World Conference on Timber Engineering Oslo 2023

EFFECT OF DIFFERENT TESTING METHODS ON THE STRUCTURAL PERFORMANCE OF WOODEN SHEAR WALLS

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ABSTRACT: The purpose of this study was to verify the effect of different testing methods on structural performance evaluation in in-plane shear tests with high-strength bearing walls. The results obtained from tie-rod type tests were used to verify the effects of axial force and placement of tie-rod on the performance evaluation of bearing walls. As a result, it was verified that axial force has almost no effect on the performance evaluation of bearing walls in general strength bearing walls. In the future, we will verify the effects of axial force and placement of tie-rod on the performance evaluation of bearing walls by changing the test specimen specifications.

KEYWORDS: Shear wall test, Column-base fixed type, Tie-rod type, Placement of tie-rod, Axial force of tie-rod

1 INTRODUCTION

In Japan, performance evaluation of bearing walls in wooden buildings is based on in-plane shear tests. There are two types of test methods: column-base fixed type and tie-rod type.

The column-base fixed type is a method of restraining lifting by attaching hold-down hardware to the legs of a bearing wall (Fig.1.1). This is currently the most used test method. However, when used for high-strength bearing walls, there is concern that the column-leg joints may fail prior to the end state of the bearing wall.

The tie-rod type is a method of restraining the lifting of bearing wall legs by using tie-rods (steel rods) (Fig.1.2). This test method is suitable for evaluating the performance of the bearing wall itself. This test method is often used for high-strength bearing walls.

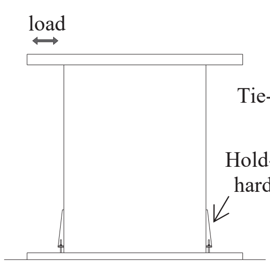

Fig 1.1: *Column-base fixed*

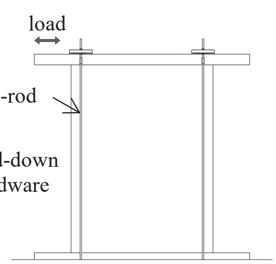

Fig 1.2: *Tie-rod type*

In recent years, high-strength bearing walls have been developed to promote the use of medium to large scale wooden buildings. Accordingly, the tie-rod type is increasingly used. However, it is not clear how different testing methods affect the performance evaluation of such high-strength bearing walls. The purpose of this study was to compare the results of tests conducted with column-base fixed type and tie-rod type, and to determine the effect of the different test methods on performance evaluation.

In the tie-rod type test method, it is common knowledge the restraint by the tie rods is such that no load is applied. The tie rods are often placed along the column core, but this depends on the test equipment and the test specimen specifications. It was thought that different axial forces and placements would affect the performance evaluation, but it was not clear how much they would affect it. Therefore, in the tie-rod type, the effects of tie-rod axial force and placement on performance evaluation were also examined.

2 SUMMARY OF RESEARCH

The purpose of this study was to verify the effect of different testing methods on structural performance evaluation in in-plane shear tests with high-strength bearing walls. In terms of the effect of restraint force on performance evaluation, differences in restraint force and left-right differences in restraint force have a slight effect on structural performance but almost no effect. Controlling the restraining force through torque management or other means would have less effect on performance evaluation. In terms of the effect of the different placements on the performance evaluation, the structural performance of the specimens with 200 mm different tie-rod placements was compared, and the results were almost the same, so there was no effect with differences in placement. In terms of the effect of the different test methods on the performance evaluation, the determinants of allowable shear strength were different, but the values were the same, so there was no effect of the final evaluation on the wall strength.

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https://doi.org/10.52202/069179-0441

3 EFFECT OF AXIAL FORCE ON THE STRUCTURAL PERFORMANCE

3.1 VERIFICATION WITH GENERAL STRENGTH BEARING WALLS

First, the effect of the axial force of the tie rods on the performance evaluation of the bearing walls was verified. The specimens were compression braced load-bearing walls (Fig. 3.1,3.2). A total of four tie rods were placed along the column cores. The left front and left back tie rods restrained the uplift of the left leg, and the right front and right back tie rods restrained the uplift of the right leg. Initially, to understand the relationship between the tightening angle and the axial force of the tie rods, the axial force was measured when the nuts of the tie rods were tightened by hand and when they were tightened half a turn each using a tool. The results are shown in Fig. 3.3 and Table 3.1. The total axial force for both the left and right sides was less than 1kN when hand tightened. At 1260- degree, the left axial force was about 36kN and the right axial force was about 44kN, with the right axial force tending to be higher. This is considered due to the distortion of the specimen and the order of tightening.

