD specification*

Table 4: *Test results and ratios for Single reinforcement specification and Single-sided fascia + hooked SD specification*

Structural performance	unit	Single reinforcement specification	Single-sided fascia + nailed SD specification	Ratio※
K	kN/㎜	0.98	0.94	95.9%
Pmax	kN	28.49	33.27	116.7%
E	kN・㎜	3104.95	3871.37	124.6%
Ds		0.33	0.35	106.0%
Pu	kN	26.09	30.15	115.5%
Py	kN	16.16	20.54	127.1%
2/3Pmax	kN	18.99	22.18	116.7%
Pr(1/120rad.)	kN	19.44	21.19	109.0%
(0.2/Ds)×Pu	kN	15.61	17.11	109.6%

※Calculated based on Single Reinforcement Specification

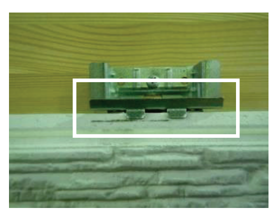

Figure 21: *Gaps created in the topmost joints due to the nearly eliminated gap in the metal fittings (under pressure)*

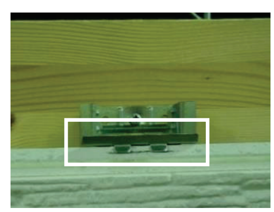

Figure 22: *Gap between fittings and no gap at uppermost joint (0 load)*

5.3 SINGLE-SIDED FASCIA ＋ NAILED SD SPECIFICATION AND SINGLE-SIDED FASCIA ＋ HOOKED SD SPECIFICATION

A comparison of the Single-sided fascia + nailed SD specification and the Single-sided fascia + hooked SD specification is shown in Table 5 and Figure 23. The structural performance of the Single-sided fascia + nailed SD specification was higher than that of the Single-sided fascia + hooked SD specification. A performance difference of about 70% was observed for the wall ratio. Yield load, maximum bearing capacity, and ultimate

https://doi.org/10.52202/069179-0443

bearing capacity increased by approximately 60%. This is due to the fact that the Single-sided fascia + nailed SD specification with nailed SD and nailed furring strips restrained the entire wall like a plywood bearing wall, which suppressed deformation such as the lifting of columns, and thus increased the bearing capacity. The most significant difference in the values was in the amount of energy absorption, which increased by approximately 2.2 times. We believe that the difference in initial stiffness and the difference in the number of joints per SD caused the difference in the ability to distribute the force to the entire wall.

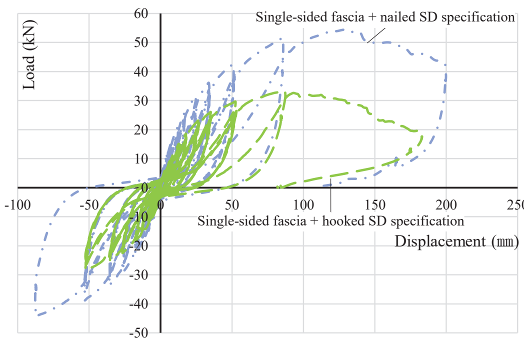

Figure 23: Relationship between load and horizontal displacement for single-sided fascia + nailed SD specification and single-sided fascia + hooked SD specification

Table 5: Difference in performance between SD specification of Single-sided fascia + nailed and SD Specification of single-sided fascia + hooked

Structural performance	unit	Single-sided fascia + nailed SD specification	Single-sided fascia + hooked SD specification	Ratio※
K	kN/㎜	1.36	0.94	144.6%
Pmax	kN	54.53	33.27	163.9%
E	kN･㎜	8466.70	3871.37	218.7%
Ds		0.31	0.35	88.5%
Pu	kN	47.63	30.15	157.9%
Py	kN	29.15	20.54	141.9%
2/3Pmax	kN	36.35	22.18	163.8%
Pr(1/120rad.)	kN	30.23	21.19	142.6%
(0.2/Ds)×Pu	kN	30.36	17.11	177.4%

※Calculated based on Single Reinforcement Specification

5.4 SINGLE-SIDED FASCIA ＋ NAILED SD SPECIFICATION AND ADDITIVE VALUE OF SINGLE-SIDED FASCIA SPECIFICATION AND NAILED SD SPECIFICATION

