

SOME PROBLEMS AND CONSIDERATIONS ON ASEISMIC DESIGN OF
WOODEN DWELLING HOUSES IN JAPAN

I. Sakamoto(I)
Y. Ohashi(II)
M. Shibata(III)
Presenting Author: Y. Ohashi

SUMMARY

It seems that several recent earthquakes have proved that most wooden dwelling houses in Japan can withstand earthquakes. The Japanese regulations require that wooden houses have bearing walls, the required length of which is determined on the basis of 0.2g. And it is expected that the maximum bearing capacity be 0.4g. In this paper, we investigated some of the factors that determine the natural period, taking the effect of non-bearing walls into consideration. And it became clear that wooden dwelling houses in Japan have a maximum bearing capacity of more than 0.4g.

INTRODUCTION

Strong earthquake which damage many wooden dwelling houses have occurred at intervals of a few years in some places in Japan. Table 1 shows several of the major earthquakes over the last 20 years. Some wooden dwelling houses have been destroyed by these earthquakes. However, according to the reports of the earthquake damages and the investigations by the authors there were actually few houses destroyed by the vibration of the earthquake. Most of the destroyed houses fell because of the ground crumbling beneath them. It seems that on the whole wooden dwelling houses in Japan have more resilient against earthquakes.

Table 1 Recent Earthquakes in Japan

Date	Name	Magunitude	Number of Damaged Houses (*;Building)	
			Totaly Damaged	Partially Damaged
May16.68	Off-Tokachi	7.9	673*	3004*
May9.74	Off-Izu-peninsula	6.9	48	125
Apr21.75	Center-Ohita	6.4	31	90
Jan14.78	Near-sea Izu Ohshima	7.0	94	539
Jun12.78	Off-Miyagi prefecture	7.4	651*	5450*
Mar21.82	Off-Urakawa	7.3	12	30
May26.83	Mid-Japan Sea	7.7	1446	2805

- (I) Associate Professor, Tokyo University, Tokyo, Japan
(II) Research Associate, Tokyo University, Tokyo, Japan
(III) Graduate Student, Tokyo University, Tokyo, Japan

REGULATION ON THE EARTHQUAKE RESISTANT DESIGN OF WOODEN DWELLING HOUSES

According to the Building Standard Law in Japan, structural calculations are required in order to build a structure. However, an expedient calculating method is allowed in the case of wooden houses constructed conventionally; therefore, most wooden houses have actually been built without structural calculation.

On the earthquake resistant design, many provisions are stipulated for every structural element. Walls are particularly recognized as the primary element which bear the horizontal force due to earthquakes; therefore, the required length of the so-called bearing wall is also provided. In this regulation, a wall with certain strength is regarded as a standard one, and the required length of the wall per 1 square meter of floor area is given. The strength of the walls with a wood brace or wall board is expressed by the ratios to the standard one. However, only braced walls are taken into consideration as bearing walls in most actual designs. The required length of bearing walls is shown in Table 2, which varies depending on the number of stories and on the materials of the roof.

Table 2 Required Length of Bearing Walls (cm/m²)

House	1-storied	2-storied		3-storied		
	first	first	second	first	second	third
Light-roofed	11	29	15	46	34	18
Heavy-roofed	15	33	21	50	39	24

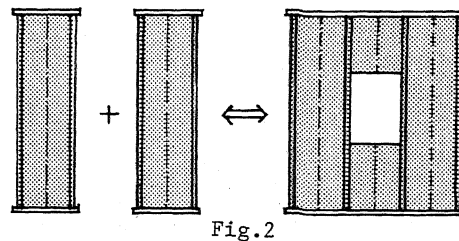
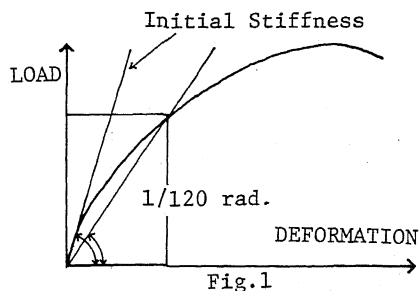
RECONSIDERATION ON THE REQUIRED LENGTH OF BEARING WALLS

In the old regulations, the required length of a bearing wall was determined so that a house would not be destroyed by an earthquake as strong as the Fukui earthquake. And as mentioned previously, recent wooden houses are stronger than previous ones. Consequently the standard coefficient of base shear was kept unchanged, and it is still 0.2 in the new regulations. On the other hand, from the investigation of the Off-Miyagi prefecture earthquake, the houses that were hardly damaged were supposed to have the maximum bearing capacity of 0.4g.

