A STUDY ON SEISMIC PERFORMANCES OF TIMBER STRUCTURES WITH MOMENT RESISTING JOINT

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ABSTRACT :

There has recently been increasing use of moment resisting joint in timber structures. In This paper, Analytical study for timber structures with a moment resisting joint have been performed. The joint is made up of steel plates, bolts and steel cotters. The plates and the bolts are embedded with timber element of frame structure. By combining those elements with steel cotters, moment resisting joints can be constructed easily. The skeleton curve of the joint was determined by results of static loading tests using a full scale timber model. The way to make hysteresis model of timber frame with the moment resisting joints from experiment results is proposed. And analysis using the model which supposed actual residence with the moment resisting timber joints was performed. The result of the analysis clearly shows seismic response characteristics and energy absorption performances of the timber frame structure.

KEYWORDS: Timber Structure, Moment Resisting Joint, Dynamic Response Analysis

1. INTRODUCTION

Development of timber frame structure with moment resisting joint is performed actively in Japan [1-4]. Because timber frame structure can realize a large opening for architectural plan. The moment resisting joint using in this study is made up of steel plates, bolts and steel cotters [1]. Although the timber frame structure is excellent in deformation capacity, the experimental result which shows brittleness destruction was reported by past research [1]. Static analysis model of the timber joint used in this research was proposed by past research [2]. In this study, the way to make hysteresis model of the moment resisting joints from experiment results is proposed. By using the model, it becomes possible to carry out seismic response analysis. The purpose of this research is to conduct response analysis and to investigate seismic response characteristics of the timber structure with moment resisting joint. And it proposes about the way to improve energy dissipation performance of the timber structure based on the analysis results.

2. OUTLINE OF THE MOMENT RESISTING JOINT

This section describes the outline of moment resisting joint. Elements which constitutes moment resisting joint are shown in Figure 1. The conceptual figure of a timber frame joint using those elements is shown in Figure 2. The joint is made up of steel plates, steel bolts (16mm in diameter) and special steel connectors in Figure 1. Those elements are castings which can be classified by Japan Industrial Standard as S45C. The bolt is fixed with adhesives into wood member. The bolts and the plates are combined with nuts. Timber frame consists of connecting the plate attached to a beam and the plate attached to a column by use of the special steel connectors. The special connector is a wedge of steel plate. Therefore, it is possible to fix members rigidly only by driving the connector into the both members. The feature of this construction method is that the work which construct timber frame is very easy.

