A Study On Structural Performance Of Steel Foundation- wooden Column Connection For Temporary Houses

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SUMMARY:
Current practice make use of hybrid members with steel-wooden or steel-concrete or concrete-wooden members are proposed all over the world. Structural performance of joints is a critical issue in such structures. Since wood has a much smaller strength compared to other materials, it is necessary to control the failure of the wood portion in a new hybrid joints with a wood component. In this study for this purpose, two types of wooden-steel joints with fasteners are proposed. Lag screw bolts and a long nut bolts are used as fasteners. Steel members are ranked from FA to FD based on Japanese code. Structural performance of the proposed joints are tested and analyzed under the effect of lateral loads. Additionally as a case study, a temporary house that is designed with proposed connections is studied.

Keywords: Steel Member, Wooden member, Connection, Bending strength, Temporary houses

1. INTRODUCTION

Generally a lot of structures by architectures are constructed on the foundation made of reinforced concrete in Japan. We would need to have hardening time after casting concrete. At that time rainy condition or some abysmal weather would affect aging time of concrete or working efficiency. Those items would be directly linked to rising up its cost problem or lowering the quality of concrete or discarding clod at excavation. To these problems, a method with steel members for the foundation is proposed (Koyama et al, 2004). With this method, we could set the foundation only putting steel members on the basement. The concrete foundation is mainly used for structures by architectures or some structures in Japan, so the cost of concrete construction isn't expensive. As we all know, the material cost of steel member is higher than that of concrete. However using steel member for the foundation don't need the hardening time, it has possibilities to shorten the work period or reduce the building cost. Consequently we would have to study the best suited construction on that foundation. In this study, we would study the combination that wooden construction and steel foundation.
In this article we conducted bending tests with joint composed wooden and steel members. Here we would use 2 types of fastener. They are lag screw bolts, long nut fixed with infill material.
The joint with lag screw bolt would be proposed by Nakatani, Komatsu, Mori et al (2006, 2008, 2008), those are used for a large scale wooden architecture in Japan, its general length is around 330mm. In this study we would improve it for smaller one, that is 80mm length. A lag screw bolt would be inserted in wood member ahead, wooden and steel member are hand-fastened with a high-tensile bolt. Hereafter we call this type-joint "LSB joint".
The infill material is applied to a joint of pre-cast concrete structure in Japan. The infill material would be poured into a hole in under part of concrete-wall, in a similar manner poured into a hole of wood and a long nut would be inserted in it. After hardening of infill material, wooden and steel member are hand-fastened with a bolt. That bolt is graded as SS400 in Japanese code. Hereafter we call this type-joint "Infill joint".
With above joints, we would analyze structural performance and strength presumption methods and study the volume of feasible structure by architecture with these joints based on Japanese code.

2. TEST METHOD AND CONFIGURATION OF JOINT

2.1. Test Method

The test setup is shown in Figure 2.1. The monotonic lateral force is loaded, bending moment is applied to the specimen until the joint or steel member would be failed. The symmetric graded glue-laminated lumber is used in this study. That glue-laminated-lumber is graded as E105-F345 in Japanese Agricultural Standard. The Wood species is Scots Pine, and its cross section is 100*200 mm. The steel member is graded as SS400 in Japan Industrial Standard.

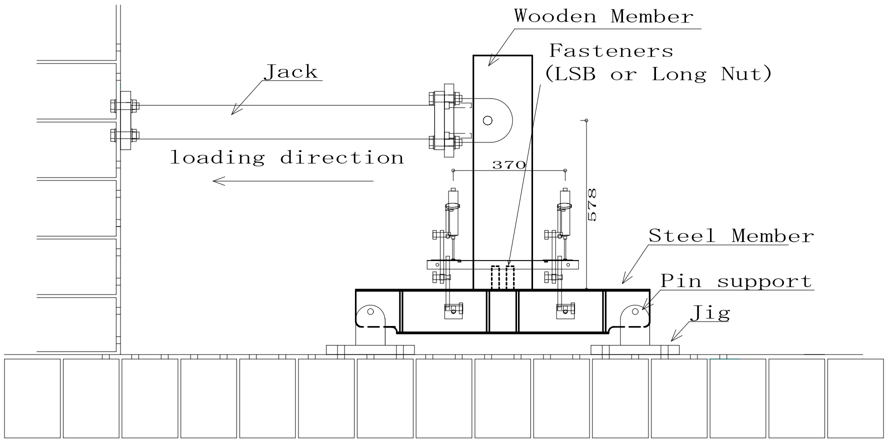

Figure 2.1. Setup of this test (Unit: mm)