By the way, the strength of each bearing wall is determined based on the load of the racking test at the deformation of 1/120 rad. And the load of 130kg per 1 meter is considered to be unit strength ratio (1.0). Consequently, the house is expected to deform up to 1/120 rad. when 0.2g is applied. Then, we can calculate the natural period of a wooden dwelling house. From the result of the above calculation, the natural period of wooden dwelling houses is estimated to be about 0.8 second for a two storied house. However, according to several reports (Ref. 1), the natural period of actual wooden dwelling houses is about 0.23 sec. There is a great difference between the estimated natural period and the observed natural period. The latter is 4 times as large as the former. This means that the difference in stiffness is 16 times. The main reasons for differences are supposed to be the following three.

1) Effect of Non-linearity on Force-Displacement Diagram

As mentioned previously, the stiffness of each bearing walls is determined on the basis of the deformation of $1/120$ rad. The natural period of 0.8 sec. is calculated based on the above stiffness. On the other hand, observed period is obtained by the measurement of micro tremors. Therefore the observed natural period is at the initial stiffness as shown in Fig. 1.



2) Increasing of the Stiffness by the Non-bearing Walls

In the calculation of the natural period, only the stiffness of bearing walls is taken into consideration. However there are many non-bearing walls in actual wooden dwelling houses. And thus it is supposed that they also are elements contributing to stiffness.

3) Frame Effect by Wall Board with Opening

The stiffness and strength of the walls are determined by the test of a single wall. However there are small walls at the top and the bottom of the greater part of openings in the actual houses. And as shown in Fig. 2 these walls are made of various kind of wall boards. Such walls with opening are expected to compose a frame with single frames.

In the following sections, we investigate the stiffness and strength of wooden dwelling houses about these three points through the research of documents and racking tests of various walls.

SURVEY AND EXPERIMENT

Survey

In this survey, we collected drawings for application of administrative confirmation of wooden dwelling houses in Tokyo, Shizuoka, and Miyagi. And we picked out the length of non-bearing walls such as mortar finish walls, Shinkabe walls, and Ohkabe walls. Data of Tokyo were based on the old Building Standard Law before the revision, 1981. While data of Shizuoka and Miyagi based on the new one. The average of the ratio of each wall is shown in Table 3.

Table 3 Ratio of the Length of each Wall to the Required one

	Braced Walls	Mortar-finish Walls	Shinkabe Walls	Ohkabe Walls
Tokyo	0.58	0.43	0.20	1.02
Shizuoka	0.68	0.38	0.17	1.00
Miyagi	0.93	0.47	0.23	1.13

Experiment

In the experiment, we applied the load at the top of the specimen in order to determine the relationship between deformation and load. The loading-procedure is cyclic reversal loading. On this experiment, 4 different types of walls were employed; braced wall, mortar finish wall with metal lath (expanded metal lath) which is used as exterior wall, Shinkabe and Ohkabe walls used as inner wall. We used the wood brace which is $\frac{1}{3}$ of the column in thickness because it is popularly used in Japan. The specimens are shown in Fig.3, and the typical Force-Displacement Diagrams are shown in Fig.4.

