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A STUDY ON EVALUATION OF SEISMIC PERFORMANCES AND ENERGY CHARACTERISTICS OF TIMBER STRUCTURES WITH SIDING BOARD

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SUMMARY

In this paper, our research group evaluated of seismic performances and energy characteristics of Japanese timber bearing wall with siding board on lateral loading tests. These tests were executed static and dynamic lateral loading. The static loading tests had sixteen specimens, which were changed of respective methods of construction of siding boards, kind of nails, intervals of running nails and etc. The dynamic loading tests had four specimens, which were change of each loading amplitude, frequency and etc.
As a result of these tests, there are wall magnification 1.88 - 3.74 of bearing wall with siding board. The equivalent viscous damping ratios of these structures are 0.07 - 0.46. The values of hysteresis energy are 7.4 - 680.0. The equivalent story stiffness are 0.02 - 1.26 kN/mm. The seismic performances and energy characteristics of bearing wall with siding board are shown.

1. INTRODUCTION

It doesn't assume that the wall where a siding board is stuck in Japan is a bearing wall. It is because it thinks that the fire resistance ability can not be sufficiently shown because the siding board has a crack or a fall in case of the earthquake. However, it is assumption that the siding board wall doesn't have seismic performance at all in Japan. There are not few buildings which the bearing wall quantity lack and the arrangement of the bearing wall are improper for in the cause of the earthquake damage of the wooden house. To evaluate these facts, the seismic performance of the non- bearing wall must be sufficiently grasped.
To grasp a structure performance by the static experiment and to grasp the vibration behavior by the dynamic experiment are the purpose of this research.

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2. OVERVIEW OF TESTS AND SPECIMENS

The static loading tests have sixteen specimens, which are changed of respective methods of construction of siding boards, kind of nails, intervals of running nails, etc. The dynamic loading tests have four specimens, which are change of each loading amplitude, frequency, and etc. And two specimens, which have plywood or brace, as test in an addition.

The static loading test is fixation type to a beam and a groundsill on a top and bottom of column, it is the plus or minus alternation repeat gradual increase loading. The number of loading repetition is three times. The dynamic Loading step is shown Table 1.

These timber flame of specimen which is shown in figure 2 is composed three columns of Japanese cryptmeria, a groundsill of Japanese cryptmeria, a beam of douglas pine and some siding boards. The experiments have the characteristic that there is a grounds. The grounds is made of dried, heartwood or sapwood of Japanese cryptomeria, or of sapwood hemlock spruce. It is size of 15 x 90 or 15 x 45 mm.

The bottom of both side columns connect to a groundsill by hold-down hardware. The top of both side columns connect to beam by bolt in the shape of battledore. The groundsill is set up steel foundation by six anchor bolts of M16. The typical siding boards are lengthways establishment, sideways establishment, or tiles establishment on timber flame.

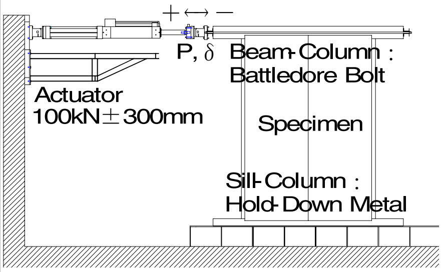


Figure 1 Loading System

Table 1 Dynamic Loading Step

Story Drift rad	Disp. mm	Frequency Hz	Time sec	Max. Vel. cm/sec
1/300	9.10	4.0	3	22.9
1/300	9.10	2.0	5	11.4
1/120	22.75	4.0	3	57.2
1/120	22.75	2.0	5	28.6
1/120	22.75	1.0	10	14.3
1/60	45.50	1.0	10	28.6
1/60	45.50	0.5	20	14.3
1/40	68.25	0.5	20	21.4

