13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 713

STATIC COLLAPSE TEST ON TIMBER SHEAR WALL STRUCTURE WITH ECCENTRICITY

Masaki AGAWA[1] and Kenji MIYAZAWA[2]

SUMMARY

In this paper, the static collapse limit and the stress properties of each member on the two-story timber shear wall structure with eccentricity subjected to static loading were discussed. A static collapse test was carried out using specimen made from traditional timber frame construction with columns and *Shin-kabé* walls. The *Shin-kabé* walls are sheathed with structural plywood, which are installed into a frame consisting of columns, a beam and a sill. The dimension of the specimen was 3.64m x 5.46m in plan and two-story in height. Through this experimental testing, the following results were obtained. 1) The static collapse limit unconsidering *P-delta* effect was about story drift angle 1/3rad. 2) The static collapse process of two-story specimen was clarified. 3) The stress properties of each member were obtained.

INTRODUCTION

About nine years passed since Hyogo-Ken Nanbu earthquake disaster in 1995. In Japan, the seismic performances of wooden house are reviewed again by experimentally and analytically. Thereby, Japanese Building Standard Law (*JBSL*) and Various Evaluation Signposts (*VES*) have been revised and improved in 2000. Therefore it is seemed that a wooden house built by *JBSL* has enough seismic performance. However, *JBSL* and *VES* cannot evaluate the response behavior and the stress properties at each part of wooden house under strong ground motion adequately. As a one of reasons, it is thought that collapse limit and processes of wooden houses have been clarified yet. For creating a more adequate evaluation signpost, it is necessary to determine the structural ability of collapse limit state quantitatively.

Since 2001, a research project on static collapse limit of timber shear wall structure has been promoted by our laboratory. The objectives of the project are to clarify the torsional behavior and stress properties of the timber shear wall structures with eccentricity and difference floor stiffness [1], the static collapse limit of two-story timber shear wall structures, which is consisted of the framing and *Oh-kabé* walls are sheathed with structural plywoods directly on the columns or on the furrings applied on the columns [2], the hysteresis characteristics of timber structure in collapse limit state. This paper presents the results of static collapse test on two-story timber shear wall structure with eccentricity, and clarifies the static collapse limit and processes, response behavior, stress properties and so on.

---

[1] Graduate. Student, Mr.Eng., Kogauin University, Japan, E-mail; dd02001@ccs.kogakuin.ac.jp
[2] Professor, Dr.Eng., Kogakuin University, Japan, E-mail; miyazawa@cc.kogakuin.ac.jp.

STATIC COLLAPSE TEST

Specimen

The Details of a specimen, plan of 1st floor and 2nd floor and detail of floor and roof, are shown in Figure 1. The specimen is 3640mm length in X-direction, 5460mm length in Y-direction and 2860mm and 2960 at each story height. The framing consisted of three, 120mm by 120mm columns and sill (*Cypress*, of which the average water content was 15.02%) spaced at 910mm, and two beams (*Douglas-fir*, of which the average water content was 8.6%), a 120mm by 180mm or 240mm. The columns are fastened to a girder (and a ground-sill with strap bolts instead of strap plates for pulling out force (but this detail is not real). The hold-down fastener is attached to 4 corner columns, and the octagonal plate fastener is attached to the other columns by eight screws.

The main resistance elements are *Shin-kabé* walls, which are sheathed with structural plywood (*Conifer*, 910mm by 1820mm with thickness 9mm, CN50 nail), which are installed into a frame consisting of columns, a beam and a sill. Moreover they are allocated to be eccentricity on each story (see plane of 1st and 2nd floor of figure 1). The roof is constructed by structural plywoods (*Conifer*, 910mm by 1820mm with thickness 12mm), which are nailed by nails of N75 and N90 with spacing 150mm or 300mm each part. The additional weights of 19.6kN were attached to the each floor. Thereby the calculation of total weight was 58.22kN.