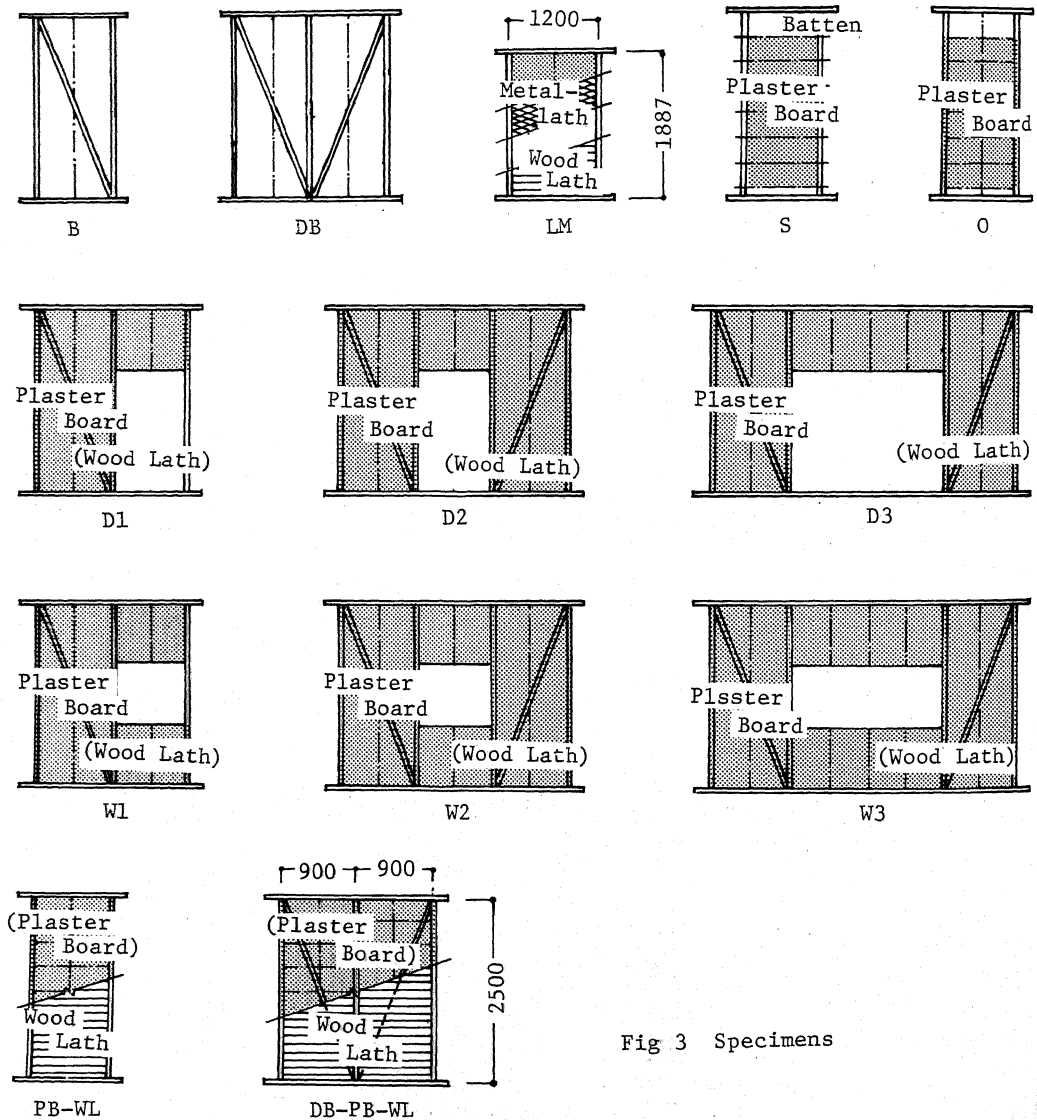


Fig 3 Specimens

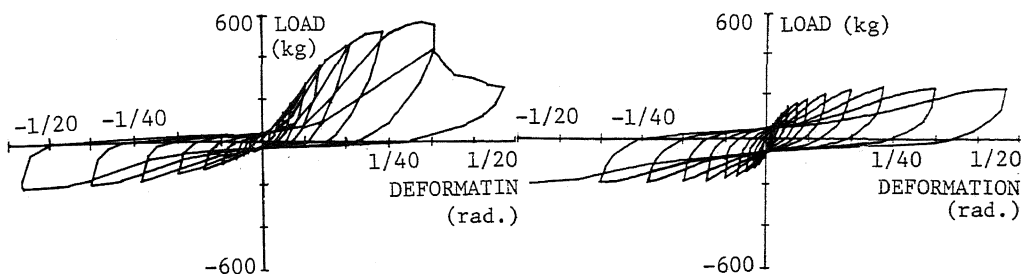


Fig.4-a F-D Diagram for B

Fig.4-b F-D Diagram for LM

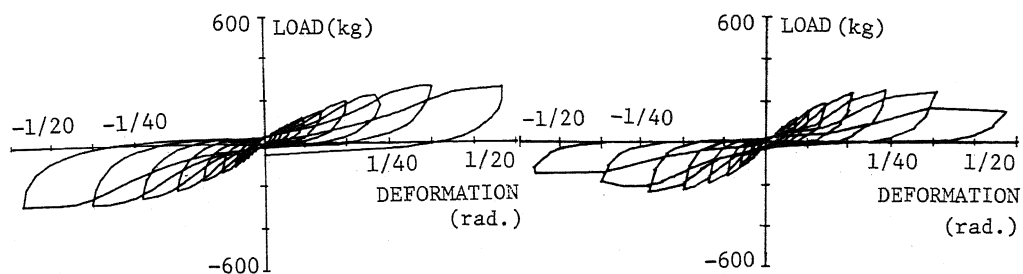


Fig.4-c F-D Diagram for S

Fig.4-d F-D Diagram for O

ESTIMATION OF STIFFNESS AND MAXIMUM BEARING CAPACITY

Stiffness

1) Initial stiffness of braced frame

The comparison between the initial stiffness of a braced frame at the deformation of $1/2500$ rad. and that of $1/120$ rad. is shown in Table 4. According to this table, The initial stiffness is about 1.8~2.5 times as great as that of $1/120$ rad. From this result, we can conclude that the natural period at the deformation of $1/2500$ rad. is calculated to be $1/1.35 \sim 1/1.6$ of that of $1/120$ rad. The histogram of the natural period* in Tokyo is shown in Fig.5 . The mean value is 0.65 sec. Table 4 also indicates that the initial stiffness of non-bearing walls is 1.5 times as great as that at $1/120$ rad.

Note: The values signed * are calculated by the appendix.

Table 4 Ratio of Initial Stiffness at $1/120$ rad.

	Initial Stiffness (kg/ $1/2500$ rad.)	Load at $1/120$ rad. (kg)	Stiffness at $1/120$ rad. (kg/ $1/2500$ rad.)	Ratio
B	23.9	276	13.2	1.81
DB	44.5	362	17.4	2.56
LM	21.2	152	7.2	2.95
S	14.2	145	6.9	2.04
O	11.7	159	7.6	1.53

2) Non-bearing walls

The brace used in this experiment is given the value of 1.50 as the coefficient in the regulation, but the actual experimental value is 1.74 of the coefficient. It is important that the strength of non-bearing walls is almost 1.0 of the coefficient, moreover the walls without openings have at least a board on both sides. Consequently the stiffness of non-bearing walls contributes to that of the whole house. If the effect of non-bearing walls is taken into consideration, the natural period of wooden house is 0.36 sec. on the average. The histogram of the above natural period is shown in Fig. 5.

3) Frame effect

Table 5 shows the load of walls with openings at the deformation of 1/120 rad. This indicates that the strength of type (D1) and (W1) doesn't increase but that of type (D2) and (D3) increases by about 10%, type (W2) and (W3) by about 10% ~ 40%. The increase of the stiffness of walls with openings, called "frame effect" depends on the board which is attached to the wall, and due to this the stiffness increased by 30% ~ 90%. When we take three factors into account, we can calculate the natural period which is close to that of actual wooden houses. And the result is shown in Fig. 5.