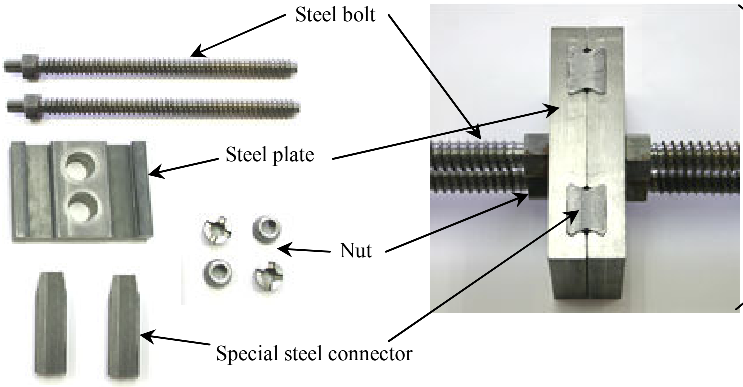


Figure 1 Elements of the moment resisting joint

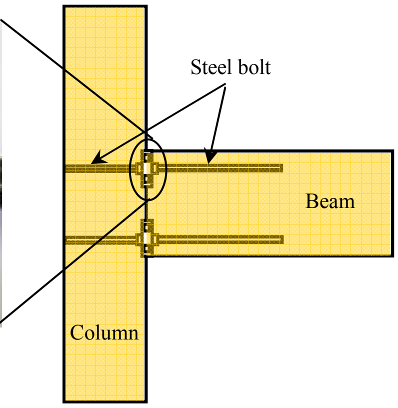


Figure 2 Concept of timber frame with moment resisting joint

3. STATIC LOADING TESTS FOR MOMENT RESISTING TIMBER JOINT

3.1. Specimen and Loading method

Experiments were carried out on two kinds of timber joints. One is beam-column joint, as is shown in figure 3. The other is column-base joint, as is shown in Figure 4. The material properties of Beam and column members are shown in Table 1. Material of those members is glued laminated wood made by European red pine, which can be classified by Japan Agricultural Standard as E120-F345. Relative rotation angle of the members used for the loading control was defined by displacement of each measure point, as shown in Figures 3 and 4.

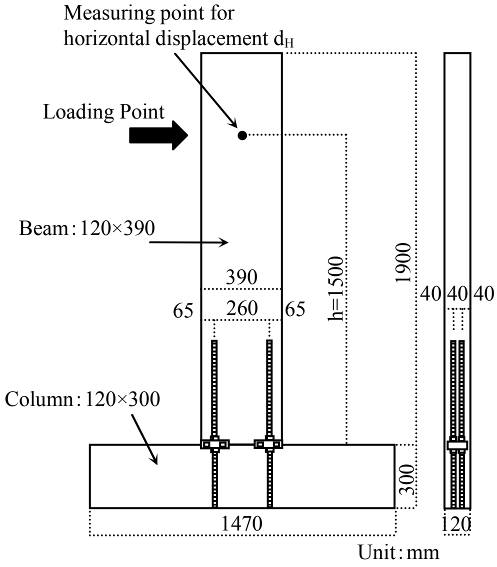


Figure 3 Specimen for Beam-Column joint

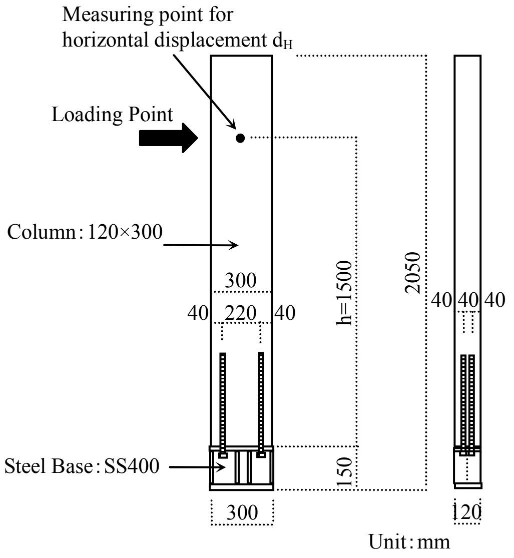


Figure 4 Specimen for Column-Base joint

Table 1 Properties of glued laminated wood

Member	Width [mm]	Height [mm]	Bending Strength [N/mm^2]	Modulus of Elasticity [N/mm^2]
Beam	120	390	34.2	12000
Column		300		

3.2. Experiment Results

The relation between Moment and drift angle for one specimen with beam-column joint is shown in Figure 5, and the relationship for one specimen with column base joint is shown in Figure 6. In both figures, the value of horizontal axis is calculated by dividing horizontal displacement d_H by height h, and the value of vertical axis is calculated by multiplying lateral load of actuator by height h. The results of other specimens show a similar tendency as a result of them. The result of beam-column joint in Figure 5 shows ductile hysteresis property after having reached maximum strength. On the other hand, hysteresis loop of column base joint after having reached maximum strength show brittle behavior because of anchor bolts of the joint having broken by tensile stress.

