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DEVELOPMENT OF HIGH STRENGTH BEARING WALLS FOR FRAMEWORK CONSTRUCTION METHOD USING 2X4 LUMBER AND PLYWOOD MADE OF JAPANESE TIMBER

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ABSTRACT: The purpose of this research is to develop a high strength bearing wall for the framework construction method using Japanese frame material and Japanese plywood. To achieve this, it is necessary to consider the combination, or balance, of plywood thickness, wood species, frame materials and type of nails. At first, single shear tests were performed on the nail joints, then the optimum combination was determined by modelling. After that, the performance of the walls was verified with in-plane shear tests using full-scale bearing walls. It was found that when the wall legs are joined to the ground with metal joints, a brittle fracture has occurred at the metal joint. Therefore, by changing the test method from the column fixed type to the tie rod type without using metal joints, column base breakage was prevented and the high strength performance of the shear wall itself was confirmed.

KEYWORDS: Framework construction method, Single shear tests, In-plane shear tests, Fixed column base, Tie rod

1 INTRODUCTION

Wooden public buildings are increasing popularity. In public buildings, a large space is often required, and research on load-bearing walls using structural plywood that can produce a high-strength load-bearing walls with easy construction has been promoted. At present, a lot of Japanese timber is being harvested and it is thought that effective utilization of this timber and the additional higher value will stabilize Japan's supply and demand of timber and stimulate forestry. However, most of the frame materials are imported materials, such as SPF, and domestic materials are rarely used. Therefore, one of the effective uses for domestic large-diameter materials is the use of the frame wall construction method for frame materials.

2 SUMMARY OF RESEARCH

We intend to develop a type of high strength frame wall construction bearing wall using domestic frame material and domestic plywood for public buildings. In order to realize this, it is necessary to consider the plywood thickness, the combination of the tree species, the frame material, and the type of nails. Therefore, after examining the optimum combination for the bearing walls from single shear tests with nail joints, in-plane shear tests (column base fixed type and tie rod type) were conducted on the actual bearing walls. The target performance is 10 times the wall strength ratio of the Japanese building code regulations, 1.96 kN/m horizontal allowable load/length of wall performance.

3 SINGLE SHEAR TESTS

3.1 SUMMARY OF EXPERIMENTS

Test bodies were made using 2×6 cedar as the center materials and plywood as the side materials (Fig. 1). The number of test specimens were 54 in total, 6 in each of 9 specifications with varying plywood thickness and tree species. Three types of plywood were selected: cedar (C), larch (L), and cedar-larch mixed plywood (M). The combination of plywood and nails were CN50 nails for 12 mm thick, CN65 nails for 15 mm thick, and CN75 nails for 24 mm thick for the purpose of exhibiting excellent one-side shear performance. The tests were performed monotonically using a 50 kN universal testing machine at Nippon Institute of Technology. The loading time was such that the time to reach the maximum load was 5 minutes ± 2 minutes. The displacement was determined by measuring the relative displacement between the frame material and the both side of plywood for recording the average.

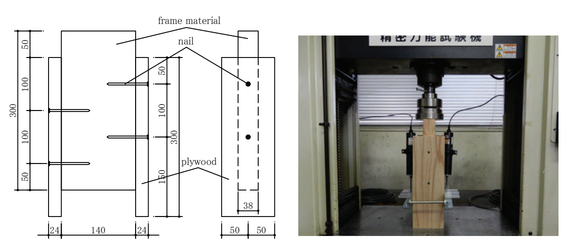

Fig. 1 *Single shear specimens*

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3.2 EXPERIMENTAL RESULTS

Table 1 shows the average and standard deviation of the experimental results of each specification, and Fig. 2 to 4 show graphs of the experimental results. Note that the test results are values for one nail. For the cedar plywood and the mixed plywood, the average value of maximum loads and allowable test stress were increased in proportion to the thickness of plywood (Table 1). The results were as follow. With larch plywood the test specimen with 15 mm thickness had similar load and maximum stress to the specimen with 24 mm thickness. In the case of cedar and composite plywood, there were many indentations and punching out of nail heads (Fig. 5 and 6). In larch plywood, bending deformation of nails was common (Fig. 7).