Next, in-plane shear tests were performed with the tie-rods tightened to the limit (1260-degree). The test results are shown in Table 3.2. While the wall magnification was equivalent to 2.5, the result was 2.8. Considering that a total axial force of about 80kN was applied, the axial force has almost no effect on the performance evaluation of bearing walls.

Fig 3.1: *Before the test*

Fig 3.2: *After the test*

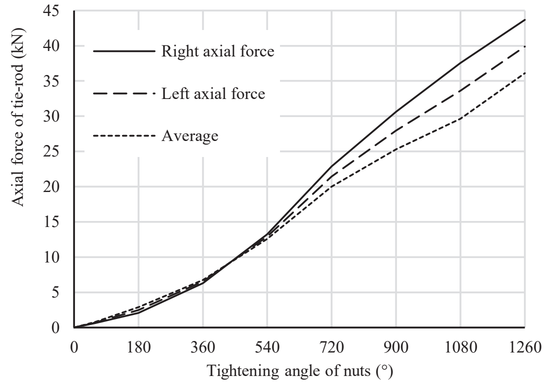

Fig 3.3: *Test results (Axial force)*

Table 3.1: *Test results (Axial force)*

Tightening angle	Axial force of tie-rod (kN)					
	Left front	Left back	Left total	Right front	Right back	Right total
By hand	0.48	0.32	0.80	0.48	0.16	0.64
180°	1.45	1.45	2.90	1.13	0.97	2.10
360°	3.22	3.55	6.77	3.55	2.74	6.29
540°	5.80	6.77	12.57	6.77	6.45	13.22
720°	9.67	10.32	19.99	11.93	10.96	22.89
900°	12.42	12.89	25.31	15.15	15.47	30.62
1080°	14.99	14.67	29.66	18.70	18.86	37.56
1260°	18.05	18.05	36.10	21.44	22.24	43.68

Table 3.2: *Test result (Shear wall test)*

	Hand-tightened	Half-turn	Axial force 20kN
K [kN/rad.]	5622.49	7576.65	7610.97
Pmax [kN]	55.57	54.37	54.07
Py [kN]	34.99	33.44	30.15
Pu [kN]	49.26	48.09	48.13
δv [rad.]	0.0087	0.0063	0.0063
δu [rad.]	0.0340	0.0339	0.0331
μ	3.8806	5.3487	5.2379
Ds	0.3846	0.3211	0.3248
Py [kN]	34.99	33.44	30.15
Pu*(0.2/Ds) [kN]	25.62	29.95	29.63
2/3Pmax [kN]	37.05	36.25	36.05
Pγ [kN]	36.17	38.64	38.75
Pa [kN]	25.62	29.95	29.63

3.2 VERIFICATION WITH HIGH-STRENGTH BEARING WALLS

The test specimens were two specifications. One is framework construction method bearing walls and the other is framed wall construction method bearing walls (Fig.3.4,3.5). Three specimens were used for each.

For the framework construction method bearing walls, 9mm plywood (JAS A class 2) was attached using CN50 nails at a pitch of 150mm in the middle passage and 75mm in the perimeter. For the framed wall construction method bearing walls, 9mm plywood (JAS A class 2) was attached using CN50 nails at a pitch of 200mm in the middle passage and 50mm in the perimeter.

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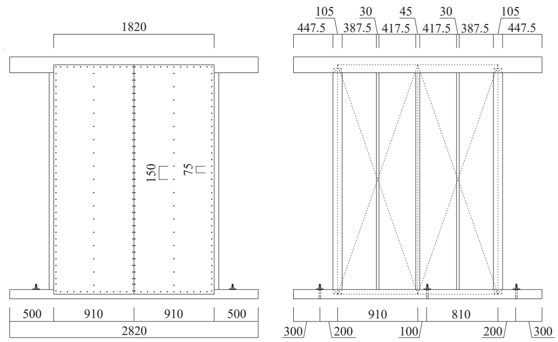

Fig 3.4: *Framework construction method bearing wall*

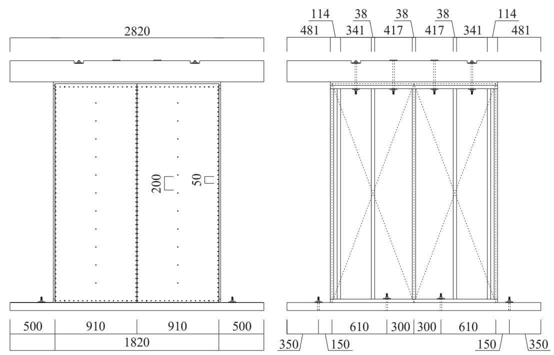

Fig 3.5: *Framed wall construction method bearing wall*

Table 3.3: *Measured results of restrained axial force*

		Left axial force [kN]	Right axial force [kN]	Left-Right differences [kN]
Framework construction	1. Hand-tightened	3.63	3.74	0.11
	2. Half-turn	14.80	16.86	2.06
	3. Axial force 20kN	20.91	20.61	0.30
Framed wall construction	1. Hand-tightened	3.19	2.59	0.60
	2. Half-turn	17.86	12.83	5.03
	3. Axial force 20kN	22.51	21.62	0.89