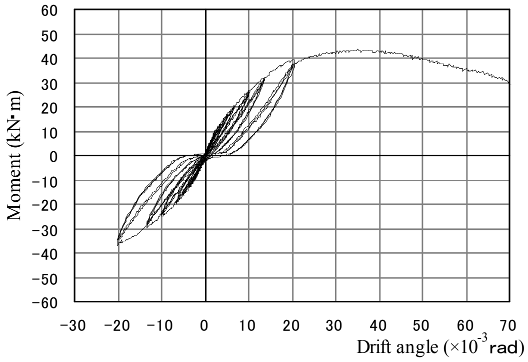


Figure 5 Hysteresis loop for beam-column joint

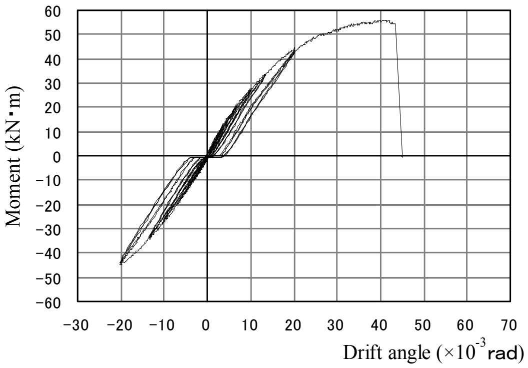


Figure 6 Hysteresis loop for column base joint

4. ANALYTICAL STUDY ON TIMBER FRAME

This section describes analytical study on timber frame model with the moment resisting joint. The analysis model was made by taking the experiment results mentioned above into account. Earthquake response simulation was performed by the analysis model.

4.1. Analysis model

Analysis model used for earthquake response analysis is shown in Figure 8, which modeled a 3 stories timber frame house, as is shown in Figure 7. The analysis model is two-dimensional frame model, which is composed of X-direction structural elements of the house shown in Figure 7.

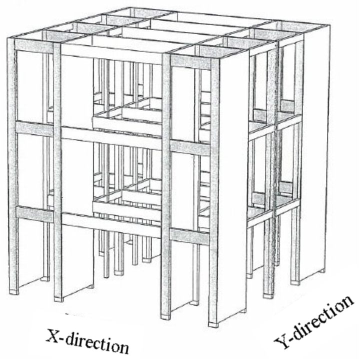


Figure 7 3-stories timber frame house

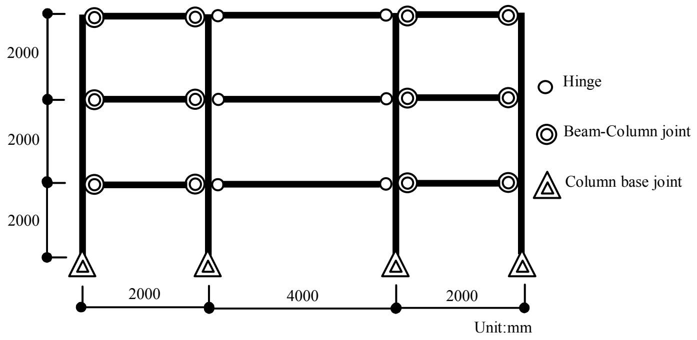


Figure 8 Analysis model

The analysis was performed only for the X-direction. In addition, analysis models of the beam-column and column-base joint are based on the experiment result mentioned above. Tri-linear model is used as skeleton curve of their models, and slip model is used as its hysteresis loop. Figures 9 and 10 show the results that compared the experiment results with the analysis models. The ground excitation used in this analysis is shown in Table 1. The maximum acceleration values of those waves are magnified so that each maximum velocity value becomes 25cm/sec and 50cm/sec. The group which magnified the maximum velocity to 25cm/sec is called as “Level-1”, and the group which magnified the value to 50cm/sec is called as “Level-2”. Integral technique is Newmark's B(B=1/4), and viscous damping ratio is 5% for the 1st mode.