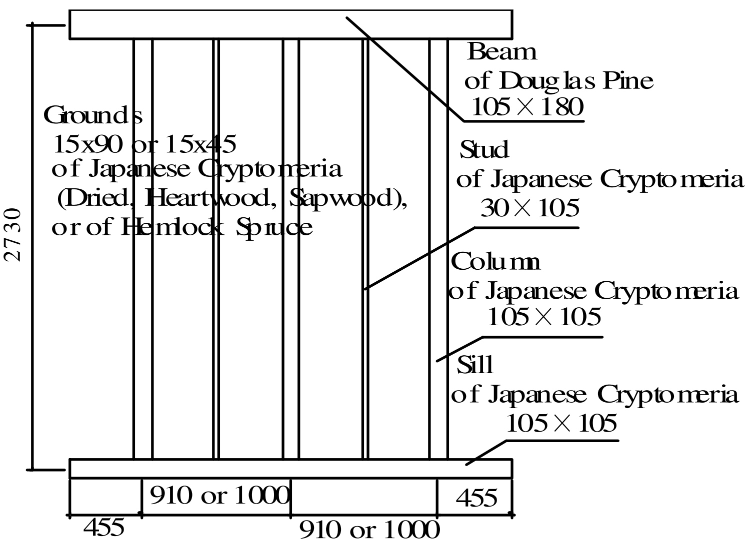


Figure 2 Frame of Specimen

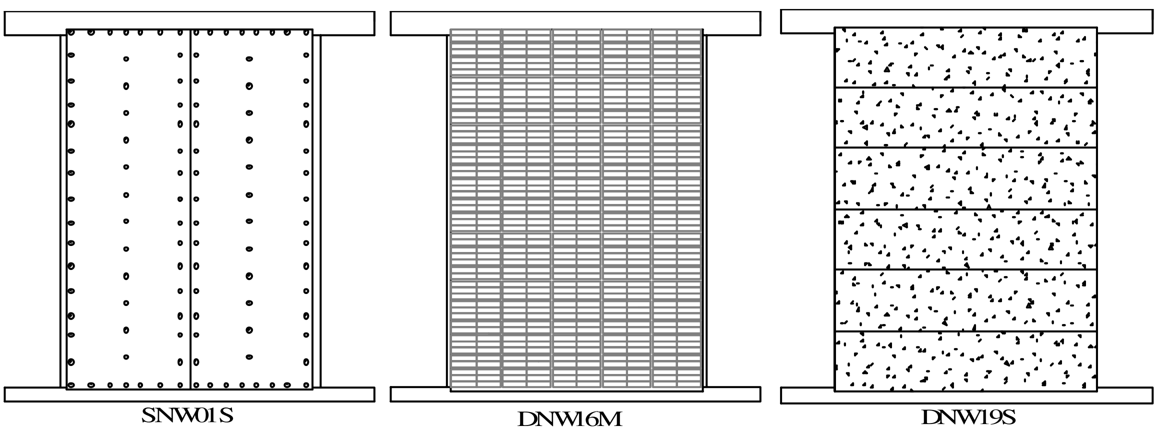


Figure 3 Typical Specimens

The Parameter of these tests is shown table 2. It is a type of siding board, a type of grounds and nail, a type of siding board's nail.
The shiplap type of siding board and the nail type of siding board are figure 4 and figure 5 respectively. The shiplap type of siding board is two types, and the nail type of siding board is six types. As the experiment move ahead, the shiplap type and the nail type add improvement. The nail is made from the stainless steel. nail type is a nail head diameter, a nail length, a nail neck diameter and a nail ring diameter.

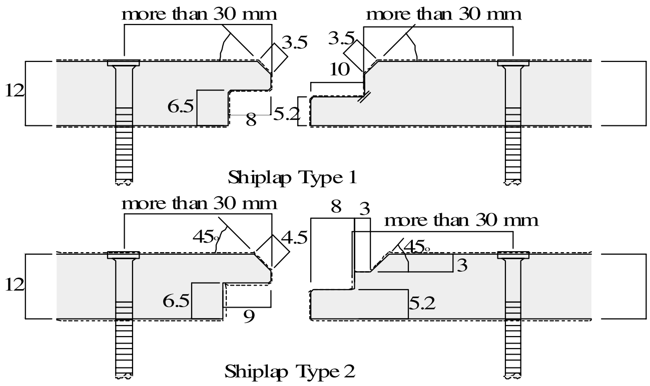
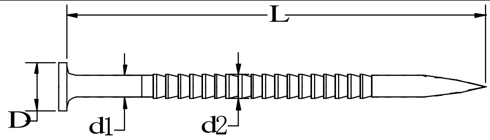