Installation for tie rod type is shown in Fig.3.6,7. There are three test conditions. One is when the tie rods are hand-tightened, another is when they are hand-tightened and then tightened a half-turn using a tool, and the third is when they are tightened until the axial force per column reaches 20 kN (the long-term design axial force for a typical Japanese house). Table 3.3. shows the measured results of the restrained axial force at each condition.

The tie rod type in-plane shear test was performed using a load frame tester in Nippon Institute of Technology (Fig.3.6,7). The loading method is 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 once). 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 3.6: *Framework construction method bearing wall*

Fig 3.7: *Framed wall construction method bearing wall*

Table 3.4,3.5 and Fig 3.8,3.9 shows the test results for each specification.

The load-displacement curve for the three conditions for the framework construction method bearing wall were almost identical. All allowable shear strengths (Pa) were determined by Pu (0.2/Ds). Compare the hand-tightening case with the half-turn and 20 kN cases. Compared the allowable shear strengths (Pa), the hand-tightening with half-turn and 20 kN cases. The value was 20% lower in the hand-tightening case. This is because Pu had the highest value, but Ds had unfavorable values. Compared to the fracture properties, the plywood peeling was total for the half-turn and 20 kN cases, whereas it was partial for the hand-tightened case. Compared the allowable shear strengths (Pa), the half-turn and 20 kN cases. The values were equivalent. The fracture properties were both plywood peeling, and the degree of plywood peeling was similar. Compared with hand-tightening and half-turn, 20 kN cases shows that the difference in initial restraint force affects the performance evaluation. Although there was a difference of approximately 10 kN in the restraint force between the half-turn and 20 kN, the allowable shear capacity was equivalent. Therefore, we believe that above a certain level of restraint force, there is no significant difference in performance.

The load-displacement curves for the framed wall construction method bearing walls were almost identical for the hand-tightened and 20 kN cases but differed for the half-turn case. All allowable shear strengths (Pa) were determined by Pu (0.2/Ds). In the case of half-turn, both Pu and Ds showed unfavorable values, resulting in lower values of allowable shear strengths (Pa) than during the other conditions. In the half-turn case, there was nail penetration but little damage to the plywood. In the case of hand-tightened and 20 kN, nail pull out and punching out occurred, and damage to the plywood was significant. The reason why the half-turn case resulted differently from the other conditions was due to the balance between the left and right restraining axial forces. In the case of half-turn, there was a relatively large left-right difference in restraint force, with a lower value for the right restraint force, which affects the time of final failure. The load-bearing wall tended to lift during other conditions, and the load-bearing wall rotated as one piece. Therefore, the allowable shear capacity showed low values due to low initial stiffness and unfavorable toughness.

Table 3.4: *Result of framework construction method bearing*

	Hand-tightened	Half-turn	Axial force 20kN
K [kN/rad.]	5622.49	7576.65	7610.97
Pmax [kN]	55.57	54.37	54.07
Py [kN]	34.99	33.44	30.15
Pu [kN]	49.26	48.09	48.13
δv [rad.]	0.0087	0.0063	0.0063
δu [rad.]	0.0340	0.0339	0.0331
μ	3.8806	5.3487	5.2379
Ds	0.3846	0.3211	0.3248
Py [kN]	34.99	33.44	30.15
Pu*(0.2/Ds) [kN]	25.62	29.95	29.63
2/3Pmax [kN]	37.05	36.25	36.05
Pγ [kN]	36.17	38.64	38.75
Pa [kN]	25.62	29.95	29.63

Table 3.5: *Result of framed wall construction method bearing*

	Hand-tightened	Half-turn	Axial force 20kN
K [kN/rad.]	5622.49	7576.65	7610.97
Pmax [kN]	55.57	54.37	54.07
Py [kN]	34.99	33.44	30.15
Pu [kN]	49.26	48.09	48.13
δv [rad.]	0.0087	0.0063	0.0063
δu [rad.]	0.0340	0.0339	0.0331
μ	3.8806	5.3487	5.2379
Ds	0.3846	0.3211	0.3248
Py [kN]	34.99	33.44	30.15
Pu*(0.2/Ds) [kN]	25.62	29.95	29.63
2/3Pmax [kN]	37.05	36.25	36.05
Pγ [kN]	36.17	38.64	38.75
Pa [kN]	25.62	29.95	29.63