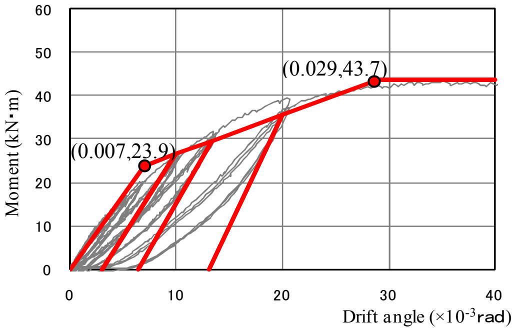


Figure 9 Analysis model for beam-column joint

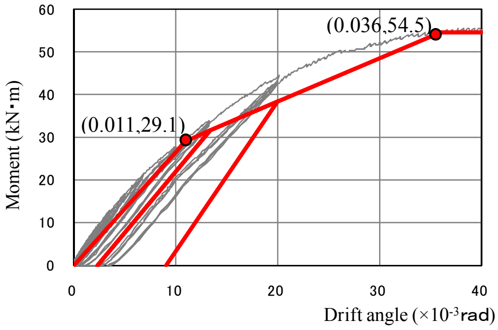


Figure 10 Analysis model for column base joint

Table 1 Input waves for earthquake response analysis

Input Earthquake	Level 1 <Max. Vel. 25cm/sec> Maximum Acceleration Value [cm/sec^2]	Level 2 <Max. Vel. 50cm/sec> Maximum Acceleration Value [cm/sec^2]
El-Centro 1940 NS	255	510
Taft 1952 EW	248	496
Hchinohe 1968 NS	165	330

4.2. *Analysis results*

The result of eigen value analysis in this model is obtained that the first natural period is 0.82 seconds, the second period is 0.24sec, and the third period is 0.12sec. And the results of step by step elasto-plastic simulations are shown in Table 2. The values of the table show the maximum response values of each story of the analysis model. The maximum response value of story drift angle of Level-2 group is 1/28 [rad] in the case of El-Centro 1940 NS. From these results, it is clearly shows that this model doesn't have enough energy absorption for earthquake excitation.

Table 2 Maximum response values

Input Earthquake	Floor	Level 1 <Max. Vel. 25cm/sec> Maximum Response Value		Level 2 <Max. Vel. 50cm/sec> Maximum Response Value	
		Acceleration [cm/sec^2]	Story drift angle [rad]	Acceleration [cm/sec^2]	Story drift angle [rad]
El-Centro 1940 NS	R	611	1/112	1045	1/51
	3	505	1/64	818	1/30
	2	286	1/60	584	1/28
Taft 1952 EW	R	653	1/118	1008	1/57
	3	487	1/69	742	1/34
	2	356	1/66	564	1/32
Hchinohe 1968 NS	R	471	1/184	784	1/92
	3	309	1/119	571	1/56
	2	284	1/110	532	1/53

4.3. *Study on the performance of timber frame in which energy dissipation device installed*

This section describes analytical study on the technique to improve energy dissipation performance of the timber frame structure. Photograph of energy dissipation equipment used for analytical study is shown in Figure 10. Friction material is inserted into hinges of this device, and energy absorption is performed using the frictional force introduced in the hinges [5]. Also since the full length of the damper is about 30cm, there is no restriction of a setting position not much. Displacement controlled dynamic loading tests to the device was performed. The results of the tests are shown in Figure 11, which are the relations between dynamic load and displacement of the device observed by cyclic loading tests for loading frequency of 1.0 Hz. The results show that the hysteresis loops are stable in spite of 20 times of cyclic loading tests.