Figure 4 Shiplap Type of Siding Board



unit : mm	L	D	d1	d2
VRN40	40	5.0	2.30	2.50
VRN45	45	5.0	2.40	2.65
S-ring Nail Type 1	50	6.6	2.85	3.10
S-ring Nail Type 2	50	6.6	2.85	2.85
S-ring Nail Type 3	50	5.5	2.70	2.80
S-ring Nail Type 4	50	5.8	2.80	2.90

Figure 5 Nail Type of Siding Board

Table 2 Overview of Speciments

Type Name	Loading Type	Siding Board, Thickness is 9mm			Type of Grounds and Nail				Type of Siding Board's Nail		Note
SNW01S	Static	910× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	t = 18mm	Vertical Grounds, Horizontal Grounds	N50 @200	VRN45	Perimeter @150, Stud @200	
SNW02S	Static	910× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds	N50 @200	S-ring Nail Type 1	Vertical @100	
SNW03S	Static	910× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds	N50 @200	S-ring Nail Type 2	Vertical @100	
SNW04S	Static	910× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds	N50 @200	S-ring Nail Type 1	Vertical @150	
SNW05S	Static	910× 1820	Sideways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds	N50 @200	S-ring Nail Type 1	Vertical @100	
SNW06S	Static	910× 1820	Sideways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds	N50 @200	VRN45	Vertical @100	
SNW07S	Static	910× 2730	Lengthways	Shiplap Type 2	Dried Cryptomeria	18mm	Vertical Grounds	N50 @300	VRN40	Vertical @100, Top and Bottom @230	
SNW08M	Static	1000× 2730	Lengthways	Shiplap Type 2	Heartwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Sub Grounds	N50 @300	S-ring Nail Type 3	Vertical @150, Top and Bottom @230	
SNW09M	Static	1000× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Sub Grounds	N50 @300	S-ring Nail Type 3	Vertical @150, Top and Bottom @230	
SNW10M	Static	1000× 2730	Lengthways	Shiplap Type 2	Sapwood of Hemlock Spruce	18mm	Vertical Grounds, Horizontal Sub Grounds	N50 @300	S-ring Nail Type 3	Vertical @150, Top and Bottom @230	
SNW11S	Static	910× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @300	S-ring Nail Type 4	Perimeter @150, Stud @150	
SNW11M	Static	1000× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @300	S-ring Nail Type 4	Perimeter @150, Stud @150	
SNW12M	Static	1000× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @300	S-ring Nail Type 4	Vertical @150, Top and Bottom @110	
SNW13M	Static	1000× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @300	S-ring Nail Type 4	Vertical @150, Top and Bottom @110	
SNW14M	Static	1000× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @300	S-ring Nail Type 4	Vertical @150, Top and Bottom @230	movable at corner
SNW15S	Static	910× 2730	Lengthways	Shiplap Type 2	Sapwood of Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @300	S-ring Nail Type 4	Perimeter @150, Stud @150	movable at corner
Type Name	**Loading Type**	**Structural Element**							**Type of Plywood's Nail**		**Note**
SPL01S	Static	Plywood, 910X2730, Thickness is 9mm							N50	Perimeter @150, Stud @200	
SBR01S	Static	Brace, 45X90, Hemlock Spruce, Brace Box Hardware are stopped.									
Type Name	**Loading Type**	**Siding Bord, Thickness is 9mm**			**Type of Grounds and Nail**				**Type of Siding's Nail**		**Note**
DNW16M	Dynamic	1000× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @200	VRN40	Vertical @450	
DNW17M	Dynamic	1000× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @200	VRN40	Perimeter @150, Stud @200	With Extrior Tiles
DNW18M	Dynamic	1000× 2730	Lengthways	Shiplap Type 1	Dried Cryptomeria	18mm	Vertical Grounds, Horizontal Grounds	N50 @200	VRN40	Perimeter @150, Stud @200	With Extrior Tiles
DNW19S	Dynamic	910× 2730	Sideways	Shiplap Type 1	Each Sliding Set up Tmber Flame by Five Metals with Vent.						