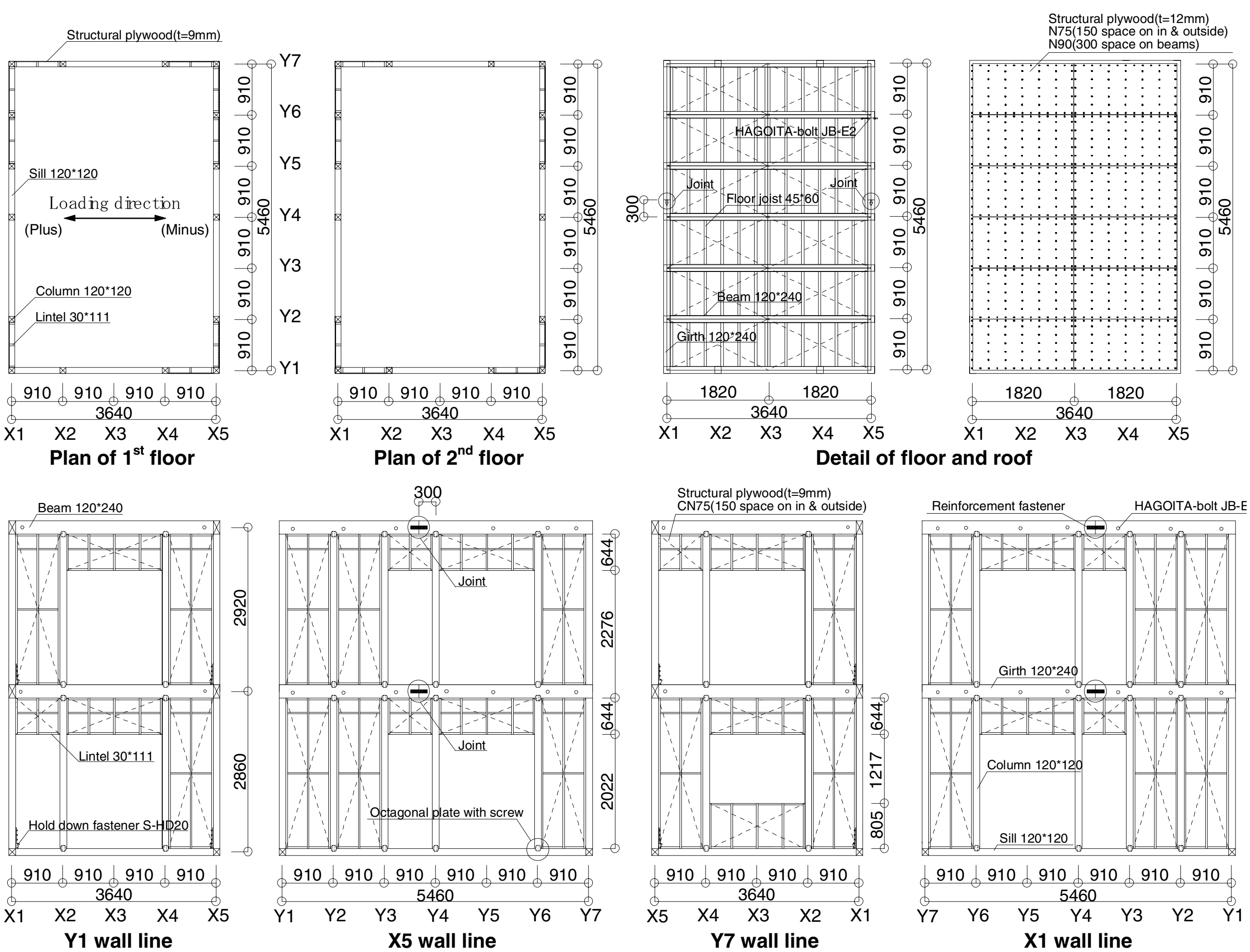


Figure 1 Details of specimen

Static loading and measurement method

The specimen was loaded by the wire and pulley to give the distributed load, which is equal to the floor area ratio for seismic force, without confining the deformation of the each floor (see Figure 2 and Picture 1). The load was controlled by the displacement of the center of gravity (on Y4 in X1 and X5). Figure 3 shows the displacement protocol.

The deformation of floor were measured, shear strain of the wall and floor and axial force of the hold-down fasteners. The deformation of floor was measured by displacement transducers. In X-direction , the displacements at each wall line and the center of gravity were measured and in Y-direction the displacement at two points (X1 and X5) was measured.