Table 1 *Average test results*

Specimen name	K (kN/mm)	S.D.	Py (kN)	S.D.	δ y (mm)	S.D.	Pmax (kN)	S.D.	δ max (mm)	S.D.
C-12	1.04	0.14	3.17	0.28	3.08	0.39	5.50	0.32	20.75	2.34
C-15	1.66	0.28	3.80	0.51	2.42	0.82	6.94	0.52	21.18	5.92
C-24	1.97	0.27	5.38	0.49	2.81	0.60	10.02	0.73	23.85	4.11
L-12	1.58	0.18	4.31	0.38	2.75	0.31	7.93	0.46	20.07	1.30
L-15	2.40	0.47	6.13	0.50	2.69	0.66	12.00	0.34	25.50	7.21
L-24	2.43	0.59	6.74	0.26	2.97	0.83	11.42	0.59	26.69	1.77
M-12	1.48	0.23	3.70	0.14	2.56	0.32	6.58	0.23	21.04	1.38
M-15	1.95	0.38	4.12	0.48	2.22	0.60	7.62	0.44	20.13	7.91
M-24	2.49	0.27	7.23	0.94	2.94	0.55	12.27	1.43	25.98	3.93

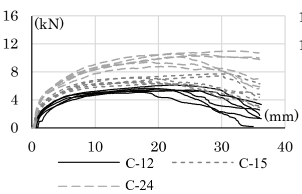

Fig. 2 *C specification load-displacement curve*

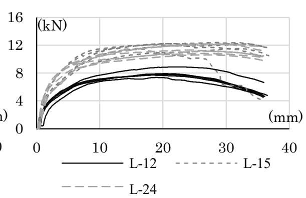

Fig. 3 *L specification load-displacement curve*

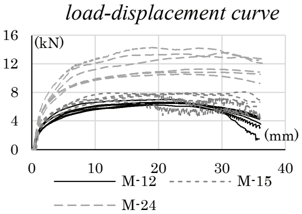

Fig. 4 *M specification load-displacement curve*

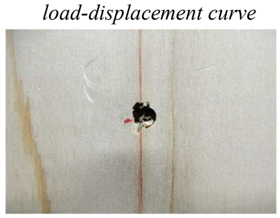

Fig. 5 *Nail head sinking*

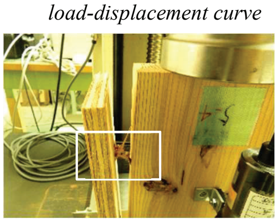

Fig. 6 *Nail punching out*

Fig. 7 *Bending deformation of nails*

4 MODELING BEARING WALLS

Assuming a wall panel with a width of 1820 mm and a height of 2460 mm, the calculation was performed assuming that the nail distance of the face material was 50 mm and 75 mm. The yield strength of one nail was determined from the test average value obtained in the experiment in 3 SINGLE SHEAR TESTS, and the allowable shear strength as a load-bearing wall was determined therefrom (Fig. 8 and 9). The wall magnification is obtained by multiplying the allowable shear strength of the load-bearing wall by the reduction factor due to toughness as the short-term allowable shear strength. Among these, the C-24, L-15, L-24, and M-24 specifications with each nail distance of 50 mm and the L-24, M-24 specifications with each nail distance of 75 mm are predicted to be high strength bearing walls (Table 2).

