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Strengthening of wood framed walls of Japanese houses using TYFO® SEH GFRP System

B. Abdullah[1], R. Jamaji[2] & S.P. Chiew[3]
[1]*West Holdings Corporation, Doctor of Eng., Chief Engineer, Hiroshima, Japan*
[2]*Fyfe Asia PTE LTD, Senior Vice President, Singapore*
[3]*School of Civil & Environ. Eng., Nanyang Tech. Uni., Doctor of Eng., Associate Professor, Singapore*

ABSTRACT: Wooden houses in Japan are usually built by post and beam methods. This paper introduces a new strengthening system for Japanese wooden houses against seismic activity by using GFRP materials. The concept is based on increasing the shear capacity of the wood framed walls by applying a diagonal GFRP bracing system. This system can be installed directly onto the external walls of the house right over the architectural finish and is able to dramatically enhance the wall shear capacity and the wall shear factor.

1 INTRODUCTION

A report by the Japanese Ministry of Transportation, Land and Infrastructure shows that 24.5 millions wooden houses are built all over the country. Of these homes, 41% need urgent seismic strengthening. Currently available strengthening systems are far beyond the budget of any ordinary Japanese family as it is required to change the structure of the house, which includes dismantling of walls and floors to add new structural members (such as wooden diagonal posts and bracings…etc.), then reassemble them and finally reapplying the architectural finishing.

This paper introduces a new strengthening system for Japanese wooden houses against seismic activity by using GFRP materials. The concept is based on increasing the shear capacity of the wood framed walls by applying a diagonal GFRP bracing system. This system can be installed directly onto the external walls of the house right over the architectural finish and is able to dramatically enhance the wall shear capacity and the wall shear factor.

To investigate the effectiveness of the system, three full scale typical wooden wall specimens with mortar finishing were prepared and tested under in-plane cyclic loadings up to failure. The control specimen (Type S0) was built of 3vertical posts, 1 horizontal top beam and 1 horizontal ground sill. Posts, beam and sill were joined by using T-shaped metal plates and nails. Wooden lath boards were then nailed horizontally to the posts to form the surface of the wall. A waterproof tar paper was then stapled to the lath boards along with a fine metal mesh to which a 15 mm layer of cement mortar finish was applied. Strengthened specimen (Type S1) was similar to Type S0, but a diagonal bracing of GFRP was bonded over the mortar finishing and then fixed onto the corners of the walls using fiber anchors. Strengthened specimen Type S2 was similar to Type S0, but had a window opening. Type S2 was also strengthening with GFRP layers bonded over the mortar finishing with the GFRP layers fixed at the corners with the fiber anchors.

The proposed GFRP strengthening system was able to increase the shear capacity of Type S1 and Type S2 specimens over that of Type S0 (control) by 9 and 5 times respectively.

2 EXPERIMENTAL TEST PROGRAMME

All the specimens and loading procedures were prepared and conducted based on the Japanese Building Standard Act, Enforcement order article 46, clauses 4 table 1-8.

2.1 *Materials*

All the wooden frame members were made of Japanese cedar, but only the upper beam was of American pine.

The mechanical properties of the unidirectional glass fiber sheets are listed in Table 1.

Table 1.Mechanical properties of GFRP

Property	ASTM Method	Typical test value
Tensile strength	D-3039	575 MPa
Elongation at break	D-3039	2.2%
Tensile Modulus	D-3039	26.1 GPa
Laminate thickness		1.3 mm

2.2 *Specimen Configuration*

The typical timber wall specimen is composed of two horizontal beams (top beam and bottom sill) three vertical columns, two vertical internal studs and twenty-four lath boards as shown in Figure 1. The distance between two vertical columns is 910 mm, while the distance between the horizontal beams is equal to 2730 mm. All specimens have a total width of 2520 mm and height of 2857 mm.

The fabrication of the wooden wall section follows the process used in construction of the wooden house in Japan. The beams and columns are connected by wooden pin and groove on the top and bottom of the columns into the beams. A T-shaped metal plate is nailed externally to strengthen the connection at both sides. The lath boards are attached to the wooden frame with nails. A waterproofing tar paper is attached to the lath boards with staples at 300mm c/c both ways followed by a metal lath (mesh) stapled to the lath boards with staples 300mm c/c both ways through the waterproofing paper. A 15mm mortar finish is then applied to the surface of the wall over the steel mesh and waterproofing paper. The complete wall specimen configuration with lath boards and mortar board installed is shown in Figure 1.