2.2. Configuration of Infill Joint

The composition of infill joint is shown in Figure 2.2. A hole in wood member is fabricated, the infill material is poured and the long nut as shown Figure 2.3. is inserted in that hole. We would have the time for hardening for two weeks, at that time the specimens are left under natural condition. Before conducting the tests, the wooden member would be put on the steel member, and those members are hand-fastened with a high-tensile bolt. The test parameter for these tests is the hole-diameter processed in wooden member. They are 27, 28, 31 and 34mm. The length of long nut is 80mm, infill material is two-liquid type epoxy-glue. The cross-section in this test is channel and ranked FA in Japanese code. The other dimensions are shown in Table 2.1.

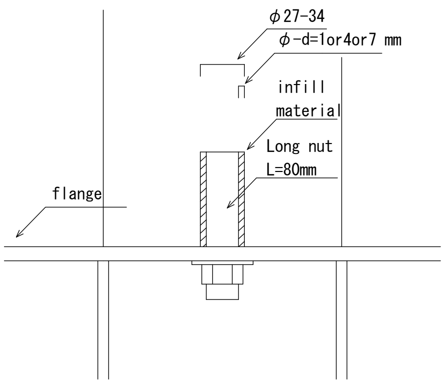

Figure 2.2. Pattern diagram of infill joint.

Figure 2.3. Long nut.

Table 2.1. test parameter and dimension of infill joint (Unit: mm)

specimen	Processing diameter	Clearance φ-d	Steel member				
			Shape of cross section	H*B	Thickness of web	Thickness of flange	Rank
φ27	27	0	Channel	150*75	9	12.5	FA
φ28	28	1					
φ31	31	4					
φ34	34	7					
* The number of specimen is 2 for each type							

2.3. Configuration of LSB Joint

The high-tensile bolt (A) and lag screw bolt (B) are shown in Figure 2.4. The composition of LSB joint is shown in Figure 2.5. The strength grade of high tensile bolt is 10.9.This length of lag screw bolt is 80mm and the length of general type is about 330mm, so it means our fastener is short type.
The H-shape members are used for the specimens with 4 lag-screw-bolts and the channel members are used for the specimens with 2 lag-screw-bolts. These steel members are ranked as FA or FB or FC or FD based on Japanese code. The combination of steel shape and arrangement of lag-screw-bolt are shown in Table 2.2 and its details are indicated in Fig.2.6.