3. DESTRUCTION OVERVIEW

The destrution overveiw of siding board is shown photograph 1 - 5.
At VRN40 or VRN45 of nail type, damage of siding board isn't seen about 1/100 rad. of story drift in the static loading tests. When the story drift is large, the punching of nails occurs and the shiplap opens.

Photo. 1
Deformation of Specimen with Siding Board at Story Drift of 1/30 rad.

Photo. 2 Crack in the corner of Siding Board

Photo. 3 Siding board comes off

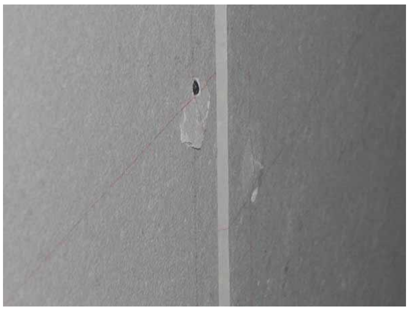


Photo. 4 Sinking of Nail to Siding Board

Photo. 5 Destruction of Metal Fittings with the Ventilation

Photo. 6
Buckling Destruction of Braces

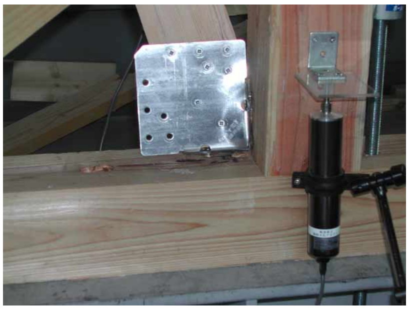


Photo. 7
Destruction of the Edge of Brace

Photo. 8
Destruction of Nail of Plywood

Photo. 9
Three Destruction Types of Stainless Nailes for Siding Board

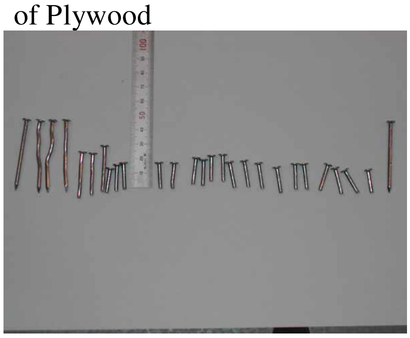
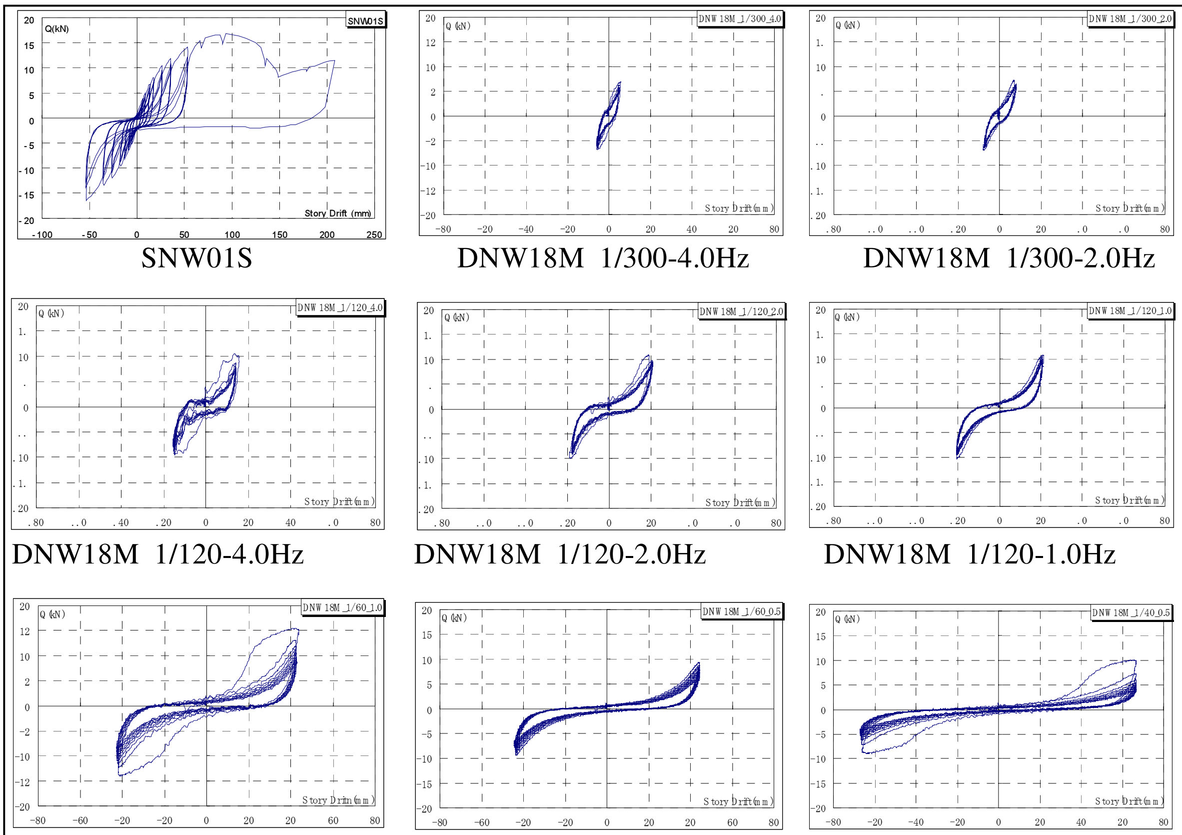