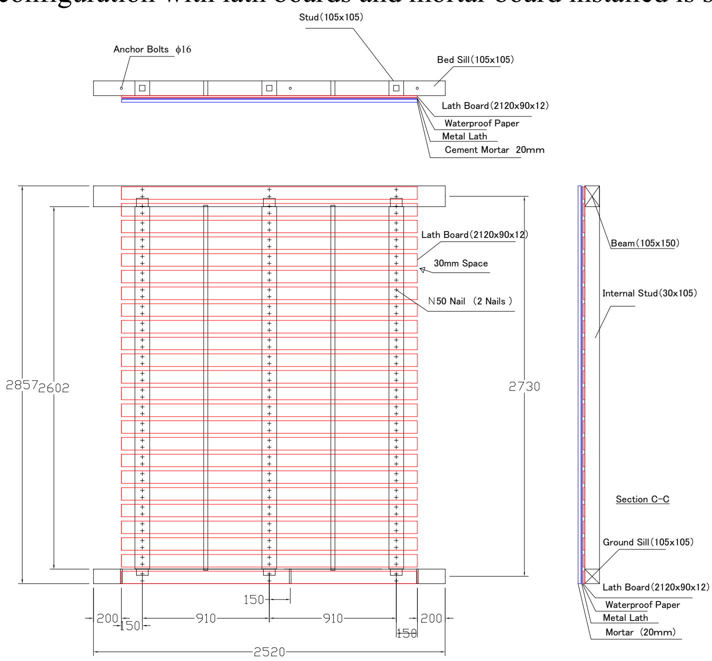

Figure 1.Specimen configuration

In the experimental program, a total of three (3) specimen Types are tested. The first Type (S0) is not strengthened and used as a control specimen as shown in Figure 3 (a). The second Type (S1) is strengthened with 1-Layer of GFRP composite in X–shaped layout as shown in Figure 3(b). The last one (S2) is strengthened with 1-Layer of GFRP composite in V-shape as to accommodate the window opening on the right side of the wall (see Figure 3(c)). The ends of the composite strips are anchored into the wooden beams and columns using specially developed fiber anchors for this purpose. Five fiber anchors are inserted at the termination point of the composite strips and spaced out evenly across the width of the strip.

(a) (b) (c)

Figure 2.Specimens with different strengthening details (a) control specimen without FRP, (b) specimen strengthened with X-shape GFRP (c) specimen strengthened with V-Shaped GFRP

2.3 *Test setup*

The test setup is shown in Figure 3. A hydraulic jack with 600 mm stroke is used to apply the cyclic loading. The left end of the hydraulic jack is fixed to the steel frame which is used as a horizontal reaction wall. A load cell with 500 kN capacity is connected to the end of the jack to measure the magnitude of the load. The wall is fixed to a steel beam with square hollow section which is anchored to the ground as a rigid sill. The horizontal movement is restrained by the metal supports at both ends of the bottom of the wall.

Four linear variant displacement transducers (LVDT) are employed to measure the displacements. The first one (H1) is used to measure the horizontal displacement at the top of the wall. The second (H2) is to measure the bottom horizontal displacement. The last two (V3 and V4) are used to measure vertical displacements at the left and right column sides; respectively.

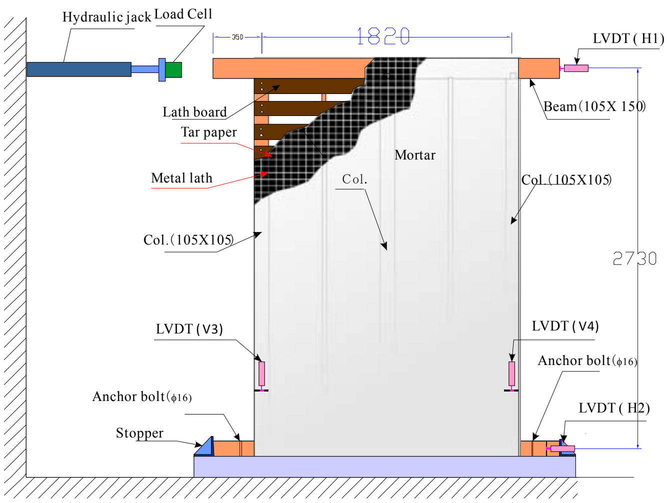

Figure 3.Test setup

2.4 *Test Procedure*

To simulate the seismic loading conditions on real timber structures, cyclic loads with gradually increased amplitude are applied to the upper beam. Totally seven cyclic loading steps are applied. Three cycles push and pull are performed in each step. Loading steps is controlled by the observed shear transformation angle (γ). The details of the loading steps are shown in Table 2. γ is the shear transformation angle of the wall. The vertical distance between the upper and lower horizontal LVDTs (H1 and H2) is equal to L= 2730 mm. The relative movement of the wall is δ1 = H1-H2. After the twenty-one cycles of cyclic loading, the specimens are loaded under static loading until the specimens fail.