Table 5 Frame Effect of Walls with Openings

	B+(PB-WL)	D1	W1	DB-PB-WL	D2	W2	D3	W3
Load	444	419	462	655	682	732	737	917
Ratio	1.00	0.94	1.04	1.00	1.04	1.12	1.13	1.40

Maximum bearing capacity

The loads at the deformation of 1/120 rad. and those at the maximum strength, namely, 1/30 rad. are shown in Table 6. In the braced frame, the maximum strengths were about 1.6 ~ 2.0 times of the load at 1/120, in the case of mortar finish wall, 1.3 times, in Shinkabe, 1.9, in Ohkabe, 1.5. These walls show a small increase in strength over the deformation of 1/120

Table 6 Ratio of the Load at 1/30 rad. to that at 1/120 rad.

	Load at 1/120 rad.(kg)	Load at 1/30 rad.(kg)	Ratio
B	271	550	2.03
DB	361	585	1.62
LM	202	257	1.27
S	141	277	1.96
O	153	233	1.52

rad. These are typical characteristics of non-bearing walls; the initial stiffness is large but the ductility is relatively small in the large deformation. The increase of the strength of walls with opening by the frame effect is shown in Table 7. The maximum bearing capacity increases by about 50% due to frame effect.

Table 7 Ratio of the Load at 1/30rad. to that at 1/120rad.

	D1	W1	D2	W2	D3	W3
Load at 1/120 rad. (kg)	419	462	682	732	737	917
Load at 1/30 rad. (kg)	693	763	1058	1170	1130	1361
Ratio	1.65	1.65	1.55	1.60	1.53	1.48

From the values of these factors, the presumption of the maximum bearing capacity can be made by substituting the coefficient of each walls previously mentioned. On the supposition that the frame effect of boards is 50% in common, the maximum bearing capacity was calculated to be 1.17g on the average for houses in Tokyo. The value of 1.17 was unexpectedly large. The above calculation was applied to the data of Tokyo based on the old regulations. The influence of the revision is not defined, but according to the surveys, the data of Shizuoka and Miyagi have more bearing walls than these of Tokyo. Therefore it is obvious that the maximum bearing capacity in Shizuoka and Miyagi is greater than in Tokyo as shown in Fig.5.