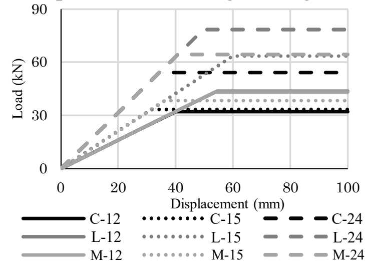

Fig. 8 *Nail 50 mm distance elastic-plastic model*

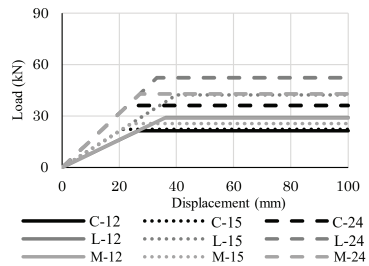

Fig. 9 *Nail 75 mm distance elastic-plastic model*

Table 2 *Modeling wall magnification*

Specimen name	Nail distance	Wall magnification
C-12	@75mm	4.66
	@50mm	6.40
C-15	@75mm	5.50
	@50mm	7.57
C-24	@75mm	7.89
	@50mm	10.85
L-12	@75mm	6.33
	@50mm	8.49
L-15	@75mm	9.02
	@50mm	10.62
L-24	@75mm	10.05
	@50mm	13.81
M-12	@75mm	5.52
	@50mm	7.59
M-15	@75mm	6.00
	@50mm	8.25
M-24	@75mm	10.48
	@50mm	14.41

5 COLUMN BASE FIXED TYPE IN－PLANE SHEAR TESTS

5.1 OUTLINE OF TEST SPECIMEN

The dimensions of the test specimen were 1820 mm (2P) in wall length and 2400 mm in wall height for wooden surface materials (Fig. 10). The framing material used was 204 cedar wood (JAS A class 2). Normally, there is only one vertical frame between panels, but with high strength load-bearing walls, the spacing between nails for holding plywood is narrow, and the vertical frame may be damaged. Therefore, the vertical frames between the panels were joined together and fastened with CN75 nails in a 300 mm distance staggered arrangement. In the same way, the orientation of the torso was changed to horizontal use to make it harder to break. The specifications of the bearing wall are 3 of C-24 specification using cedar 24 mm plywood material, L-15 specification using larch 15 mm plywood material, and L-24 specification using 24 mm larch plywood material. In the L-15 and L-24 specifications, the each nail distance for securing the vertical frames were changed to double-rows with CN75 nails 100 mm distance. For the joint connectors, HD metal joints with the short-term reference strength of 60 kN were used for the column pedestal, and HD metal joints with the short-term reference strength of 40 kN were used for the column base fixed type tests.

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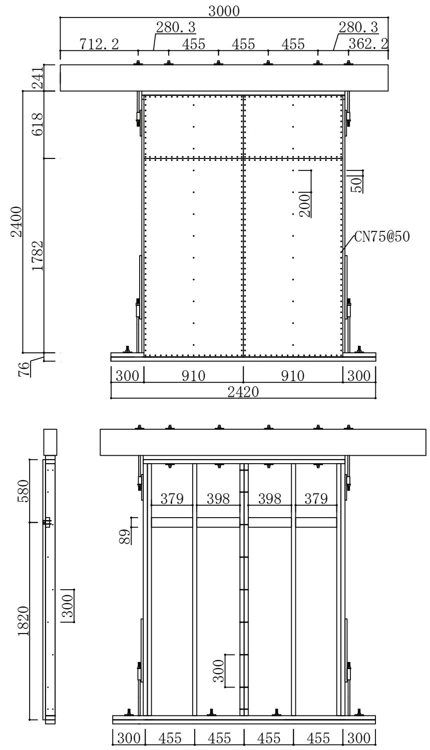

Fig. 10 C-24 specification test body

5.2 TESTS METHOD

The column-base fixed type in-plane shear tests were performed using a load frame tester in Nippon Institute of Technology (Fig. 11). The loading method was repeated three times in alternating positive and negative, and the loading cycle was apparent shear deformation angle 1/450, 1/300, 1/200, 1/150, 1/100, 1/75, 1/50, 1 / 30 rad. (only 1/30 rad. was repeated one time).