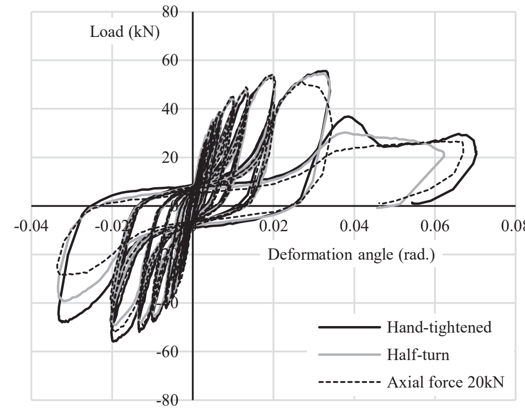

Fig 3.8: *Load-displacement curve*
Framework construction method bearing wall

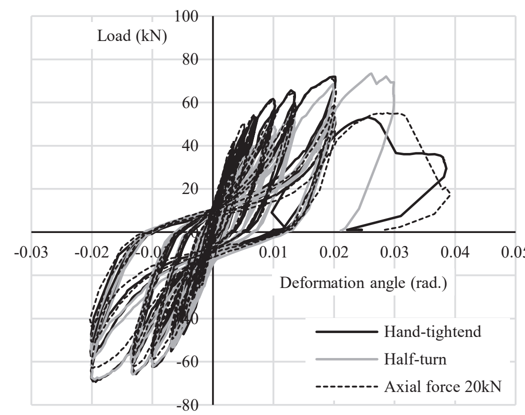

Fig 3.9: *Load-displacement curve*
Framed wall construction method bearing wall

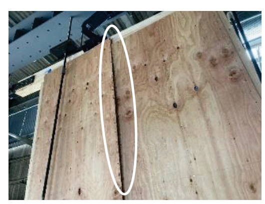

Fig 3.10: *Plywood peeling half-turn and 20 kN cases*

Fig 3.11: *Plywood peeling hand-tightened case*

Fig 3.12: *Nail penetration half-turn case*

Fig 3.13: *Nail punching out hand-tightened and 20 kN*

4 EFFECT OF TIE-ROD PLACEMENT

4.1 TEST OVERVIEW

The effect of the placement of the tie rods on the performance evaluation of the bearing walls was verified. In-plane shear tests had different tie-rods placement. The test results of the previous research were compared again,

https://doi.org/10.52202/069179-0441

and a new perspective on the effect of the placement of the tie rods on the performance evaluation of the bearing walls was verified.

4.2 TEST SPECIMENS AND TEST METHODS

The tie rod type in-plane shear test was performed using a load frame tester in Nippon Institute of Technology (Fig.4.1,4.2). The loading method is 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. 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 4.1: *Placement of tie rod (First and second specimens)*

Fig 4.2: *Placement of tie rod (Third specimens)*

4.3 TEST RESULTS

Table 4.1 shows the test results and Figure 4.3 shows the load-displacement curves. The allowable shear strengths (Pa) were determined by the yield strength, Py, for the first specimen, and by the toughness value, Pu (0.2/Ds), for the second and third specimens. The load-deformation angle curves at ultimate failure were different for the first, second, and third specimens. These differences were due to different factors of fracture properties. Since the results of the first specimen were different from those of the other specimens, a comparison of the second and third specimens was conducted to verify the effect of the different placements on the performance evaluation. The load-displacement curves were almost identical. The allowable shear strengths (Pa) showed 11.6 for the second and 10.2 for the third, a difference of about 10%. The left and right restraints at 1/600 rad. were generally in agreement. The left restraint force at 1/50 rad. was generally consistent. The right restraining force showed approximately 167 kN for the second body and 212 kN for the third body, a difference of about 20%. However, the differences in determinants and allowable shear strengths (Pa) were all about 10%, and the load-displacement curves and fracture characteristics were almost identical, suggesting that the differences in tie-rod placements had little effect on the performance evaluation of the bearing walls.