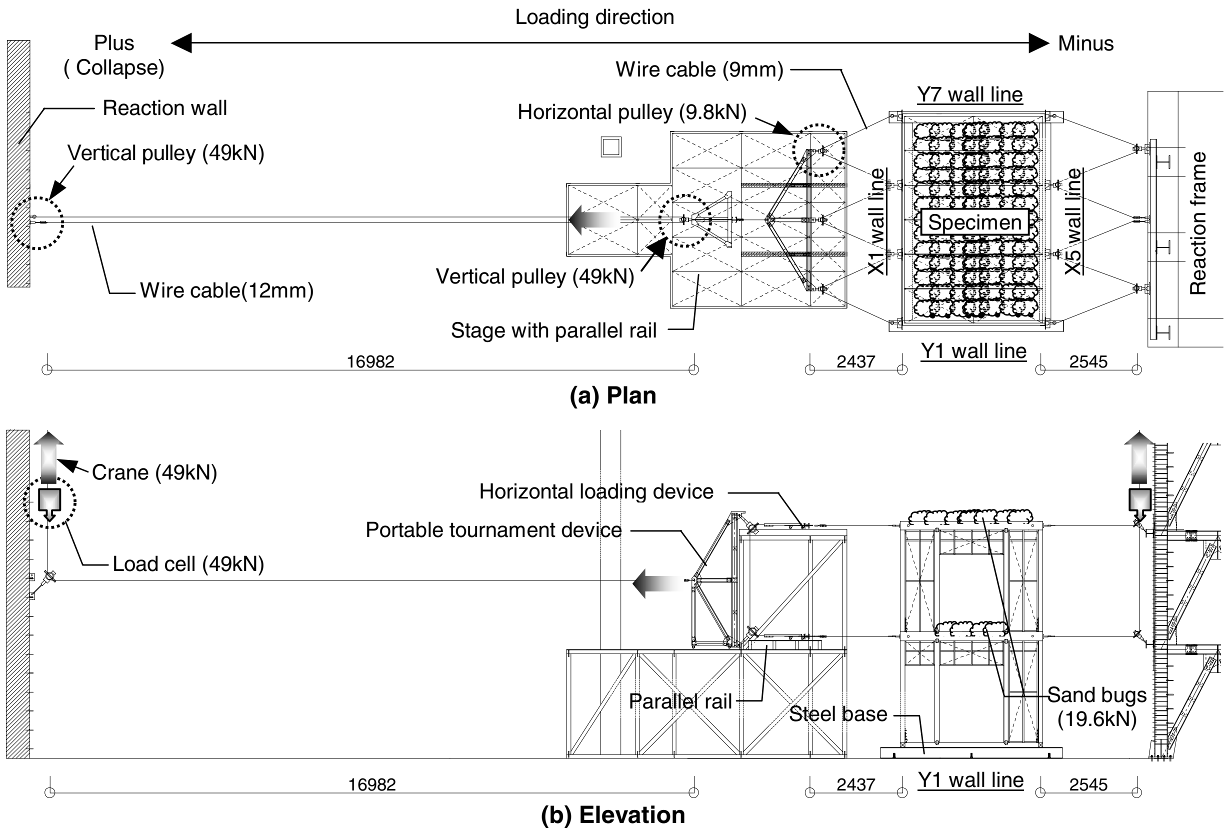


Figure 2 Loading method

(a) Specimen **(b) Additional weights**

Picture 1 Review of test

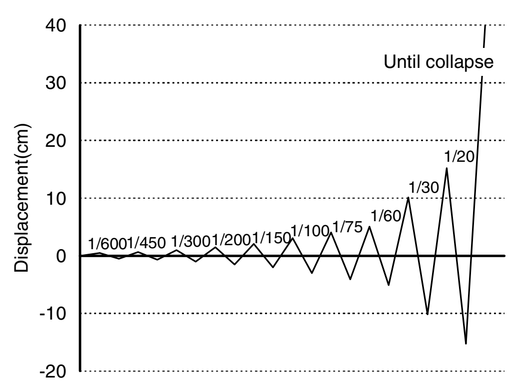


Figure 3 Loading protocol

RESULTS AND DISCUSSIONS

Variations of natural frequency for conditions of specimen

Figure4 shows the variations of the natural frequency and the each mode shape for the conditions of specimen. Where 1st mode shape is the translational motion including torsion in X-direction, 2nd mode shape is the translational motion Y-direction and 3rd mode shape is the torsional motion, and the each natural frequency is measured by the microtremer. Table 1 shows the conditions of specimen, which mean that the additional weights attached or not on the each floor, the hold-down fasteners fastened or not on the columns of the corners and the specimen destroyed or not by static loading.