Photo. 10
Three Destruction Types of Stainless Nailes for Plywood

At S-sing nail types, damage of siding board isn't seen about 1/75 rad. of story drift in the static loading tests. When the story drift is large, the pulling-out of a nail occurs and the shiplap opens.
Damage of siding board isn't seen about 1/120 rad. of story drift in the dynamic loading tests. In 1/60 rad., the float from the grounds become seen in both sides of the siding board. In 1/40 rad., shear destruction is seen to the part of the nail and getting out of the nail is seen by shiplap. The damage of siding board is not severe at all. The phenomenon of the damaging of a stainless nail not to be damaged or to do a break is seen. It is shown photograph 9 and photograph 10. The damage on the additional tests is shown in photograph 6 - 8.

4. MEASURING RESULTS

A hysteresis loop of shear force - story drift relation are shown in figure 6. In case of the dynamic loading test, it isn't considering that the inertia force revises.
SNW01S) The secant stiffness is 0.511 kN/mm at 1/300 rad., 0.40 at 1/120, 0.27 at 1/60, 0.23 at 1/40 in static loading test.
DNW18M) The secant stiffness is 0.87 - 1.18 kN/mm at 1/300 rad., 0.50 - 0.66 at 1/120, 0.20 - 0.35 at 1/60, 0.15 at 1/40 in the dynamic loading test. The secant stiffness is above being 1.6 times to 1/120 rad. and being about 0.75 - 1.3 times to above 1/60 rad.
The secant stiffness of DNW16M is 0.42 - 0.44 kN/mm at 1/300 rad., 0.23 - 0.28 at 1/120, 0.08 - 0.14 at 1/60, 0.04 at 1/40.
The secant stiffness of DNW17M is 0.71 - 0.84 kN/mm at 1/300 rad., 0.47 - 0.56 at 1/120, 0.25 - 0.36 at 1/60, 0.13 at 1/40.
The secant stiffness of DNW19S is 0.10 - 0.18 kN/mm at 1/300 rad., 0.05 - 0.19 at 1/120, 0.04 - 0.03 at 1/60, 0.13 at 1/40.