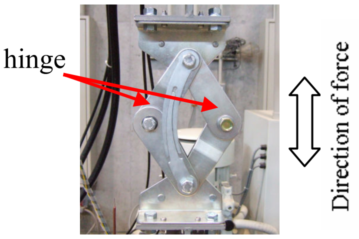
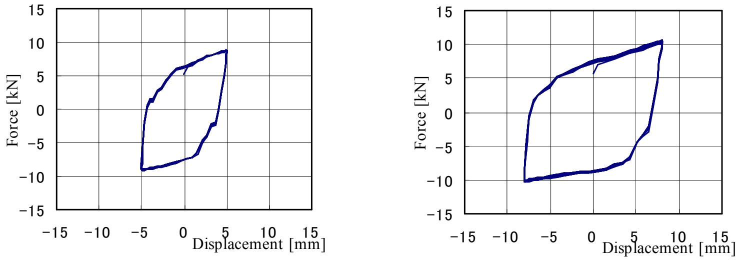


Figure 10 Friction damper



(a) Maximum amplitude of 5mm (b) Maximum amplitude of 8mm

Figure 11 Relations between force of actuator and displacement of device

Here the results of analysis in the case of installing this friction damper in the frame model shown in Figure 8 are described. The installation positions of the damper are shown in Figure 12. In addition, the damper was modeled in elasto-plastic spring, as shown in Figure 13. The result of eigen value analysis in this model is obtained that the first natural period is 0.43 seconds, the second period is 0.13sec, and the third period is 0.09sec. The results of response analysis using the earthquake mentioned above are shown in Table 3. From comparison of Table 2 and Table 3, by installing the damper shows that the response value was reduced about 30% at the maximum.

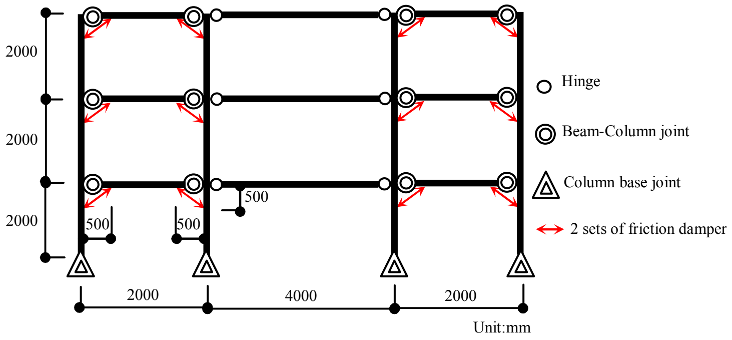


Figure 12 Analysis model with friction damper

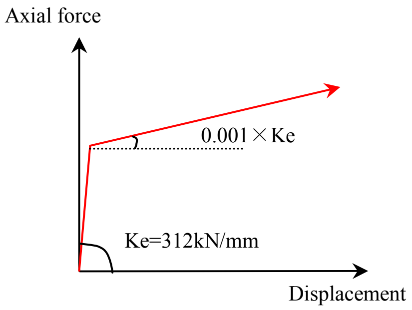


Figure 13 Elasto-plastic spring for friction damper

Table 3 Maximum response values of timber frame model with friction damper

Input Earthquake	Floor	Level 1 <Max. Vel. 25cm/sec> Maximum Response Value		Level 2 <Max. Vel. 50cm/sec> Maximum Response Value	
		Acceleration [cm/sec^2]	Story drift angle [rad]	Acceleration [cm/sec^2]	Story drift angle [rad]
El-Centro 1940 NS	R	409	1/1115	876	1/231
	3	384	1/260	748	1/93
	2	316	1/135	588	1/66
Taft 1952 EW	R	416	1/1094	682	1/345
	3	381	1/268	599	1/124
	2	344	1/144	513	1/81
Hchinohe 1968 NS	R	257	1/1409	365	1/896
	3	243	1/718	345	1/331
	2	212	1/268	339	1/165

5. CONCLUSIONS

Results obtained from this study are summarized as follows:
1) The way to make hysteresis model of timber frame with the moment resisting joints from experiment results was proposed. And results of having analyzed using the analysis model was in good agreement with the experiment result.
2) Analysis using the analysis model which supposed actual residence with the moment resisting timber joints was performed. And the results of the analysis clearly showed energy absorption characteristic of the model for earthquake excitation.
3) The technique using vibration control device as a method for improving the energy absorption performance of timber frame with the moment resisting joints was shown.

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