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EXPERIMENTAL STUDY ON BEHAVIOR OF WOODEN DWELLINGS CONSIDERING HORIZONTAL DIAPHRAGM ACTION

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SUMMARY

This paper describes an experiment and its results using a full-size authentic model of 2 story wooden dwelling house, and examines a proposed theoretical model to simulate the behavior of wooden dwellings subjected to horizontal load from the viewpoint of effect of horizontal diaphragm action.

INTRODUCTION

The conventional type wooden dwellings in Japan are not fully engineered, because they derive from traditional wooden buildings. Some structural elements such as braced bearing walls have been studied and employed in the structural system of dwellings, but the behavior of a whole structure consisting of horizontal diaphragms and vertical frames with bearing walls subjected to horizontal load such as seismic force and wind pressure have been scarcely investigated.

This paper describes an experiment and its results using a full-size authentic model of 2 story wooden dwelling house, and present a comparison of experimental behavior and theoretically simulated one, especially from the view point of effect of horizontal diaphragm action.

EXPERIMENT

A full-size authentic two story model of wooden dwelling house was constructed just for the experiment. The elevation and the plans of the first and the second floor are shown in Fig. 1 and Fig.2, respectively, in which openings in the second floor are also indicated. The elevation of each frame is shown in Fig. 3, in which the arrangement of bracings are also indicated.

The area of the first floor is 72.87m^2 (7.28m x 10.01m). The height of the first story and the second one are 299cm and 292cm, respectively. The dimension of columns is 12cm x 12cm in cross section. That of bracings is 5.3cm x 10.5cm in cross section in the first story and is 3.5cm x 10.5cm in the second story. The second floor diaphragm is composed of floor beams, sub-beams and joists, as shown in Fig.4, sheathed with 3 feet by 6 feet lauan plywood boards, 12mm thick, which are nailed with spacing of 15cm on center.

The experiments were carried out according to several construction stages and loading patterns. The whole schedule is omitted because it is explained in another paper (Ref. 1) and this paper deals with limited experimental data. Among the all stages of experiment, the following two stages are considered in this paper.

CASE 1 : TEST NO.WY-2: There is no opening in the second floor diaphragm except for the opening for a staircase.

CASE 2 : TEST NO.WY-1: There is an opening in the second floor diaphragm as shown in Fig.2.

The "local loading ", in which a concentrated horizontal load was applied to each frame line one by one, was employed to study the effect of horizontal diaphragm action. The reversible horizontal load was applied by means of hydraulic jack actuator through an electronic load cell on a frame line at the second floor level. The points of the loading are indicated in the elevation (Fig.1). The magnitude of load was limited to such a level as the structural elements (frame members and joints) suffers little structural damage to keep the structure in good condition for further tests. Therefore The maximum interstory drift of the first story of the frame under loading was kept less than about 1/300 radian, that is, 1.0cm.

The behavior of the model were measured by 59 electronic transducers, most of them were installed on the second floor level and the first floor level to measure the horizontal behavior, and the others were installed at the base to measure uplift and sinking of columns. The results of the experiment are introduced later, when the comparison between the experimental results and the theoretical simulation is explained.

THEORETICAL ANALYSIS AND SIMULATION

A theoretical model is introduced to simulate the behavior of the actual model subjected to horizontal load. The model , as illustrated in Fig.5, is composed of columns, beams and of springs (or shear panels) which represent shear stiffness of walls of vertical frame as well as of diaphragms of the second floor and the roof.

The following assumptions are made.

1) Columns and beams are rigid, that is , they do neither yield axial elongation and shrinkage nor flexial deformation.
2) All crossings, column-column, column-beam and beam-beam, are hinged.
3) The diaphragm of the first floor is infinitely rigid.
4) The force-displacement relationship of all springs are elastic and linear.
5) The frame line Y5 is ignored because of simplicity. A bearing wall (bracing) in this line is located close to the center of the model and resists the load of X-direction. Therefore The effect of the existence of the wall is supposed to be very small when the model is loaded in Y direction.