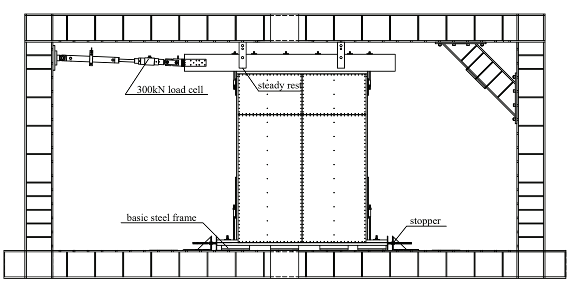

Fig. 11 Specimen installation state

5.3 EXPERIMENTAL RESULTS

Tables 3 and 4 show the experimental results for each specification, and Fig. 12 shows a graph of the test results. Comparing the structural performance of the three specifications, the initial stiffness and maximum load were in the order of L-15, L-24, and C-24. However, when compared by wall magnification, the C-24 specification, L-15 specification, and L-24 specification were in descending order. In the case of the C-24 specification, in which the nails of the vertical frame were placed as usual, the vertical frame between the panels was greatly displaced, and the outer vertical frame caused bending failure at the time of tearing (Fig. 13, 14). In L-15 and L-24, because the number of nails between panels was increased, the displacement of the vertical frame was suppressed, but aggregated shear failure of the vertical frame was induced at the wall legs (Fig. 15, 16).

Table 3 *Test results*

	C-24	L-15	L-24
K (kN/mm)	1.39	1.91	1.60
Py (kN)	32.50	36.59	32.22
Pmax (kN)	52.88	64.26	57.07
δu (mm)	210.46	100.82	132.98
Pu (kN)	48.18	57.22	48.90
δv (mm)	34.62	29.96	30.52
μ	6.08	3.37	4.36
Ds	0.30	0.42	0.36

Table 4 *Calculation result of wall magnification*

	C-24	L-15	L-24
P_{γ} (kN)	28.91	39.05	33.17
2/3Pmax (kN)	35.25	42.84	38.05
(0.2/Ds)×Pu (kN)	32.18	27.25	27.16
Py (kN)	32.50	36.59	32.21
P_0 (kN)	28.91	27.25	27.16
Wall magnification	8.10	7.64	7.61

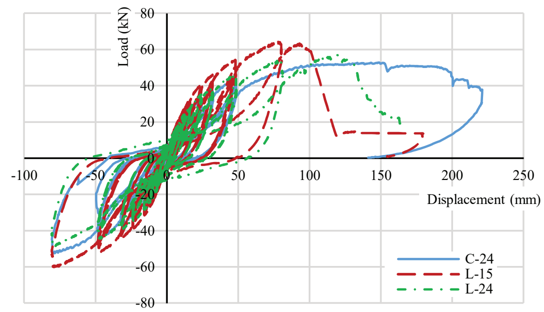

Fig. 12 Load-displacement curve

Fig. 13 *Misalignment between vertical frames*

Fig. 14 *Bending deformation of vertical frame*

Fig. 15 *Suppression of vertical frame displacement*

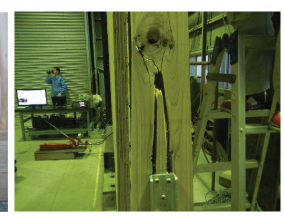

Fig. 16 *Collective shear failure*

5.4 COMPARISON OF TEST RESULTS AND MODELING

A comparison of the modeling and test results showed that all specifications were below the wall magnification of the modeling (Table 5). It is considered that the wall magnification of the test was lower than the estimated value due to the occurrence of brittle collective failure and the sinking at the upper and lower ends of the vertical frame, which was ignored in the calculation. In addition, in the modeling, it is assumed that the joint is destroyed, but in the experiment assuming high magnification, such as in this study, the frame material was destroyed.

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Therefore, when the wall magnification was calculated from the yield load that was not affected by the fracture and compared with the estimated results, the results were almost similar.