In the case of the stage-1, the natural frequency is 4.83Hz of 1st mode shape, 6.60Hz of 2nd mode shape and 7.90Hz of 3rd mode. The each natural frequency of stage-2, -3 is smaller than one of stage-1, because of the additional weights were attached to the each floor. In the case of the stage-4, the natural frequency of 1st mode shape is 3.91Hz and is 20% larger than one of stage-3. This tendency means that the torsional stiffness on the legs of the columns becomes larger. Moreover, in the case of the stage-6, the each natural frequency is 2.64Hz of 1st mode shape, 4.04Hz of 2nd mode shape and 5.55Hz of 3rd mode. When this result is changed to the ratio of stage-6 to stage-4 for the each natural frequency, they are 33% of 1st mode shape, 6% of 2nd mode shape and 18% of 3rd mode shape. Therefore, the damage of X (loading)-direction was remarkable and of Y-direction by the torsion was small.

Table 1 Conditions of specimen

Condition of specimen	Before test				After test	
	Stage-1	Stage-2	Stage-3	Stage-4	Stage-5	Stage-6
Load of additional weights	No	Only 1F	1F and 2F	1F and 2F	1F and 2F	1F and 2F
Fasten of Hold-down fastener	No	No	No	Yes	Yes	Yes
Maximum story drift angle of 1F	-----	-----	-----	-----	1/650rad.	1/60rad.

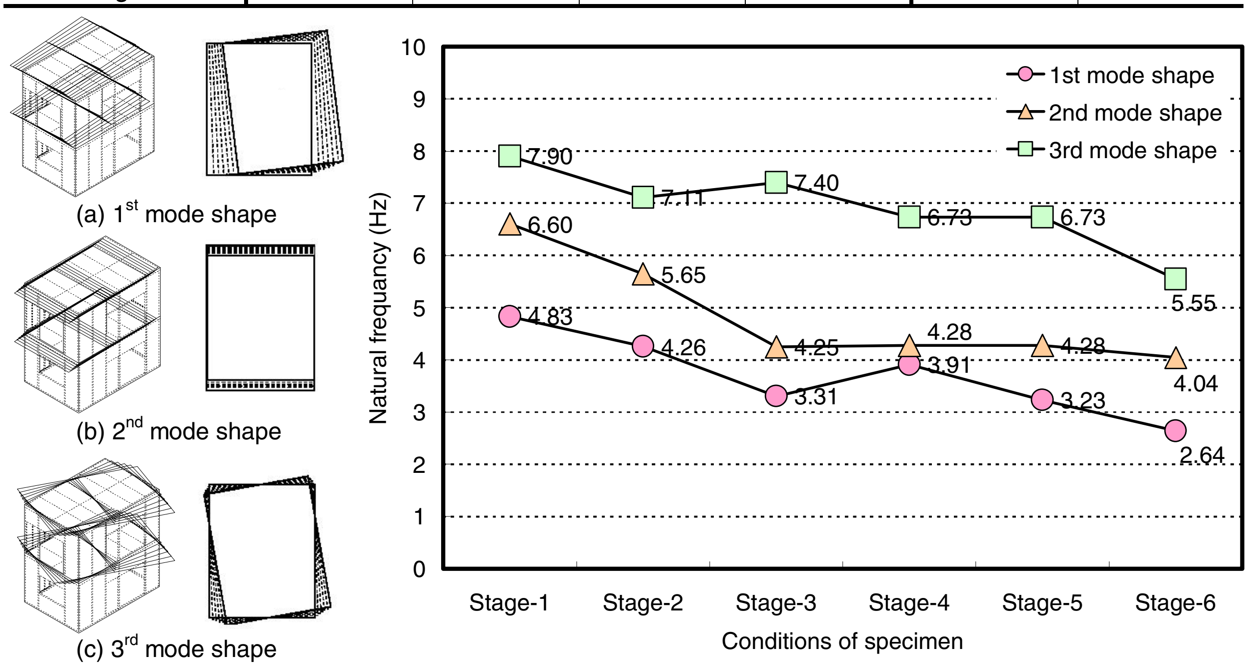


Figure 5 Variations of natural frequency and each mode shape

Relation between story shear force and relative story displacement of each story

Figure 6 shows the relation between the story shear force and the relative story displacement of the each story. The story shear force of the each story is included the additional shear force Q_Δ by *P-delta* effect, and the skelton curve shown in figure 6 is not included the Q_Δ. The additional shear force Q_Δ by *P-delta* effect on 1st story is calculated following equation;