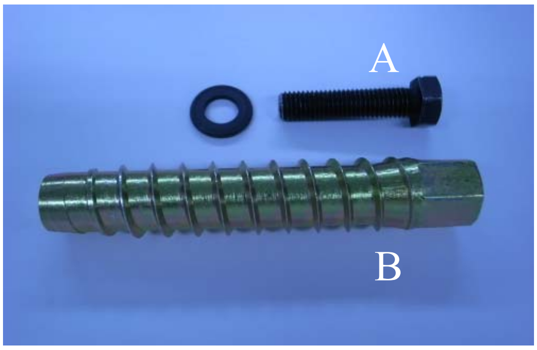

Figure 2.4. Lag screw bolt

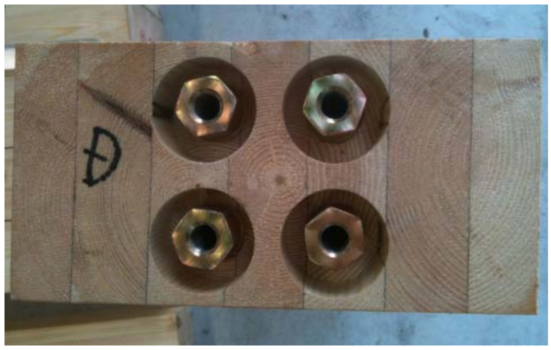

Figure 2.5. Inserted condition of lag screw bolt

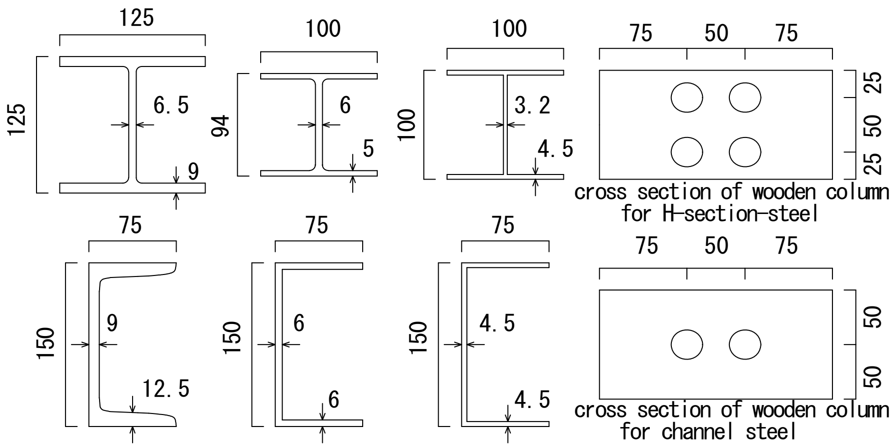

Figure 2.6. The dimension of each members and the arrangement of lag screw bolt (Unit: mm)

Table 2.2. Test Parameter and Dimension of LSB Joints (Unit: mm)

specimen	The number of lag screw bolt	Steel beam				
		Shape of cross section	H*B	Thickness of web	Thickness of flange	Rank
HA	4	H-section	125*125	6.5	9	FA
HB			100*100	6	5	FB
LHC				3.2	4.5	FC
CA	2	Channel	150*75	9	12.5	FA
LCC				6	6	FC
LCD				4.5	4.5	FD
* The number of specimen is 1 for each type						

3. TEST RESULT

3.1. Infill Joint

The moment and rotation curves are shown in Figure 3.1. Finally the fastener would be pulled out and the load would get down to almost zero. The outline of specimen and the pulling out of that fastener are shown in Figure 3.3 and 3.4. The apparent yield strength, the point when we could hear a big sound and the bending strength are shown in Table 3.1. The bending strength of wooden member is 22.8 kNm based on Japanese Agricultural Standard, the joint efficiency is about almost 20%.
The relationship between bending strength and processing diameter is indicated in Figure 3.2. We could confirm the high correlation, that means that the adhesive area would affect to that strength.