SNW01S | DNW18M 1/300-4.0Hz | DNW18M 1/300-2.0Hz

DNW18M 1/120-4.0Hz | DNW18M 1/120-2.0Hz | DNW18M 1/120-1.0Hz

DNW18M 1/60-1.0Hz | DNW18M 1/60-0.5Hz | DNW18M 1/40-0.5Hz

Figure 6 Hysteresis Loop of Shear Force - Story Drift

The secant stiffness of specimen DNW17M is about two or three times as high with any transformation as specimen DNW16M and this is because the nail driving interval is 1/2 - 1/3.
The secant stiffness of specimen DNW17M (tile's there being) is rather about 0.8 times in 1/120 rad. than specimen DNW18M (doing tile nothing), it is approximately the same value after that.
The secant stiffness of specimen DNW19S (sideways, the metal fittings with the ventilation) was about 0.1 times more than specimen DNW18M (lengthways). As for this, the metal fittings with the ventilation are to be supporting siding only by, and free to the direction of the loading in the surface.

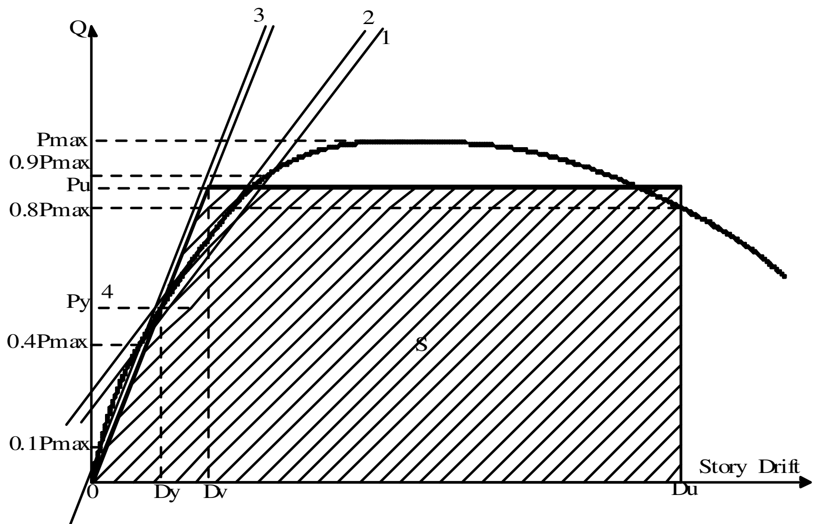


Figure 7 Bi-linear Model

Table 3 The Results of Experiments

Type of Specimen	SNW01S	SNW02S	SNW03S	SNW04S	SNW05S	SNW06S	SNW07S	SNW08M	SNW09M	SNW10M	SNW11S	SNW11M	SNW12M	SNW13M	SNW14M	SNW15S	SPL01S	SBR01S
Pmax (kN/Actual Wall Length m)	16.77	27.5	26.83	22.38	15.75	11.91	20.56	19.95	22.01	21.44	21.05	22.35	19.95	22.85	22.74	21.34	18.42	11.43
δpmax (10^{-3}rad)	34	39	37	40	46	41	42	42	41	48	41	46	42	43	40	44	42	15
Py (kN/Actual Wall Length m)	8.99	14.83	14.99	11.62	10.01	6.72	12	11.23	12.21	12.1	11.85	12.32	11.42	12.6	12.59	12.19	11.76	6.15
δy (10^{-3}rad)	8	8	8	8	11	6	8	4	5	6	6	6	6	7	6	8	6	4
Pu (kN/Actual Wall Length m)	14.92	24.66	24.08	19.78	14.17	10.69	18.13	17.45	19.43	19.37	18.65	19.79	17.82	20.68	20.33	18.84	16.76	10.24
δu (10^{-3}rad)	48	52	54	58	82	104	54	68	68	71	58	69	66	68	70	55	66	27
δv (10^{-3}rad)	13	13	12	14	16	12	13	7	9	10	9	10	9	12	10	13	9	7
K (MN/rad)	1.13	1.97	1.93	1.42	0.87	0.87	1.44	2.64	2.24	2.02	2.07	2.03	1.9	1.7	2.02	1.48	1.9	1.53
μ	3.651	4.132	4.331	4.157	5.051	8.596	4.284	10.303	7.802	7.369	6.486	7.123	7.031	5.63	6.96	4.342	7.553	4.094
Ds	0.398	0.371	0.361	0.37	0.331	0.248	0.364	0.226	0.262	0.27	0.289	0.275	0.277	0.312	0.278	0.361	0.266	0.373
Pu·(0.2/Ds) (kN/Actual Wall Length m)	7.49	13.29	13.33	10.7	8.55	8.62	9.96	15.44	14.83	14.35	12.91	14.39	12.87	13.26	14.63	10.44	12.59	5.49
2/3Pmax (kN/Actual Wall Length m)	11.17	18.33	17.88	14.91	10.5	7.94	13.71	13.3	14.67	14.29	14.03	14.90	13.30	15.23	15.16	14.23	12.279	7.617
$P_{1/300rad}$ (kN/Actual Wall Length m)	4.66	9.59	9.39	6.53	4.59	4.41	6.72	9.9	9.92	9.06	9.43	9.71	8.67	9.05	9.34	8.14	9.12	5.41