Figure 24 shows a comparison of the load-horizontal curves of the measured values (hereafter referred to as "measured values") and the added values (hereafter referred to as "added values") of the Single-sided fascia + nailed SD specification and the Single-sided fascia specification + nailed SD specification. The measured values showed an increase in structural performance compared to the added values. The difference between the measured values and the additive law is considered to be due to the difference in stress transfer to the frame. Looking at the fracture behavior of the nailed SD and Single-sided fascia + nailed SD specifications, both specifications showed cracking of the SD and fracture of the furring strips (Figures 25 and 26), and the damage to the SD was almost the same. However, looking at the backside of the specimens, the Single-sided fascia + nailed SD specification showed greater damage to the frame due to the dislodging of the studs, the penetration of the foundation by the fascia, and the pulling out of the columns due to the rupture of the pile plate (Figs. 27 and 28). No damage to the frame occurred in the nailed SD and Single-sided fascia specifications. The installation of the nailed SDs caused the entire wall to deform as a single unit, which transmitted sufficient force to the fascia and increased the stress transmitted to the frame, resulting in damage to the frame, such as column pull out. This suggests that the difference between the measured and added values was caused by the increase in the maximum bearing capacity.

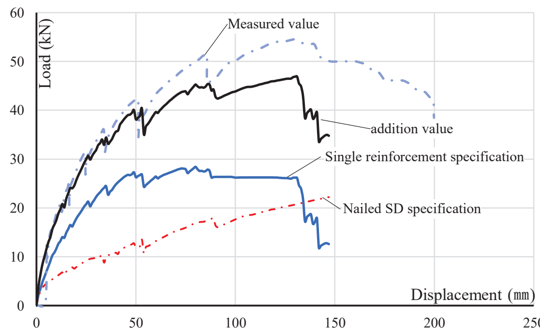

Figure 24: Relationship between load and horizontal displacement of added values for single-sided fascia + nailed SD specification and single-sided fascia + nailed SD specification

Figure 25: Cracks from around nails

Figure 26: Cracks in the furring strips

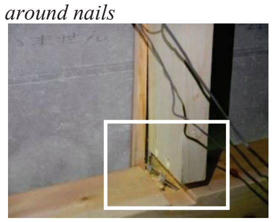

Figure 27: Dislodgement of inter-posts

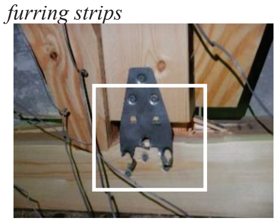

Figure 28: Rupture of Yamagata Plate

5.5 SINGLE-SIDED FASCIA ＋ HOOKED SD SPECIFICATION AND ADDITIVE VALUE OF SINGLE-SIDED FASCIA SPECIFICATION AND HOOKED SD SPECIFICATION

A comparison of the Single-sided fascia + hooked SD specification (hereafter referred to as "measured value") and the additive value of the Single-sided fascia

https://doi.org/10.52202/069179-0443

specification + hooked SD specification (hereafter referred to as "additive value") is shown in Figure 29. There is almost no difference between the measured values and the additive values, indicating that the additive law is valid. This is due to the fact that the SDs hardly bear the load-bearing capacity and depend on the load-bearing capacity of the structural members, which is why there is no difference. Also, there is a difference in final failure between the measured value and the added value. In the case of the measured value, the strength was reduced due to the pull out of screws attached to the fascia plate (Figure 30), whereas in the case of the added value, the strength was reduced due to the buckling failure of the fascia (Figure 31), resulting in the difference in the graphs near the endpoint.

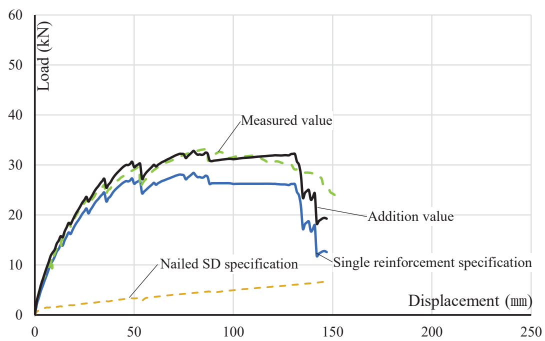

Figure 29: *Relationship between load and horizontal displacement for the added values of single-sided fascia + hooked SD specification and single-sided fascia + hooked SD specification*

Figure 30: *Fascia plate screws missing*

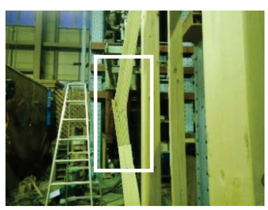

Figure 31: *Buckling failure of Fascia*

6 CONCLUSION

The burden ratio was 46.5% for nailed SD and 8.7% for hooked SD. Although SD exterior walls are not included in the structural design as load-bearing walls, it was found that the wall ratio of the current mainstream "hooked SD" was about 70% lower than that of the nailing SD, which was the mainstream at that time.

ACKNOWLEDGEMENT

The test specimens and test site for this study were provided by POLUS R&D Center of Life Style.

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