According to the assumptions 1) and 2), each bay of the vertical frame as well as the horizontal diaphragm deforms parallelogramatically. The displacement of the model subjected to horizontal load is represented by the equations based on the equilibrium with reference to each frame. The schematic diagram of displacement of the floors and notations are shown in Fig. 6 . The unknown quantities are horizontal displacements of frame 1, 2, 3 and 4 in Y-direction and of frame 5, 6 in X-direction, in the first story and in the second story.

The stiffness of the vertical frames is estimated based on the following formula (Ref.2).

$$k=(Pr \times SR \times M \times n)/(H \times R) \qquad (1)$$

where Pr:Specific Load to determine SR (130kg/m)
SR:Strength Ratio of Braced Wall (2.0 for 1st Story, 1.5 for 2nd Story)
M :Module (0.91m)
n :Number of Module of Braced Wall (Table 1)
H :Height of Story (299cm for 1st Story, 292cm for 2nd Story)
R :Specific Deformation in Radian to determine SR (1/120)

The shear stiffness of the diaphragm is expressed as the resistance to give unit relative displacement between adjacent vertical frames in Y-direction. The stiffness of the floor diaphragms is estimated based on the following formula.

$$k=Kd \times (W/Wo) / (D/Do) \qquad (2)$$

where Kd:Stiffness of Diaphragm of Wo x Do (750kg/cm for 3.64m x 3.64m)
W,D :Width and Depth of Diaphragm (Table 2)

The value of Kd, 750kg/cm, is roughly estimated one based on the data from an experiment carried out by the authors on the diaphragm of 3.64m x 7.28m and of approximately similar specifications. There is no reliable data for the roof, then the half value of the second floor was assumed. The values used for the computation are listed in Table 1 and 2.

COMPARISON OF EXPERIMENT AND SIMULATION

Based on the above mentioned theoretical model associated with these data, the behavior of the model was simulated by giving a force on each frame line one by one as in the experiment. Then the displacements of the second floor in the experiment and those of the theoretical simulation are shown in Fig.7, in which the solid line denotes the experimental results and the broken line denotes the simulated results. The maximum displacement in the experiment and that in the simulation are modified to be equal in the figures because the relative deformation of the vertical frames and that of the horizontal diaphragms are of interest to discuss the diaphragm action.

The following facts are observed in the experimental results.
1) The torsional behavior is produced in the same time with the deformation of the horizontal diaphragms, when an end frame line is loaded.
2) The horizontal diaphragms carry a great deal of shear force when an middle frame line is loaded, if there is no opening in it.

The results of the theoretical simulation coincide with those of the experiment pretty well in connection with the above mentioned behavior. However, the deformation of the diaphragm between the frame X7 and the frame X11 in CASE 2, in which there is an opening as shown in Fig.2, is relatively larger in the experiment than in the simulation. This fact suggests that the stiffness of the diaphragm with opening might be overestimated in the simulation. The overestimation is supposed to be mainly due to the assumption 1) in the previous chapter. Therefore some modification should be made in estimating the stiffness of a diaphragm with opening, if the model itself is not changed. Through the modification it is expected to be possible to simulate the behavior of a wooden dwelling house under horizontal load by making use of the theoretical model introduced in this paper.

CONCLUSIONS

The theoretical simulation gives good agreement with experimental results. Using the theoretical model presented in this paper, static and dynamic behavior of a dwelling house considering horizontal diaphragm action subjected to horizontal load such as wind pressure and seismic action could be simulated.

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Table 1 STIFFNESS OF VERTICAL FRAME (CASE 1 AND 2)

	SR	n	k(kg/cm)		SR	n	k(kg/cm)
k_1	2.0	4.0	379	k_1'	1.5	2.0	142
k_2		4.0	379	k_2'		4.0	284
k_3		5.5	521	k_3'		4.0	284
k_4		6.0	569	k_4'		2.0	142
k_5		6.0	569	k_5'		4.0	284
k_6		4.0	379	k_6'		4.0	284

Table 2 STIFFNESS OF HORIZONTAL DIAPHRAGM

		CASE 1			CASE 2		
	kd	W	D	k(kg/cm)	W	D	k(kg/cm)
ka	750	7.28	3.64	1500	7.28	3.64	1500
kb		2.73	2.73	750	2.73	2.73	750
kc		7.28	3.64	1500	3.64	3.64	750
ka'	750/2	7.28	3.64	750	7.28	3.64	750
kb'		7.28	2.73	1000	7.28	2.73	750
kc'		7.28	3.64	750	7.28	3.64	750