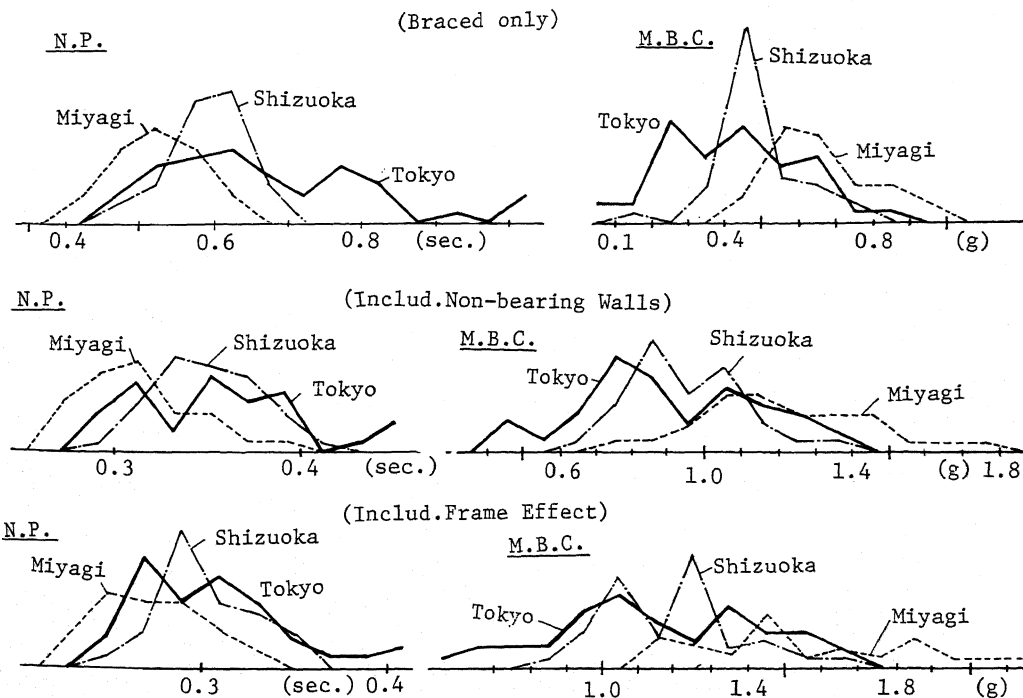


Fig.5 Histogram of the Natural Period and the Maximum Bearing Capacity

CONCLUSIONS

- 1) We studied 3 primary factors which are concerned with the natural period of wooden dwelling houses. They are the non-linearity of the stiffness, the influence of non-bearing walls and the frame effect of the wall board. Considering these factors, the natural period is presumed to be 0.31 sec., that is close to the observed value, namely, 0.23 sec.
- 2) The maximum bearing capacity is supposed to be 1.17g. The value is considerably greater than that in houses without non-bearing walls.
- 3) The increase of stiffness and strength is due to the non-bearing walls that consist of wall boards. Hence, under the present regulations, a wooden dwelling house without any non-bearing walls should not be designed.

REFERENCE

- 1) K.Kanai, "On the damage on Wooden Dwelling House", Research Report No.2 on Earthquake Insurance, Association for Estimation of Loss Ratio, 1982

APPENDIX

As mentioned in the text, the natural period of a house which has minimum requirement of bearing walls only is 0.8 sec.. Therefore, if three primary factors are taken into consideration, the natural period T of a house which has additional bearing walls as well as non-bearing walls is obtained from the following equation.

$$T = \frac{0.8}{\sqrt{S}}$$

In this equation, S is the ratio of the existing stiffness to the stiffness at the deformation of $1/120$ rad. in the case of minimum bearing wall and expressed as follows.

$$S = K_b \times L_b \times R_b + \sum (K_n \times L_n \times R_n) \times F_s$$

where K : real coefficient of the strength of walls
 L : total length of the wall/required length of the bearing wall
 R : ratio of the initial stiffness to that at the deformation of $1/120$ rad.
 F_s : frame effect in stiffness
 b : bearing wall
 n : non-bearing wall

In the same way, maximum bearing capacity C is obtained from the following equation.

$$C = 0.2 \times \{ (K_b \times L_b \times M_b) + \sum (K_n \times L_n \times M_n) \times F_m \}$$

where 0.2 : design base shear coefficient
 M : ratio of the load at the deformation of $1/30$ rad. to that of $1/120$ rad.
 F_m : frame effect in maximum bearing capacity