Table 5 *Comparison of wall magnification*

Specimen name	C-24	L-15	L-24
Nail distance	CN75 @50mm	CN65 @50mm	CN75 @75mm
Modeling wall magnification	10.85	10.62	10.05
Wall magnification calculated from P_0	8.10	7.64	7.61
Wall magnification calculated from Py	9.11	10.25	9.03

5.5 SUMMARY OF COLUMN BASE FIXED TYPE IN-PLANE SHEAR TESTS

When more nails were struck into two vertical frames, the force concentrated on the metal joint, causing collective destruction of the metal joint. In order to achieve a wall magnification of 10 times, it is necessary to consider the number of nails that hold the panels together and the metal joint that suppresses collective destruction.

6 TIE ROD TYPE IN-PLANE SHEAR TESTS

6.1 SUMMARY OF EXPERIMENTS

When the degree of fixation of the vertical frame increased from the destructive properties in Fig.16, collective destruction of the outer vertical frame occurred. It is considered that the stress is concentrated on the wall bases due to the increased wall strength. The performance of the bearing wall itself could not be verified with the fixed column base, and there was concern that the wall strength would be determined by the performance of the metal joint. In order to grasp the performance of the load-bearing wall itself, it is necessary to conduct an experiment that does not break the column base metal joints before the wall itself. Therefore, a tie rod type in-plane shear test was carried out in which the lifting of the load bearing wall legs was suppressed with a tie rod. The tie rod type in-plane shear test is suitable for evaluating the shear performance of the load-bearing wall.

6.2 OUTLINE OF TEST SPECIMEN

From the modeling of wall magnification in 4 MODELING BEARING WALLS, tie rod type tests were performed with C-24 specification, L-15 specification and L-24 specification. In the case of the tie rod type, it is described as TC-24 specification, TL-15 specification, TL-24 specification, and the number of test specimens was one each.

6.3 TEST METHOD

The tie rod type in-plane shear test was performed using a load frame tester in Nippon Institute of Technology (Fig. 17). The loading method was repeated three times in alternating positive and negative, and the loading cycle is apparent shear deformation angle 1/600, 1/450, 1/300, 1/200, 1/150, 1/100, 1/75, 1/50, 1 / 30 rad. (only 1/30 rad. was repeated one time). The tie rod test was repeated when the true shear deformation angle, which is the apparent shear deformation angle minus the deformation angle due to the rotation of the leg, reached each specific deformation angle.

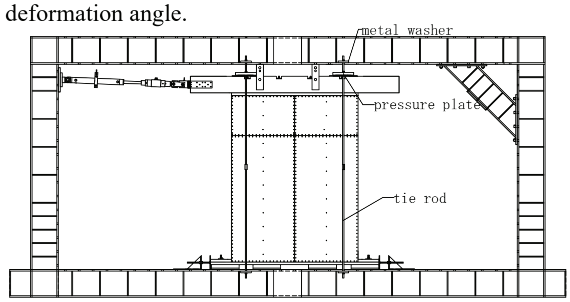

Fig. 17 *Specimen installation state*

6.4 EXPERIMENTAL RESULTS

Tables 6, 7 show the experimental results for each specification, and Fig. 18 shows a graph of the test results. In the TC-24 and TL-15 specifications, measurement was not possible until the end due to measurement failure. In TL-24, the wall magnification was determined by Py, and the value was 8.61 times. Comparing the TL-24 with the other two specifications, the one with the highest rigidity and maximum load was the TL-24 specification, so it is considered that the other two specifications will not perform any better. When confirming the fracture properties, the entire bearing wall showed rocking behaviour, cracks occurred in the lower frame from deformation after 1/50 rad. (Fig. 19, 20). In all specifications, cracks were caused by nails hit into the lower frame at the final failure. This failure could reduce the ultimate performance of the walls.