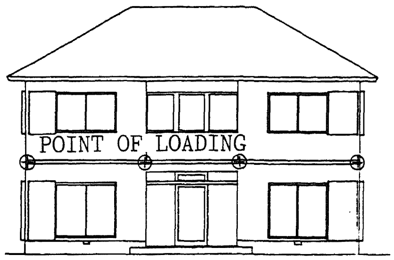

FIG.1 ELEVATION OF THE MODEL

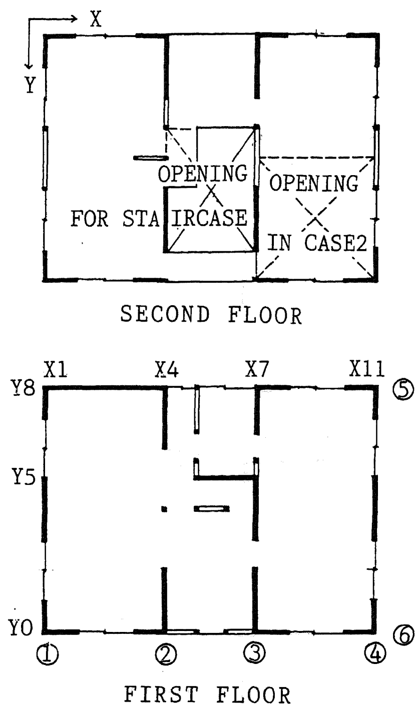

FIG.2 PLAN OF THE MODEL

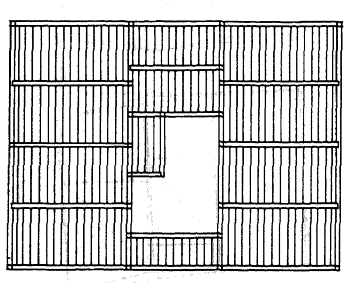

FIG.4 PLAN OF THE HORIZONTAL FRAME (SECOND FLOOR)