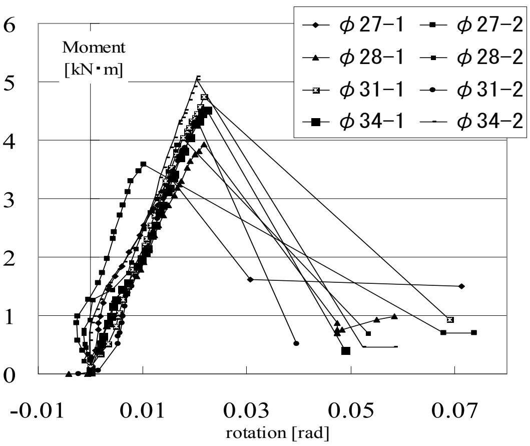

Figure 3.1.
Moment-rotation curve of infill joint

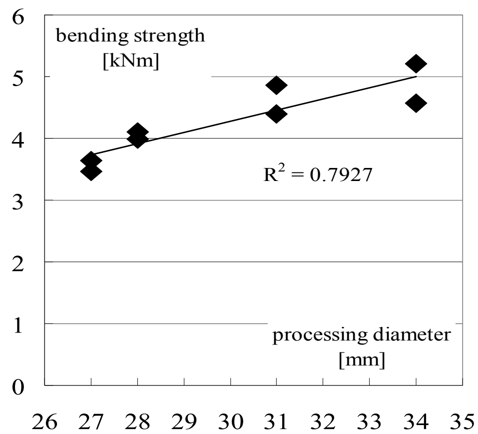

Figure 3.2.
Bending strength-processing diameter

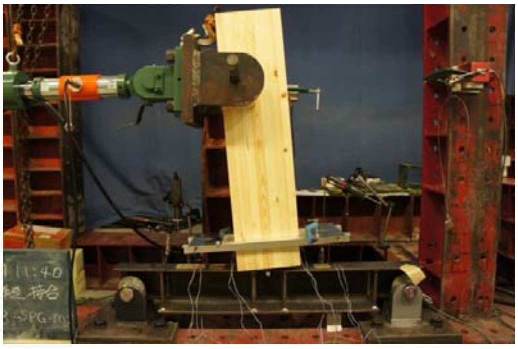

Figure 3.3. An example of final condition

Figure 3.4. Pulled out of infill joint

Table 3.1. Test Results of Infill Joints

specimen		Each strength [kN m]			Joint efficiency
		Apparent Yield strength	Sounded point	Bending strength	
φ27	-1	1.45	2.66	3.47	0.15
	-2	1.73	3.47	3.64	0.16
φ28	-1	1.85	3.53	3.99	0.18
	-2	1.91	3.24	4.10	0.18
φ31	-1	1.39	3.76	4.86	0.21
	-2	1.73	3.64	4.39	0.19
φ34	-1	1.27	3.74	4.57	0.20
	-2	1.68	3.87	5.21	0.23

3.2. LSB Joint

In these specimens, we could see four fracture patterns. The wood fracture to fiber direction (Figure 3.5., hereafter “WF”.), pulled out of lag screw bolt (Figure 3.6., hereafter “LP_O”), the plate buckling of flange in steel member (Figure 3.7., hereafter “FL_OB”) and out plane buckling of steel member (Figure 3.8., hereafter “BOD”) are shown. We could view the all fracture pattern in Table 3.2. With FA rank steel member, we couldn’t see the failure on steel members.
The moment and rotation curves are shown in Figure 3.9. and 3.10. All specimens obviously have yield point, and hold the strength after its maximum load. The bending strength with 4 lag screw bolts is higher by 1.4 times than that with 2 bolts.
The joint efficiencies are about 25% (with 4 LSB) or 19% (with 2 LSB)

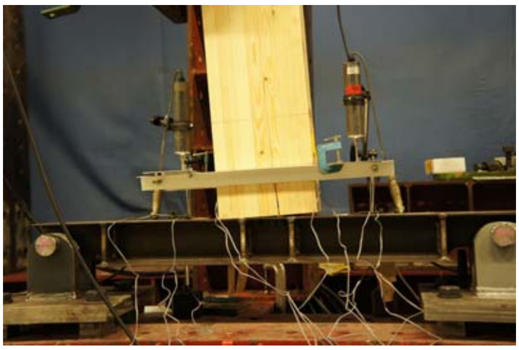

Figure 3.5. Crack directed wood fiber

Figure 3.6. Pulled out of lag screw bolt

Figure 3.7. Plate-buckling (HB)

Figure 3.8. Out-plane buckling (LHC)

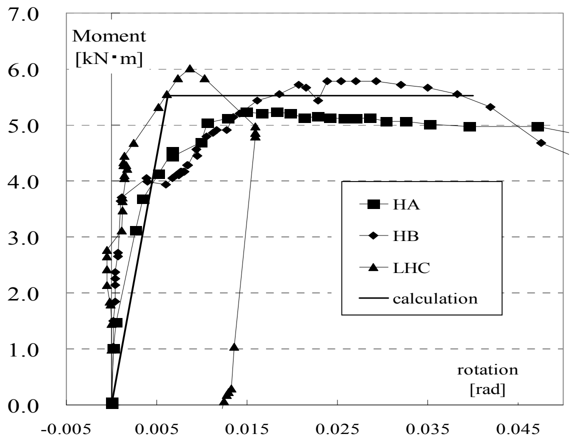

Figure 3.9. Moment-rotation curve
(with 4 lag screw bolts)