$$Q_\Delta = \frac{W_2(x_1 + x_2) + W_1 x_1}{h_1} \tag{1}$$

where, W_1, W_2 is the mass of the each story, x_1, x_2 is the relative story displacement of the each story and h_1 is the height of 1st story.

As for the 1st story, the story displacement is 13.8mm(1/207rad.) when *Co* (which is the value divided the story shear force of the 1st story by total weight) is 0.2. In this region, the relation between the story shear force and the story displacement shows elasticity. The story displacement is 114.5mm(1/25rad.) when *Co* is 1.0. But the story shear force is not reached the maximum value then. The story shear force is reached to the maximum value 65.24kN when the story displacement is 138.3mm(1/20rad.). Afterward the story shear force decreases gently, the specimen collapsed when the story displacement is reached to 840mm (1/3.4rad.). Other, the story displacement of 2nd story is smaller than 1/60rad.. And the additional shear force Q_Δ is larger when the story drift angle is larger than 1/10rad.(see table 2). Therefore the static collapse limit unconsidering *P-delta* effect was about story drift angle 1/3rad, and it was confirmed that *P-delta* effect is larger in region of over 1/10rad..

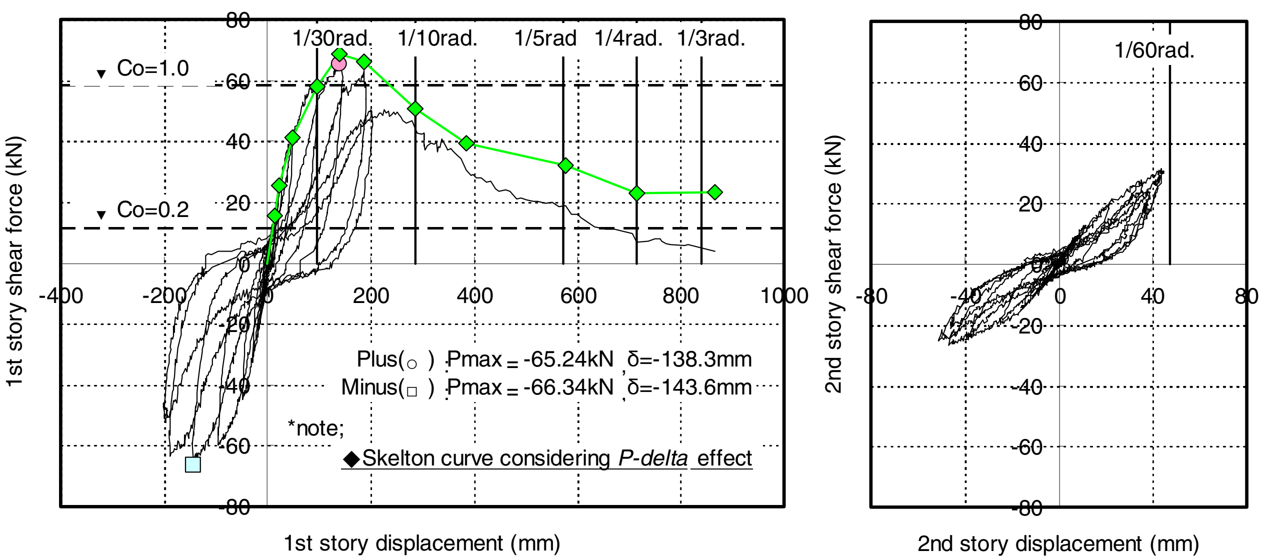


Figure 6 Relation between story shear force and relative story displacement

Table 2 Influence of P-delta effect

1st Story shear force (kN)	1/200rad.	1/120rad.	1/60rad.	1/30rad.	1/20rad.	1/10rad.	1/3.4rad.
Considering P-delta effect	14.64	25.50	41.09	57.88	68.76	50.73	23.13
Unconsidering P-delta effect	14.26	24.88	39.81	55.40	65.24	44.01	3.76
Additional shear force Q_Δ (kN)	0.37 (0.006)	0.62 (0.011)	1.28 (0.022)	2.48 (0.043)	3.52 (0.060)	6.72 (0.115)	19.37 (0.333)

Note: The values of between parentheses in table 2 mean the base shear coefficient (= $Q_{⊿}$/Total weights).

