Study on Seismic Performance Evaluation for Wooden Structure by Limit Proof Calculation

―― Influence of the deformation mode in the contraction ――

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Abstract

In the Limit Proof Calculation Method for Wooden Structure, to trace the rigidity deterioration of a structure, the deformation mode is used instead of the natural mode.

The authors studied on the effect, that is caused by the use of the deformation mode, on the results of the seismic performance. From the analytical study by a 2 D.O.F. model, it was clarified that the variation of the deformation mode is classified to three patterns that are decided by a combination of the stiffness and mass: error increases in the two patterns, and error reduces in the other pattern. Furthermore, from the parameter study by a 3 D.O.F. model, it was clarified that in a 3 D.O.F. model the use of the deformation mode gives larger error than the case of a 2 D.O.F. model.

Keywords: Wooden Structure, Seismic Performance Evaluation, Limit Proof Calculation, Contraction, Deformation Mode

1. Introduction

With the huge damages of wooden structures by the 1995 Hyogoken-Nanbu Earthquake, the Building Standards Act and the Enforcement Ordinance of Construction Standard Law were revised in 2000. By the revision, the Performance Code and the Limit Proof Calculation were introduced to the seismic performance evaluation of wooden structure. The revision aims at improvement of the seismic performance of wooden structure. However, considering on the wooden structures, it is very difficult to evaluate seismic performance appropriately, because of the complexity of the structure, the illegibility of the mechanical property, and so on. Then, the authors have been studied on the mechanical properties of wooden structure, and on the method to evaluate seismic performance of wooden structure[1~3].

The objective of this study is to clarify the characteristics of the Limit Proof Calculation Method for Wooden Structure. In the normal Limit Proof Calculation Method, the natural mode of the model should be calculated in each step when the rigidity deteriorated. On the other hand, in the Limit Proof Calculation Method for Wooden Structure, the natural mode of the model is calculated only on the initial stiffness, and the deformation mode is used to trace the variation of the rigidity of the model.

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In this paper, the effect of the use of the deformation mode on the seismic performance evaluation will be studied by two stages. The first stage is the analytical study by a 2 D.O.F. model. The second stage is the parameter study with a 2 D.O.F. model and a 3 D.O.F. model. In the following, "strict contraction" shall mean the contraction by the accurate natural mode of the structure, and "convenient contraction" shall mean the contraction by the deformation mode.

2. Analysis of the contraction technique

2.1 Procedure of the contraction in the Limit Proof Calculation

As summarized in Fig. 2.1, the procedure of the Limit Proof Calculation Method for Wooden Structure is separated to five steps.

In the first step, characteristics of restoring force of each earthquake resisting element are evaluated by physical experiment.

In the second step, multi D.O.F. spring-mass model is built. In this step, the characteristics of restoring force of each story of the structure are evaluated by the sum of the earthquake resisting elements on the story. The summation is based on the rigid floor assumption, then it becomes impossible to trace torsional behavior of the structure.

In the third step, the multi D.O.F. model is contracted to the equivalent 1 D.O.F. model. In the contraction, the first natural mode is calculated on the initial stiffness of the model.

In the fourth step, the rigidity deterioration of the model is evaluated by the Equivalent Linearization Method. In this method, the accurate natural mode is need in order to evaluate the behavior of a structure that the rigidity was deteriorated. However, in the Limit Proof Calculation Method for Wooden Structure, in order to simplify the procedure, the deformation

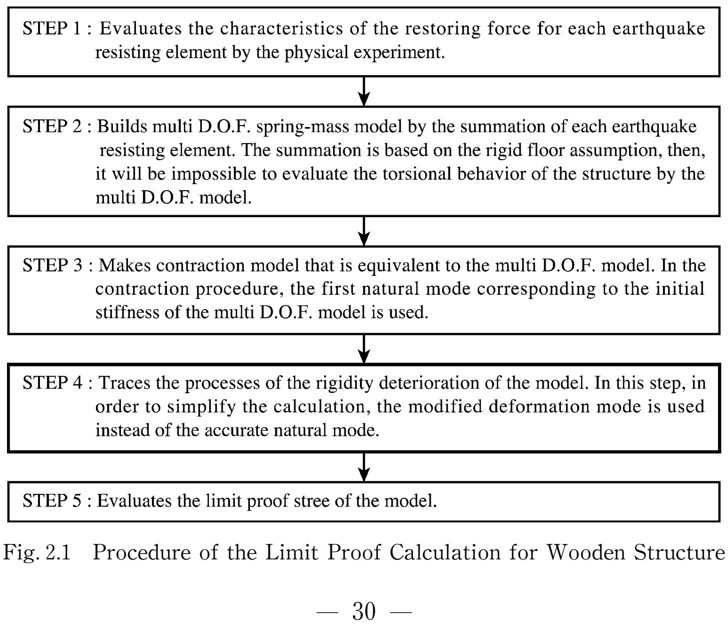

Fig. 2.1 Procedure of the Limit Proof Calculation for Wooden Structure

mode is used instead of the accurate natural mode.

In the last step, the limit proof stress of the model is evaluated.

2.2 Definition of the models

In the study, the 2 D.O.F. model and the 3 D.O.F. model, that are illustrated in Fig. 2.2, will be used. The mechanical properties of each model are defined by the parameters α_i and β_i : α_i is the mass ratio of the i-th story to the first story, and β_i is the stiffness ratio of the i-th story to the first story.

In the examination that is presented in chapter 4, the first eigenvalue and the first natural mode of a 3 D.O.F. model are calculated by the static reduction technique illustrated in Fig. 2. 3.

2.3 Analysis of the contraction procedure

To clarify the differences between the strict contraction and the convenient contraction, the methods are examined analytically by a 2 D.O.F. model, in the following.