Table 6 *Test results*

	TC-24	TL-15	TL-24
K (kN/rad.)	3536.12	3700.01	5980.68
Py (kN)	30.80	27.20	30.70
Pmax (kN)	53.33	49.73	56.92
δu (rad.)	0.0406	0.0512	0.0650
Pu (kN)	47.55	44.67	53.01
δv (rad.)	0.0134	0.0121	0.0089
μ	3.02	4.24	7.34
Ds	0.45	0.37	0.27

Table 7 *Calculation result of wall magnification*

	TC-24	TL-15	TL-24
P_Y (kN)	26.51	26.81	34.90
2/3Pmax (kN)	35.55	33.15	37.95
(0.2/Ds)×Pu (kN)	21.35	24.15	39.20
Py (kN)	30.80	27.20	30.70
P_0 (kN)	21.35	24.15	30.70
Wall magnification	5.99	6.77	8.61

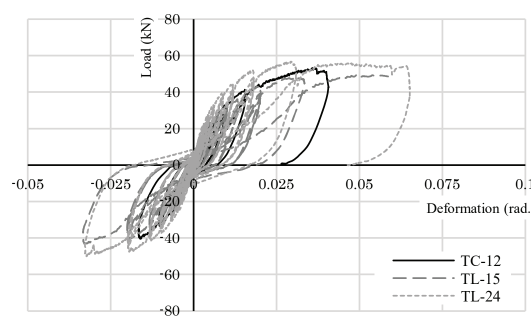

Fig. 18 *Load-deformation angle curve*

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Fig. 19 *Crack of lower frame*

Fig. 20 *Cracking progress*

6.5 OVERVIEW OF ADDITIONAL TEST

An additional test was performed to find a specification that can exceed the wall magnification by 10 times, because the target specification did not exceed the target wall magnification of 10 times. The nails were placed in one low frame material, thus the nail interval became shorter, then frame material was broken. Therefore, it was thought that cracking of the framed material could be prevented by staggering the nails between the vertical frames. In addition, since the frame material can be connected not only with nails but also with plywood, it is considered that rigidity and strength can be improved. We set the TL-24W specification (Fig. 21). The TL-24W specification uses a zigzag arrangement of 75 mm nails to hold the plywood, so that more nails can be hit than a 50 mm distance single row arrangement, while keeping the gaps between nails and preventing the nail spacing from becoming shorter. Since there were originally two vertical frames between panels, nails were struck in one vertical frame in a staggered arrangement. As a result of estimating the wall magnification by the method described in 4 MODELING BEARING WALLS before starting the final version of test, wall magnification was estimated 19.33 times. The test method was the same as in Section 6.3.