Static collapse process and damage on part of specimen

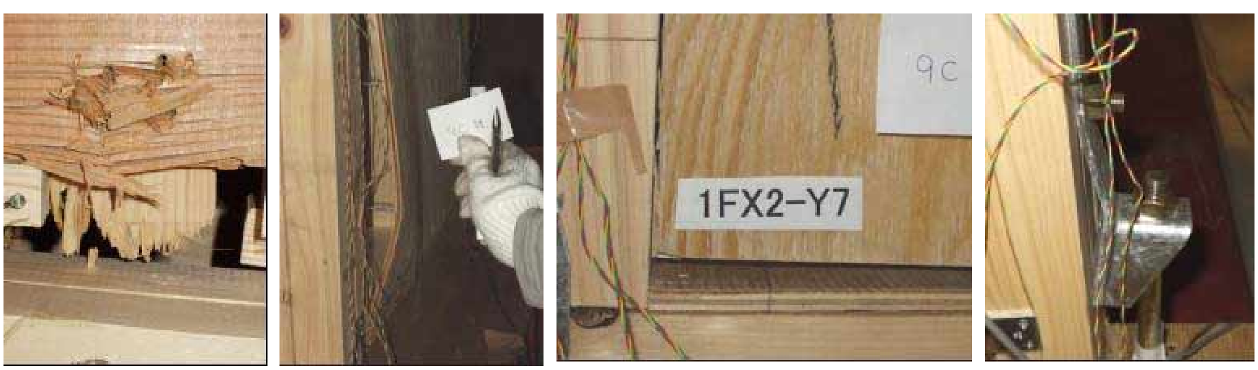
Picture 2 and 3 show the static collapse process and the damage on part of specimen.

The damages on part of specimen were not found at from the initial deformation to story drift angle 1/120rad.. The deformation of 1st story becomes larger at from 1/120rad. to 1/60rad., and the failure of *Shin-kabé* walls, the bend of Hold-down fastener, the gap and the compressive strain of the lintel and the column and the rise on the leg of the column were founded. At the over 1/30rad., the structural plywood of *Shin-kabé* walls in Y1 wall line were buckled to transverse location on walls. And at from 1/20rad. to 1/10rad., the structural plywood of *Shin-kabé* walls in Y7 wall line were buckled to transverse location on walls, and the damage and the deformation were concentrated to 1st story suddenly In this time the damage by torsion was not found on the orthogonal wall line for the loading direction. Afterwards at over 1/4rad. (700mm), the failure of Hold-down fastener in Y1 wall line and the crack failure of the mortise on the legs of the columns were founded. However, the specimen did not collapse when the static loading was stopped at 1/3.8rad. (750mm) to observe the damage of specimen. Finally, the columns of 1st story were broken at over 1/3.6rad. (840mm), and the only 1st story of specimen collapsed.

(a) 1/200rad. (14mm) **(b) 1/60rad. (48mm)** **(c) 1/30rad. (95mm)**

(d) 1/20rad. (143mm) **(e) 1/4rad. (700mm)** **(h) 1/3.4rad. (840mm)**

Picture 2 Static collapse process of specimen



(a) Broken column **(b) Buckled plywood** **(c) Gap of plywood and sill** **(d) bend of Hold-down**

Picture 3 Damage on part of specimen

Torsional deformation of specimen

Figure 7 shows the torsional deformation of the 1st story for from Co=0.1 to 1.14 and until collapse. Where a θ_g and a θ_t shown in figure 7 mean the story drift angle on the center of gravity and torsional angle in plane.