Table 4.1: *Test results*

	First	Second	Third
K [kN/rad.]	13084.3	12331.8	12972.2
Pmax [kN]	87.9326	83.58	82.24
Py [kN]	50.00	44.56	50.34
Pu [kN]	82.03	73.78	78.69
δv [rad.]	0.0038	0.0036	0.0038
δu [rad.]	0.0062	0.0059	0.0060
μ	6.4797	4.6553	3.3386
Ds	0.2891	0.3468	0.4196
Py [kN]	50.00	44.56	50.34
Pu*(0.2/Ds) [kN]	56.74	42.54	37.50
2/3Pmax [kN]	58.62	55.72	54.82
Pγ [kN]	67.08	68.03	70.53
Pa [kN]	50.00	42.54	37.50

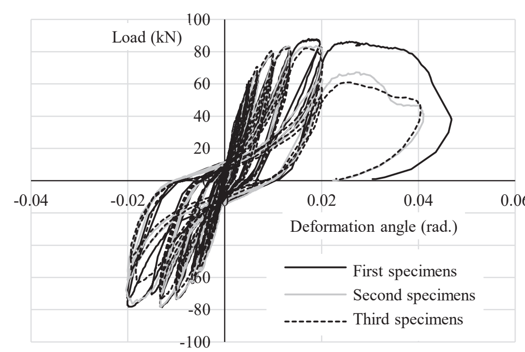

Fig 4.3: *Load-displacement curve*

5 EFFECTS OF DIFFERENT TEST METHODS

5.1 TEST SUMARY

The effects of different testing methods for in-plane shear tests on the performance evaluation of load-bearing walls. The influence of the different test methods is verified by comparing the results of in-plane shear tests using the fixed column leg and tie-rod methods.

5.2 TEST METHODS

The tie rod type in-plane shear test was performed using a load frame tester in Nippon Institute of Technology (Fig.5.1,5.2). The loading method is 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. 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 5.1: *Specimen installation state (Column-base fixed type)*

Fig 5.2: *Specimen installation state (Tie-rod type)*

5.3 TEST RESULTS

The load-displacement curves are shown in Figure 5.3 and the test results are in Table 5.1,5.2. The allowable shear strengths (Pa) were 10.21 kN and 10.47 kN for the column-base fixed type and tie-rod type, respectively, with the tie-rod type showing a slightly higher value. The allowable shear strengths (Pa) were determined by 0.2Pu √(2μ-1) for the fixed column leg method and Py for the tie-rod method, and the determining factors differed depending on the test method. Comparing the determinants, only 0.2Pu√(2μ-1) is higher for the tie-rod type. The other determinants were higher for the column-base fixed type. Since the column-base fixed type showed more favorable performance in terms of bearing capacity and the tie-rod type showed more favorable performance in terms of toughness, the different test methods are considered to have an influence on the performance evaluation. However, since the allowable shear strengths (Pa) values were comparable, we believe that the different testing methods have little effect on the final evaluation.

Table 5.1: *Test results*

	Column-base fixed type	Tie-rod type
K [kN/rad.]	1395.30	1696.49
Pmax [kN]	17.37	16.02
Pu [kN]	16.05	14.55
δv [rad.]	0.011	0.008
δu [rad.]	0.063	0.062
Ds	0.314	0.270

Table 5.2: *Determinants of allowable shear strengths*

	Column-base fixed type	Tie-rod type
Py	11.20	10.47
Pu*(0.2/Ds)	10.21	10.75
2/3Pmax	11.58	10.68
Pγ	11.42	11.01
Pa (kN)	10.21	10.47

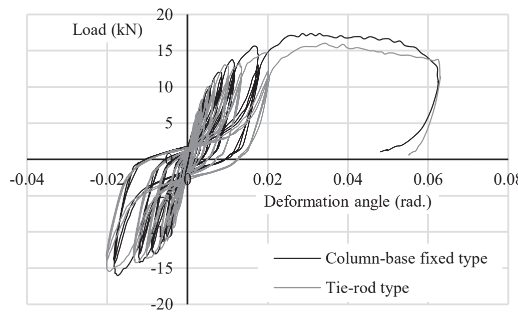

Fig 5.3: *Load-displacement curve*

5.4 SUMMARY

Although the determinants were different, the allowable shear strengths (Pa) were almost identical. Therefore, the differences in test methods affect the performance evaluation but have little effect on the final allowable shear strengths (Pa) evaluation.

6 CONCLUSION

In terms the effect of restraint force on performance evaluation, differences in restraint force and left-right differences in restraint force have a slight effect on structural performance but almost no effect. Controlling the restraining force through torque management or other means would have less effect on performance evaluation. In terms of the effect of the different placement on the performance evaluation, the structural performance of the specimens with 200 mm different tie-rod arrangements was compared, and the results were almost the same, so there was no effect with differences in placement. In terms of the effect of the different test methods on the performance evaluation, the determinants of allowable shear strength were different, but the values were the same, so there was no effect of the final evaluation on the wall strength.

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