$P_{1/d00rad}$ (kN/Actual Wall Length m)	6.32	12.88	11.96	8.97	6.44	5.96	8.52	10.87	11.48	10.7	10.75	10.76	10	10.33	10.75	9.4	10.24	6.81
$P_{1/1d0rad}$ (kN/Actual Wall Length m)	7.4	14.35	12.98	9.62	7.6	6.03	9.78	11.29	12.14	11.65	11.55	11.45	10.63	11.41	11.95	10.26	10.74	7.93
$P_{1/1d0rad}$ (kN/Actual Wall Length m)	9.31	15.91	15.67	11.74	8.74	7.12	12.02	13.02	13.97	13.46	13.45	13.36	12.59	13.67	14	12.31	12.57	9.25
Po (kN/Actual Wall Length m)	7.49	13.29	13.33	10.7	8.55	6.72	9.96	11.23	12.21	12.1	11.85	12.32	11.42	12.60	12.59	10.44	11.76	5.49
Pa (kN/Unit Wall Length m)	4.12	7.30	7.32	5.88	4.70	3.69	5.47	5.62	6.11	6.05	6.51	6.16	5.71	6.30	6.30	5.73	6.46	3.02
Dispersion Coefficient	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Effetctive Wall Length Coefficient	2.10	3.73	3.74	3.00	2.40	1.88	2.79	2.86	3.11	3.09	3.32	3.14	2.91	3.21	3.21	2.93	3.30	1.54

5. ALLOWABLE STRESS FOR TEMPORARY LOADING AND WALL MAGNIFICATION

The way that it is calculated Pu, Dv, Du, and etc. from the envelope, which is found from the static load - the displacement relation, is shown in figure 3. It found allowable stress for temporary loading, which is shown in table 3, from the minimum value of 2/3Pmax, Py, P1/120 and 0.2Pu/Ds. In the computation of the wall magnification, it isn't considering a loose coefficient and a reduction coefficient by the construction.
Each allowable stress for temporary loading is decided from Py（seven specimens）or 0.2Pu/Ds（nine specimens）.

6. ENERGY CHARACTERISTICS

An equivalent viscous damping constant, an equivalent rigidity and an energy of hysteresis, which are defined in figure 8, are shown in figure 9 - 11 respectively.
SNW01S) The equivalent viscous damping constant is 0.09-0.18.
DNW18M) The equivalent viscous damping constant is 0.07-0.23. The looseness becomes bigger with the dynamic test about an equivalent viscous damping constant and an energy of hysteresis in each displacement than with the static test. After the third cycle in the dynamic tests, it is near the lower limit of equivalent viscous damping constant in case of the static test.
The equivalent viscous damping constant of the dynamic tests, of which specimens are DWN16M, DWM17M and DWN18M about 0.07 - 0.23, taking a similar value. The equivalent viscous damping constant of DWN19S is about 0.10 - 0.46 and is about 1.4 - 2.0 times as big as the other specimens. The influence of the metal fittings with the ventilation could be confirmed.