As for the initial deformation region, which is from θ_g =1/650rad. to 1/450rad., the torsional deformation is not found because the applied load is too small. However, the torsional deformation becomes larger when the applied load and the story drift angle become larger(at from θ_g =1/300rad. to 1/30rad.). And the maximum value of θ_t is 9.3E-3rad. at θ_g =1/20rad.. Afterwards the torsional deformation becomes smaller, the value of θ_t is 5.3E-3rad. at θ_g =1/10rad., the value of θ_t is 1.0E-3rad. at θ_g =1/4rad., a tendency of an almost linear decrease is shown in figure 7. This means that the orthogonal wall line for loading direction inhibited the torsional deformation, and is discussed in reference 3 too. Therefore it is confirmed that the the orthogonal wall line inhibit the large torsional deformation in the ultimate region.

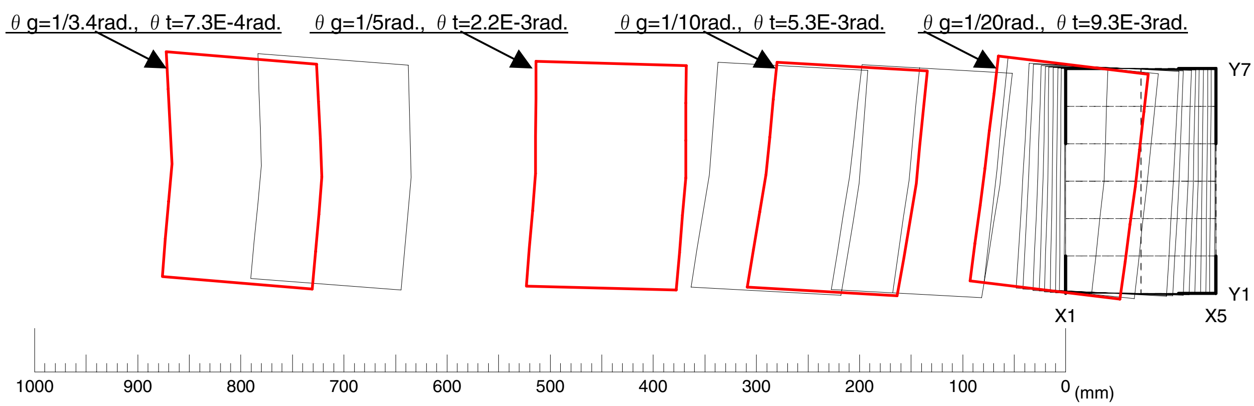


Figure 7 Torsional deformation of specimen in 1st story

Elasto-plastic properties of each wall line

Fig.8 shows the relation between the shear force and the story drift angle for each wall line. Where, the each shear force was calculated from the shear stress of the structural plywood and columns measured by strain gauges.

The elasto-plastic properties of Y1 and Y7 wall line in the loading direction have reached to ultimate region. Howerver the elasto-plastic properties of X1 and X5 wall line in the orthogonal direction for them have stopped at the elastic region mostly. Therefore the decrease of the shear stiffness in the orthogonal wall lines is smaller than the one in the wall lines of loading direction, and the torsional stiffness is kept. Herefrom it is clarified that the torsional deformation is inhibit by the orthogonal walls.

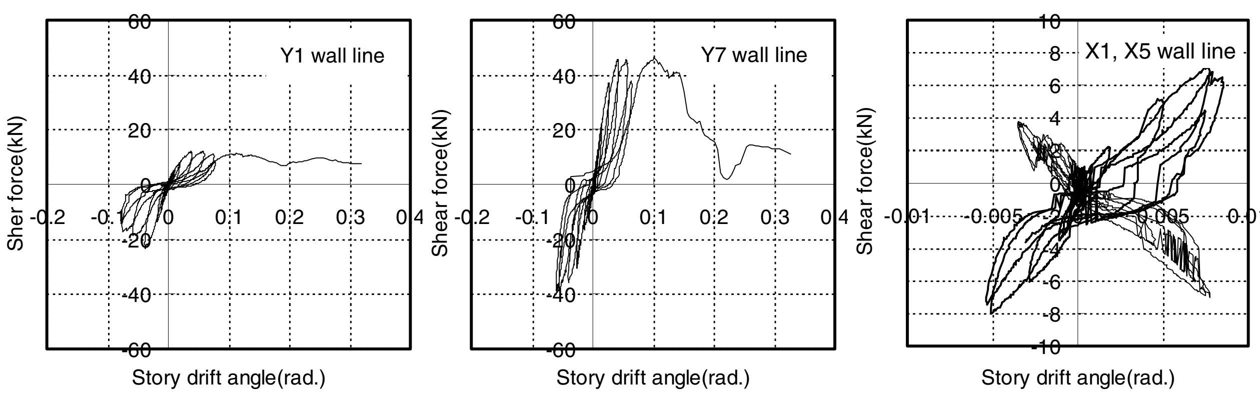


Figure 8 Relation between shear force and story drift angle for each wall line in 1st story

Share ratio of shear force for each wall line in loading direction

Fig. 9 shows the share ratio of shear force for each wall line in loading direction. Where, the values of the number ratio of walls in loading direction were written in figure 9.