Table 2 loadings steps used in the cyclic test

Step	Shear transformation angle γ		Tangent γ	L	δ1 = H1-H2
	rad	degree		mm	mm
1	1 /450	0.127322	0.002222226	2730	6.07
2	1/300	0.190983	0.003333346	2730	9.10
3	1/200	0.286475	0.005000042	2730	13.65
4	1/150	0.381967	0.006666765	2730	18.20
5	1/100	0.57295	0.010000333	2730	27.30
6	1/75	0.763933	0.013334124	2730	36.40
7	1/50	1.1459	0.020002667	2730	54.61

3 SHORT-TERM SHEAR CAPACITY

3.1 *Short-term shear capacity of wooden framed wall (Po)*

The Japanese building standard specifies that the value of the short-term shear capacity of framed wooden wall (Po) is the smallest among the following values:

A. Shear capacity when shear transformation angle is equal to 1/120 rad. (P120).
B. Yield capacity (Py)
C. 2/3rd the value of maximum load
D. The value of $(0.2Pu)x\sqrt{(2\mu-1)}$

Where: (Pu) is the ultimate load capacity and (μ) is the ductility factor (Figure 3)

3.2 *Short-term allowable shear capacity of wooden framed wall (Pa)*

The short-term allowable shear capacity of wooden framed wall (Pa) can be calculated by using equation 1.

$$Pa = Po \times \alpha \quad (1)$$

Where (Po) is the short-term shear capacity of wooden framed wall, and (α) is a reduction factor which takes into account the materials durability the environmental and execution related effects. In this study (α) factor will be set to 1.

3.3 *Wall shear factor*

The wall shear factor (n) can be calculated based on the value of the short-term allowable shear capacity and by applying equation 2.

$$n = Pa \times (1/1.96 \times L) \quad (2)$$

Where L is the length of the wall (L=1.82m)

3.4 *Load-shear transformation angle relationship (bilinear model)*

The shear wall factor (n) and the allowable shear capacity (Pa) of the framed wall will be calculated based on a bilinear model of the load-shear transformation angle relationship curve. Figure 3 shows the details of the bilinear model.

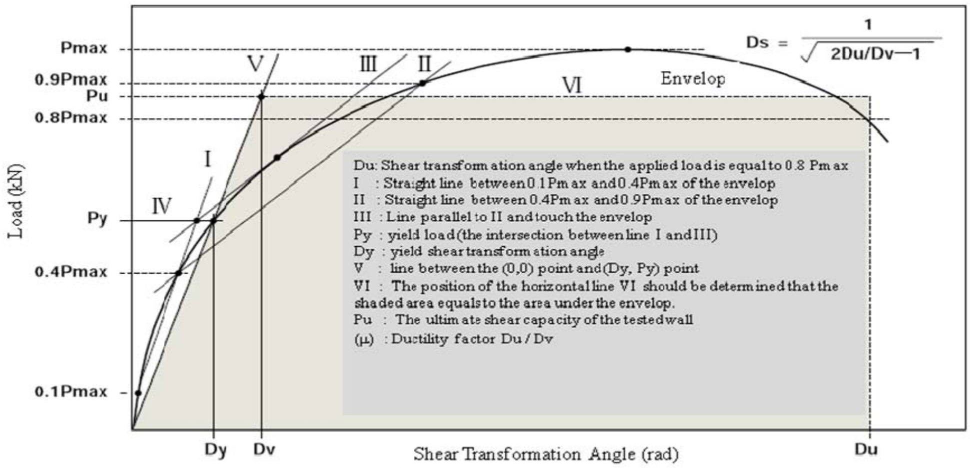

Figure 3.Bilinear model

4 EXPERIMENTAL RESULTS

4.1 *Cyclic response*

The hysteretic performances of the specimens are compared by the curves shown in Figure 4. For the control specimen without FRP strengthening, the load almost does not increase from the third step of the cyclic loading. After the fifth step, the load carrying capacity begins to drop. For the specimens with FRP strengthening, the loads keep increasing throughout all the loading steps. In the unloading stage, the loads do not drop in a sharp mode as the un-strengthened specimen does. The system absorbed energies for the specimen Type S1 and Type S2 are 5.3 times and 3 times larger than that of Type S0, respectively. Therefore, it can be concluded that the FRP strengthening measure can significantly enhance the seismic resistance capacity of the wooden walls.