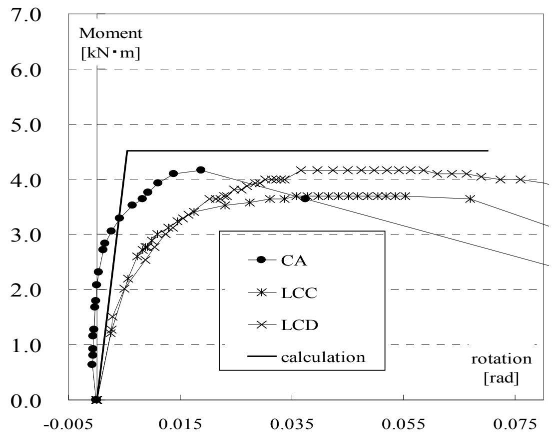

Figure 3.10. Moment-rotation curve
(with 2 lag screw bolts)

Table 3.2. Test Results of LSB Joint

Specimen	Bending strength [kN m]	Fracture mode	Joint efficiency
HA	5.34	WF	0.23
HB	5.89	LP_O, WF, FL_OB	0.26
LHC	6.01	BOD, WF	0.26
CA	4.29	LP_O	0.19
LCC	3.81	LP_O	0.17
LCD	4.22	LP_O, FL_OB	0.19

4. ANALYSIS OF STRENGTH

4.1. Infill Joint

In the previous chapter, the pulling out of a long nut would be a trigger a failure of infill joint. At that time we could confirm the shear fracture of wood around a long nut. So the distribution of shear stress along processed line and the rotation-center would be supposed as shown Figure 4.1., with that model the bending strength could be analyzed. With the Eqn. 4.1, the bending strength is calculated, compared with sounded strength and maximum load in Figure 4.2. As shown the figure, experimental results is enough lower than calculated values. In this model we supposed the effect of shear stress only, however, multiple stresses might be occurred. Then for these specimens, the experimental approximate expression indicated in Figure 3.2. is useful to calculate its strength.

$$M_{ana.} = (\tau * S) * L \tag{4.1}$$

where,

τ :shear strength (9.09N/mm^2)(Kambe et al, 2010), S :shear area [mm^2], L :(referred Figure.4.1)