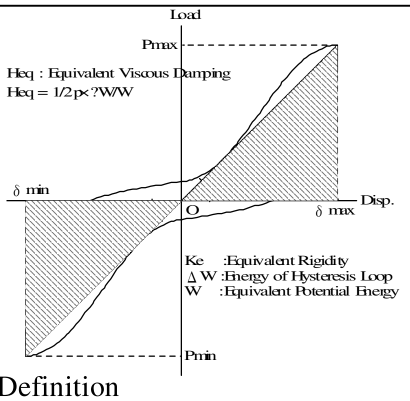


Figure 8 Definition
of Equivalent Viscous Damping

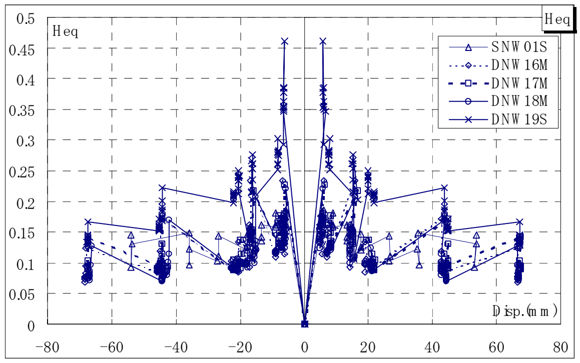


Figure 9 Testing Result
of Equivalent Viscous Damping

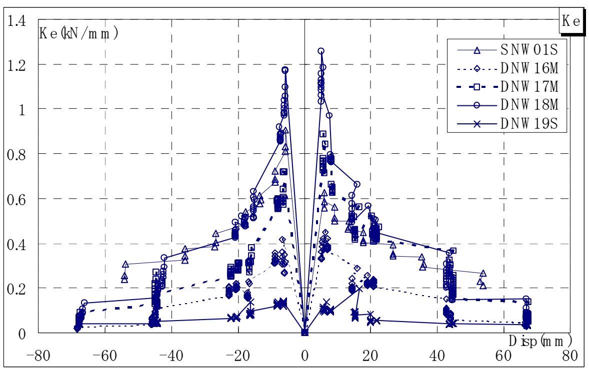


Figure 10 Testing Result
of Equivalent Rigidity

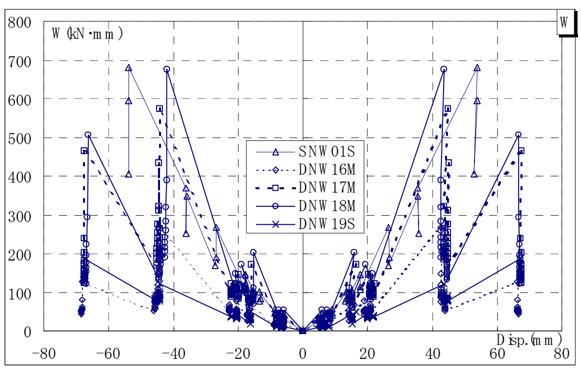


Figure 11 Testing Result
of Energy of Hysteresis Loop

Each equivalent rigidity is 0.21 - 0.90 kN/mm (SNW01S), 0.02 - 0.44 (DNW16M), 0.04 - 0.88 (DNW17M), 0.05 - 1.26 (DNW18M) and 0.03 - 0.19 (DNW19S). As for the specimen of any dynamic test, when comparing to SNW01S, the lower limit of equivalent rigidity is quite low.
Each energy of hysteresis is 24.7 - 680.0 (SNW01S), 7.4 - 267.0 (DNW16M), 22.7 - 573.4 (DNW17M), 24.3 - 675.1 (DNW18M), 8.2 - 186.8 (DNW19S). The maximum equivalent viscous damping constant of DNW17M is 2.14 times to DNW16M. The maximum equivalent viscous damping constant of DNW18M is 1.17 times to DNW17M. The maximum equivalent viscous damping constant of DNW19S is 2.14 times to DNW18M.

6. CONCLUSIONS

With the static and dynamic tests with the identical specification, the difference of the destruction property, the secant stiffness, the energy absorption performance could be confirmed. The difference of the destruction property, the proof stress performance and the energy absorption performance with the dynamic tests could be confirmed with the difference in the nail driving interval (DNW16M and DNW17M), the difference of the existence or non-existence of the exterior tile (DNW17M and DNW18M), and the difference of the nail fixedness and the metal fittings fixedness with the ventilation (DNW19S and the other specimens).

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