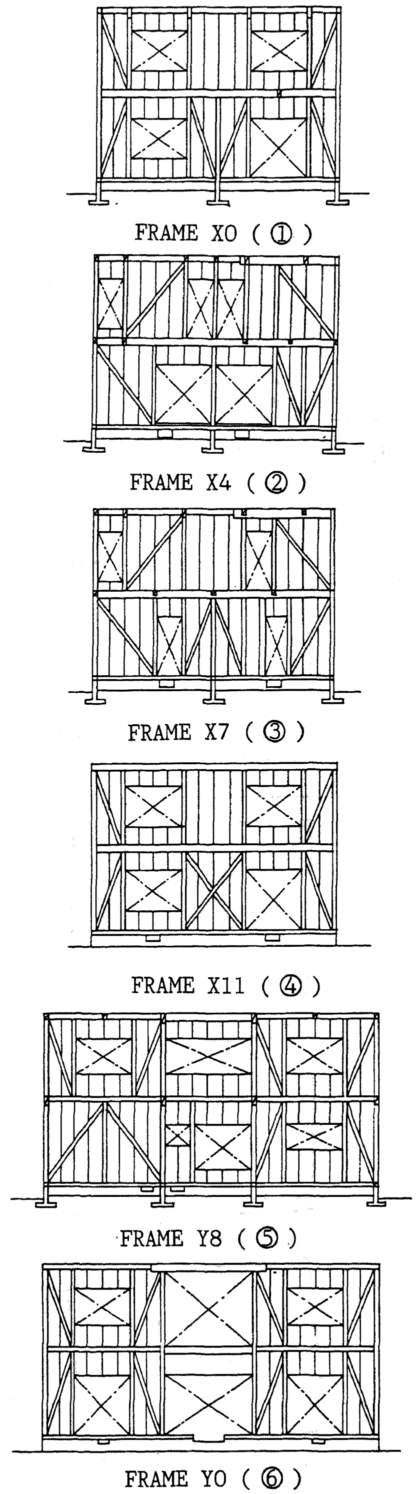

FIG.3 ELEVATION OF THE VERTICAL FRAMES

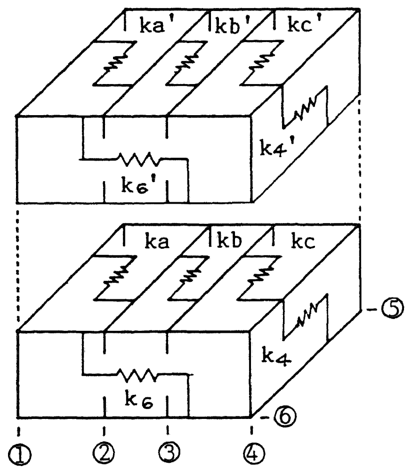

FIG.5 THEORETICAL MODEL FOR SIMULATION

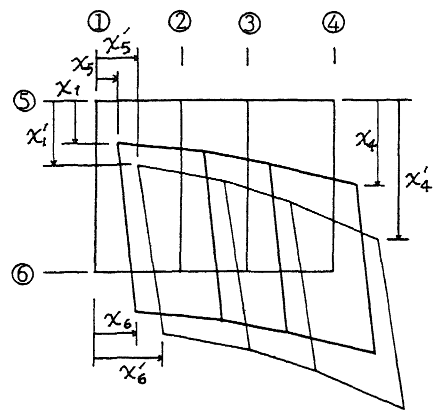

FIG.6 DISPLACEMENT OF FLOORS

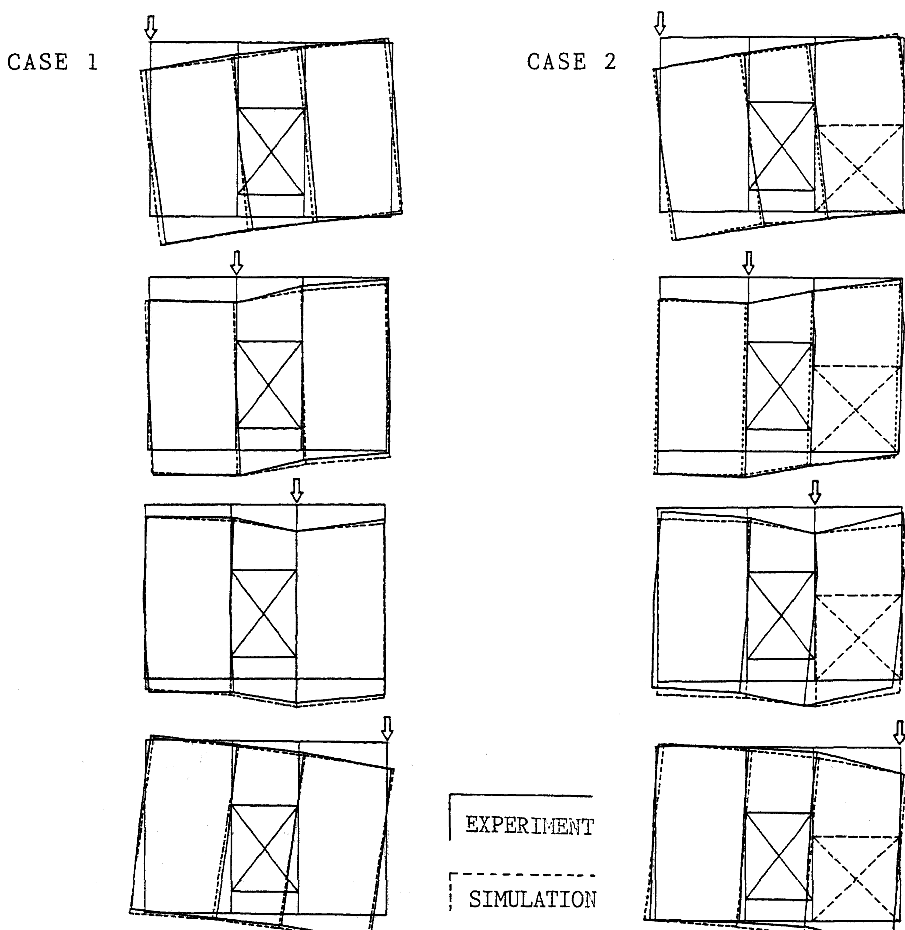

FIG.7 COMPARISON BETWEEN EXPERIMENT AND SIMULATION