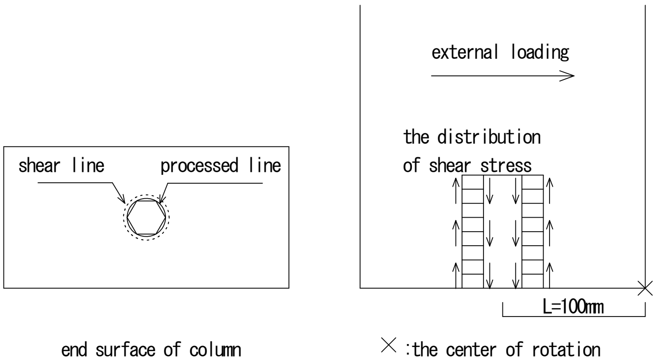

Figure 4.1. Analysis model of infill joint

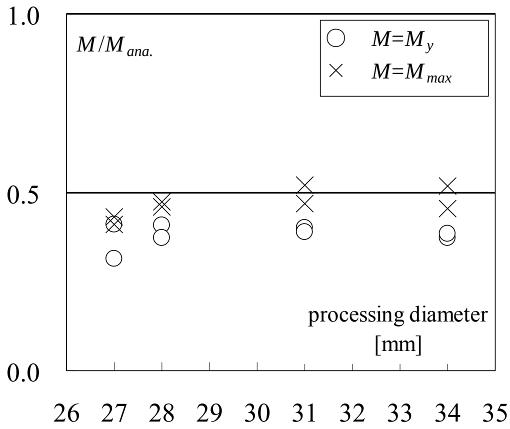

Figure 4.2. Analysis results of infill joint

Table 4.1. Analysis results

Specimen		$M/M_{ana.}$			Specimen		$M/M_{ana.}$		
		Apparent yield	Sounded strength	Maximum strength			Apparent yield	Sounded strength	Maximum strength
ϕ 27	-1	0.17	0.31	0.41	ϕ 31	-1	0.15	0.40	0.52
	-2	0.20	0.41	0.43		-2	0.18	0.39	0.47
ϕ 28	-1	0.21	0.40	0.46	ϕ 34	-1	0.13	0.38	0.46
	-2	0.22	0.37	0.47		-2	0.17	0.39	0.52

4.2. LSB Joint

In LSB joints, we could see the fracture of wood or pulling out of LSB. Then bending strength would be calculated by two methods. Nakatani (2006) have studied the estimation method of pulling out of LSB, and Nakatani et al (2008, 2008) proposed the calculation method of bending strength of joints with above theory. Its bending stiffness and bending strength could be analyzed with Eqn. 4.2. and 4.3 considering the stress distribution and deformation as shown in Figure 4.3. As the same with infill joint considering shear stress around the fastener, the shear fracture around LSB would be analyzed with the model in Figure 4.4.

The comparison with these methods and test results are shown in Figure 4.5., the calculated results considering shear stress could be about quarter-higher than the experimental results. On the other hand, the values from pulling out model could estimate the experimental results in high precision.

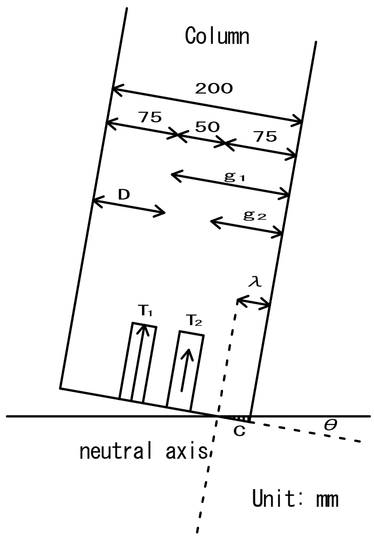

Figure 4.3. Analysis model for pulling out of lag screw bolts

$$R_{JC} = Ks(g_1 - \lambda)^2 + Ks(g_2 - \lambda)^2 + \frac{bk_{eo}\lambda^3}{3} \tag{4.2}$$

$$M_y = R_{JC} \cdot \theta_{\max} = \left\{ Ks(g_1 - \lambda)^2 + Ks(g_2 - \lambda)^2 + \frac{bk_{eo}\lambda^3}{3} \right\} \frac{P_{\max}}{Ks(g_1 - \lambda)} \tag{4.3}$$

where,
R_{JC}: rotation stiffness, M_y: bending strength. K_S: pulling stiffness, P_{max}: Pulling strength, b: width of wooden member, k_{e0}:embeddeing factor, θ: rotation.