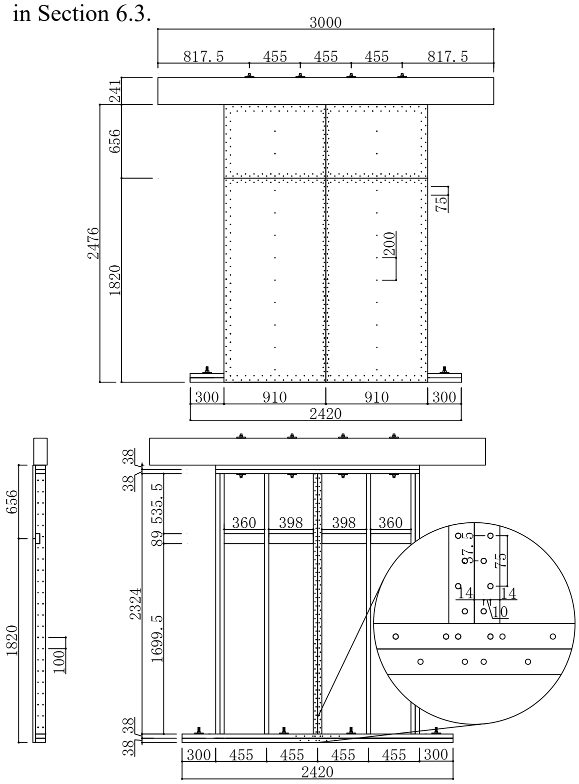

Fig. 21 *TL-24W specification test body*

6.6 ADDITIONAL TEST RESULTS

Tables 8, 9 show the experimental results for each specification, and Fig. 22 shows a graph of the test results. The TL-24W specification showed higher structural performance than the TL-24 specification from the beginning of deformation. This is considered to be due not only to an increase in the number of nails, but also to an increase in rigidity caused by connecting the frame members with plywood. When the fracture properties were confirmed, the vertical frame protruded from the minute deformation (1/450 rad.) because the bearing wall exhibited rocking behavior (Fig. 23). This is probably because the rigidity of the wall itself has increased and the legs have been rotated without deforming the wall. When the interlaminar deformation angle reached 1/50 rad., cracks occurred in the lower frame, although slightly less than before (Fig. 24). It is considered that the reason why the wall magnification of the experiment was lower than that of the modeling is that the deviation between the vertical frames from the initial stage of deformation is more remarkable than before, even though the vertical frame sinks (Fig. 25 and 26). However, the structural performance reached 12.39 times, exceeding the target wall magnification of 10 times.

Table 8 *Test results*

	TL-24	TL-24W
K (kN/rad.)	5980.68	8274.40
Py (kN)	30.70	44.21
Pmax (kN)	56.92	77.00
δu (rad.)	0.0650	0.0556
Pu (kN)	53.01	70.46
δv (rad.)	0.0089	0.0085
μ	7.34	6.53
Ds	0.27	0.29

Table 9 *Calculation result of wall magnification*

	TL-24	TL-24W
Pγ (kN)	34.90	48.54
2/3Pmax (kN)	37.95	51.33
(0.2/Ds)×Pu (kN)	39.20	48.59
Py (kN)	30.70	44.21
P0 (kN)	30.70	44.21
wall magnification	8.61	12.39

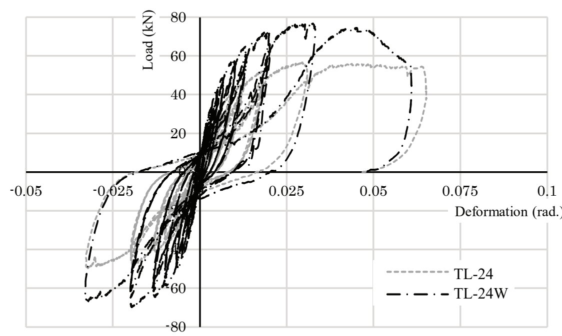

Fig. 22 *Load-deformation angle curve*

Fig. 23 *Lift of vertical frame*

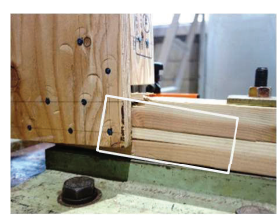

Fig. 24 *Cracking of the base*

Fig. 25 *Vertical frames misalignment*

Fig. 26 *Sinking of vertical frame*

6.7 SUMMARY OF TIE ROD TYPE IN-PLANE SHEAR TESTS

Even in the case of a shear wall test with a wall magnification of about 10 times, which was the target in this study, the performance of the shear wall itself could be evaluated by changing the test method to a tie rod type. In actual design, it is conceivable to prevent breakage in the vertical frame by increasing the number of vertical frames according to the pulling force acting on the vertical frame and installing appropriate HD metal joints.

7 CONCLUSION

Through this research, it was possible to realize a high-strength framework construction method wall (equivalent to a wall magnification of 10 times the wall strength ratio of the Japanese building code) using domestic Japanese cedar framing materials and Japanese plywood that are commercially available, without using special tools or special materials. Also, within the scope of this research, to make higher structural or fully effective performance of the surface material, two vertical frames between the panels were joined, nailing to the head joint and base through plywood, it is necessary to increase the degree of fixing between the vertical frames between panels. The tie rod type test method is better than the column base fixed type test method for verifying higher performance wall, such as 10 times the wall strength ratio of the Japanese building code regulations using Japanese timber.

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