In the initial deformation region, the values of Y1 and Y7 are 0.31 and 0.69, these values are nearly equal to the each number ratio of walls. However in the over story drift angle of 1st story 120rad., the values of Y1 and Y7 are 0.21 and 0.79. Afterwards the each value are constant until 1/15rad., the values of Y1 and Y7 are 0.4 and 0.6 in 1/3.4rad.. In this time, the share ratio of the shear force of the columns in 1st story is 0.21, and showed the comparatively large value.

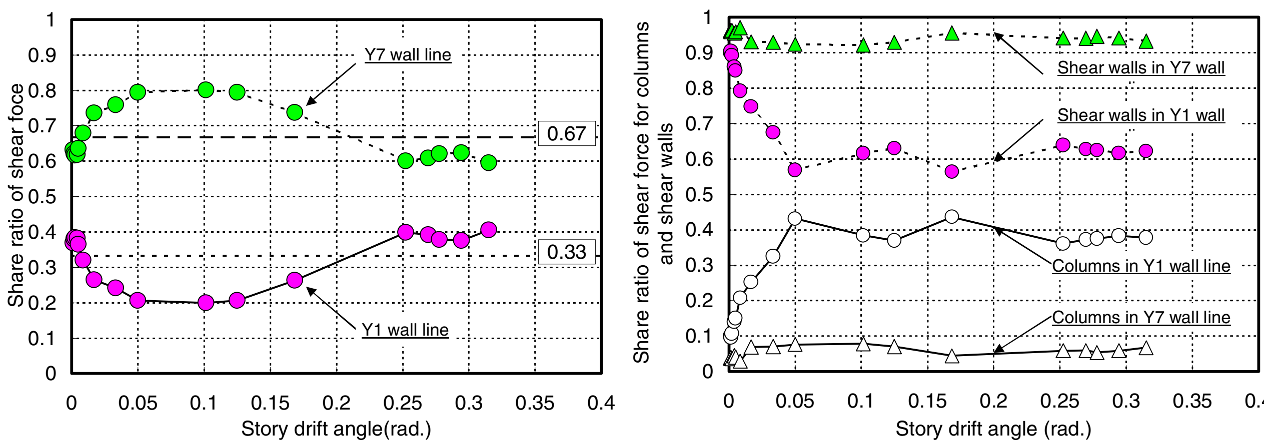


Figure 9 Relation between of share ratio of shear force and story drift angle for each wall line

CONCLUSIONS

We executed the static collapse test to examine the structural ability and the stress properties in collapse limit state of the timber structure. Through this experiment the following were found. 1) The static collapse limit unconsidering *P-delta* effect was about story drift angle 1/3rad. 2) The static collapse process of two-story specimen was clarified. 4) The deterioration of the stiffness on the frame with large opening is remarkable, and the effect of eccentricity on rotational deformation is large. 3) The stress properties of each member were obtained.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Katsuya HANANO, Doppo MATSUBARA, Hiroshi NISHIOKA and member of our laboratory for help with this experiment. They also wish to express their thanks to Kogakuin University as a special research found, Higashi Nihon House Co., Ltd. for financial support.

REFERENCES

1. M.AGAWA, K.MIYAZAWA et al., “Experimental study on seimic performance of wooden houses in consideration of floor stiffness and wall layout”, Journal of structural engineering, Vol. 49B, 2003, Japan
2. M.AGAWA, K.MIYAZAWA et al., “Experiment study on static collapse limit of two-story timber shear wall structure subjected to static loading”, Journal of structural engineering, Vol. 50B, 2004, Japan

3. M.AGAWA and K.MIYAZAWA, "Study on dynamic torsional properties and seismic design methods of wooden houses with eccentricity in wall layout for elastic and ultimate limit states", 7th World Conference of Timber Engineering, 2002.