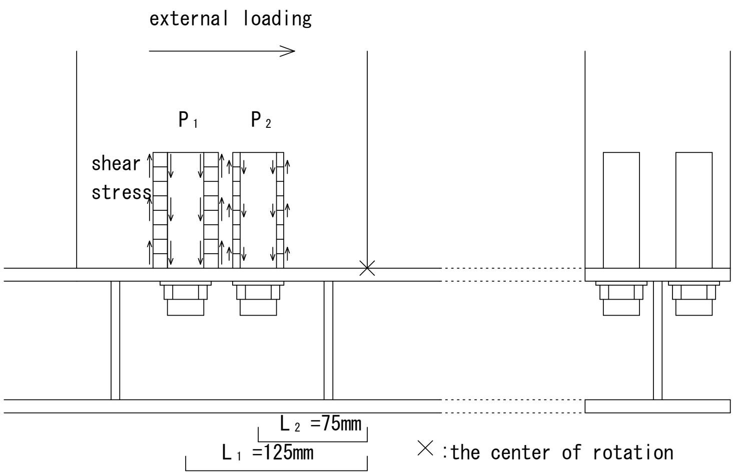

Figure 4.4. Analysis model for shear stress around lag screw bolts

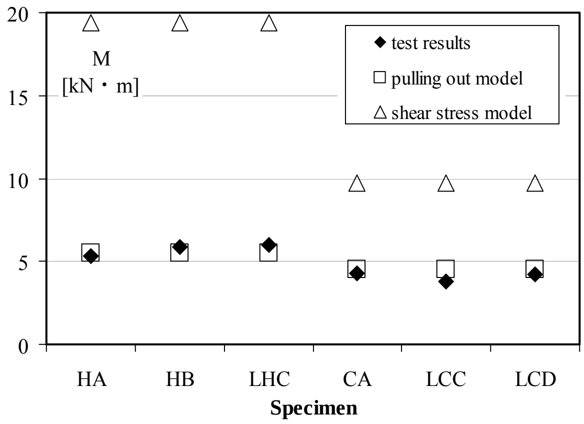

Figure 4.5. Analysis results of LSB joints

5. STRUCTURAL DESIGN OF A TEMPORARY HOUSE

In the previous sections, experimental and analytical studies of the proposed joints are presented. In the current section, it will be attempted to calculate the necessary strength of a single story temporary housing unit. Design will be based on allowable stresses for a small scale earthquake force. The dead weight of the structure is calculated per Japanese Code (2008). The presumed design conditions for earthquake-force are followings;
Z (seismic zoning factor): 1.0
R_t(vibration characteristic): 1.0
A_1(distribution factor): 1.0
Dead load: 300N/mm^2

With above conditions, the total earthquake-force is calculated in 6.48 kN. At that time, the stress distribution in columns might be shown in Figure 5.1., we could presume that the moment at a bottom joint is 4.42 kNm.
As a result, the joints with 4 lag screw bolts (HA, HB and LHC) have enough bending strength for a assumed temporary house as shown Table 3.2. However for HB and LHC, the steel members are failed. Thus, HA is the most useful method for this house. The other joints have possibility, we would have to improve the configuration of those joints.

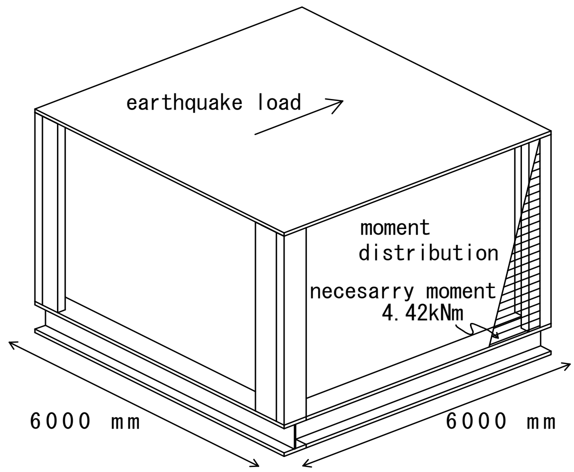

Figure 5.1. An assumed temporary houses

6. CONCLUSION

In this study, we proposed a joint to combine wooden and steel members, and analyzed the structural performance with bending tests. Additionally the theoretical models for its strength are studied. We under stood followings;

1. With the theoretical equation for lag screw bolts, we could estimate the bending strength and stiffness of LSB joints. The proposed equation is for long type lag screw bolts, we would confirm the wide applicable range for short type fasteners.
2. We would conduct bending tests with some types. The needful strength for the joint in a temporary house would be compared with those results. As a result, LSB joint with 4 lag screw bolts and FA steel foundation have enough strength for that house. The other types are short of a little strength.
3. For those specimens, we used some ranked steel member for the foundation, they are FA, FB, FC and FD. Under FB rank in H-section members and under FD rank under channel members, they might fail in buckling. So we should set the limitation for steel members.
4. For infill joint, the theoretical method based on shear stress couldn't estimate the bending strength. However the processing-diameter has a high correlation with the bending strength, the experimental approximate expression is useful to estimate the strength.

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