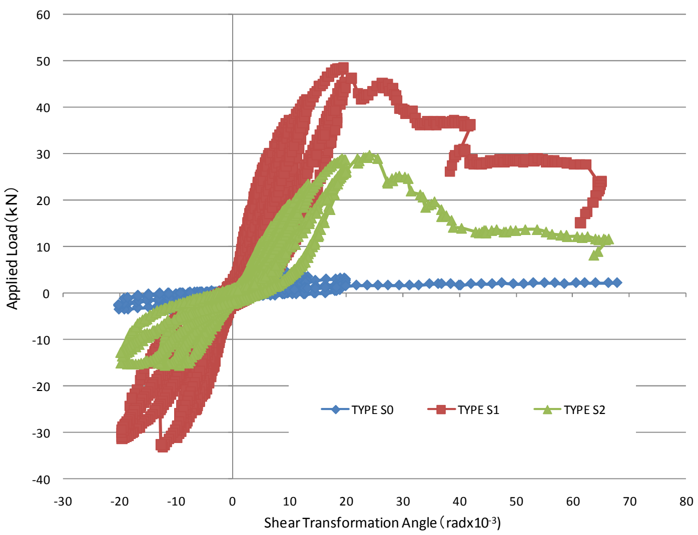

Figure 4.Hysteretic performance

4.2 *Shear Capacity and wall shear factor*

Based on the previous bilinear model the shear capacities and the wall shear factor are calculated. Figure 5 shows the bilinear model for specimen Type S1, while Table 3 shows a comparison of the loading results for the three tested specimens. It is clear that strengthening wooden framed wall with GFRP can enhance its shear capacity enormously.

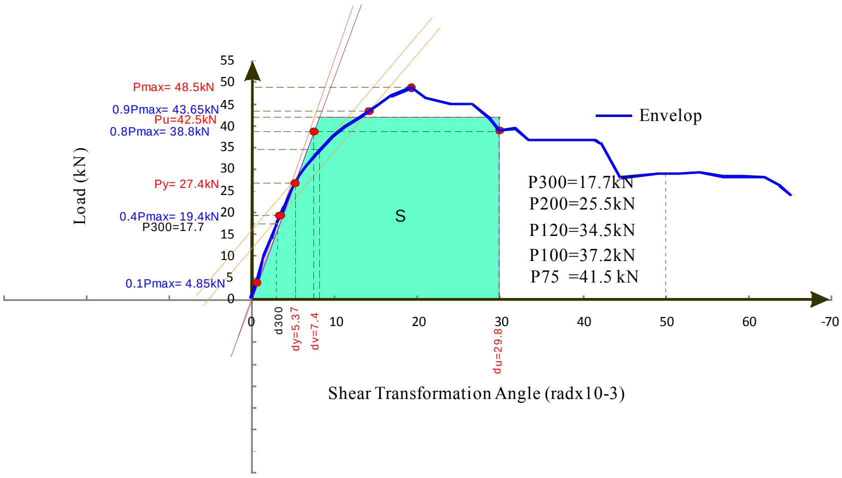

Figure 5.Specimen Type S1 (bilinear model)

Table 3 Test results

	Max. Load P max(kN/m)	S.D.A of Max. Load θ max(10^{-3}rad)	Yield Load P y(kN/m)	S.D.A of Yield load θ y(10^{-3}rad)	Utimate Load Pu(kN/m)	S.D.A of Ultimate Load θ u(10^{-3}rad)
Type-S0	2.66	9	1.73	1.85	2.29	12.11
Type-S1	26.6	26.6	15.1	5.37	23.35	29.8
SE	900%	196%	773%	190%	920%	146%
Type-S2	16.04	24.12	14.8	6.78	14.1	31.97
SE	503%	168%	755%	266%	516%	164%

	S.D.A of Yield Point* θ v(10^{-3}rad)	Stifness K (MN /rad)	Ductility Factor μ	0.2 P u･√ (2 μ -1) (kN/m)	Allowable Shear Capacity(Pa) (ｋＮ／ｍ)	Wall Shear factor n
Type-S0	3.38	0.93	3.58	1.14	1.14	0.6
Type-S1	7.4	2.81	3.96	12.29	9.21	4.7
SE	119%	202%	11%	978%	708%	
Type-S2	11.81	2.18	2.69	5.9	4.425	2.3
SE	249%	134%	-25%	418%	288%	

S.D.A : Shear deformation Angle SE : Strengthening effectiveness *: bilinear model

5 CONCLUSIONS

Based on the experimental study the following conclusions can be made;

1. The introduced strengthening system was able to enhance the load shear capacity of wooden framed wall by 900% and 503% in specimens Type S1 and S2, respectively.
2. The introduced strengthening system was able to increase the wall shear factor (n) to 4.7 and 2.3 in specimens Type S1 and S2, respectively.
3. The introduced strengthening system is a promising technique to protect the existing Japanese wooden houses against seismic risks.

6 REFRENCES

- Japan house foundation, wood material technology center. (Allowable stress design approach of framed wooden houses.) (in Japanese)