The equation of motion of a 2 D.O.F. model is descried as

$$m\begin{bmatrix}\alpha_2 & 0\\ 0 & 1\end{bmatrix}\ddot{\mathbf{X}} + \mathbf{C}\dot{\mathbf{X}} + k\begin{bmatrix}\beta_2 & -\beta_2\\ -\beta_2 & \beta_2+1\end{bmatrix}\mathbf{X}=\mathbf{F}. \tag{2.1}$$

Here, $a=\alpha_2$, $b=\alpha_2+\beta_2+\alpha_2\beta_2$, $c=\beta_2$ and $d=\sqrt{b^2-4ac}$.

From Eq. (2.1), the first eigenvalue ω_1, the first natural period T_1, and the first natural mode $\{u_{12}\ u_{11}\}^t$ become as follows.

$$\omega_1^2=\frac{b-d}{2a}\omega_0^2, \tag{2.2}$$

$$T_1= T_0\sqrt{\frac{2a}{b-d}}, \tag{2.3}$$

$$\frac{u_{12}}{u_{11}}=\frac{2c}{2c-b+d}. \tag{2.4}$$

Here, $T_0=2\pi/\omega_0$, $\omega_0^2=k_e/m$ and u_{ij} is the j-th component of the i-th natural mode.

The equation of motion of the contracted model becomes as

$$\mathbf{M}_u\ddot{\bar{\mathbf{x}}} + \mathbf{C}\dot{\bar{\mathbf{x}}} + \mathbf{K}_e\bar{\mathbf{x}}=\mathbf{F}(t) \tag{2.5}$$

The deformation mode that is used in the convenient contraction is defined by Eq. (2.6), where u_{ij} $(j=1, 2)$ are the components of the accurate first natural mode of the model. The deformation mode after the rigidity deterioration is calculated by Eq. (2.7).

$$\delta_i^{(1)}=\frac{u_{12}}{u_{11}}\delta_1^{(1)} \tag{2.6}$$

$$\delta_i^{(n)}=(\delta_i^{(1)}-\delta_{i-1}^{(1)})\frac{\delta_1^{(n)}}{\delta_1^{(1)}}\cdot\frac{k_{e1}^{(n)}}{k_{ei}^{(n')}}+\delta_{i-1}^{(n)} \tag{2.7}$$

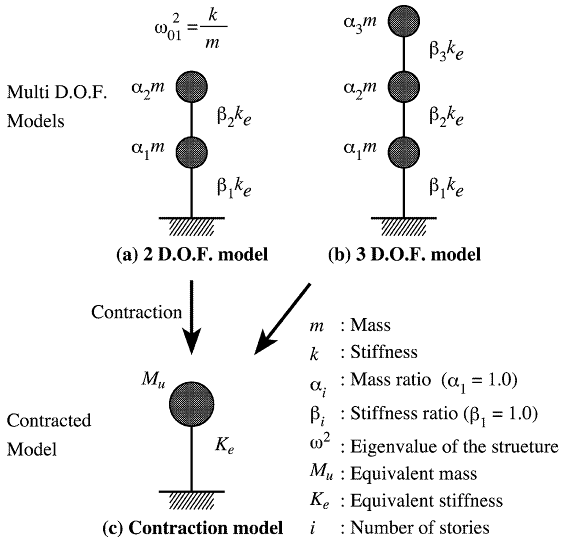

Fig. 2.2　Models used on the parameter study

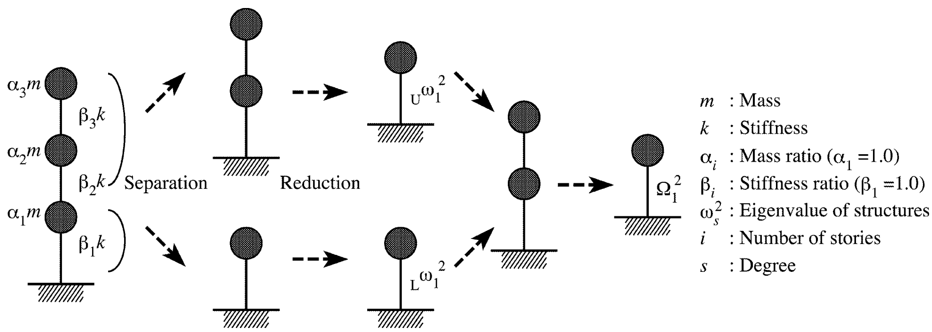

Fig. 2.3　Static reduction process of a 3 D.O.F. model

Here, $\delta_i^{(n)}$ is the i-th component of the deformation mode at the n-th stage of the rigidity deterioration.　Then $n=1$ means the initial state of the model.

By the equations from Eq. (2.5) to Eq. (2.7), the equivalent mass M_u, the equivalent stiffness K_e, the equivalent eigenvalue ω_e^2 and the equivalent natural period T_e become as follows.

$$M_u = m\left\{1+\Sigma\left(\alpha_i\frac{\delta_i}{\delta_1}\right)\right\}^2 \Big/ \left[1+\Sigma\left(\alpha_i\frac{\delta_i}{\delta_1}\right)^2\right\}\Big] \tag{2.8}$$

$$K_e = k_e\left\{1+\Sigma\left(\alpha_i\frac{\delta_i}{\delta_1}\right)\right\} \Big/ \left[1+\Sigma\left\{\alpha_i\left(\frac{\delta_i}{\delta_1}\right)^2\right\}\right] \tag{2.9}$$

$$\omega_e^2 = \frac{K_e}{M_u} = \omega_0^2 \Big/ \left\{1+\Sigma\left(\alpha_i\frac{\delta_i}{\delta_1}\right)\right\} \tag{2.10}$$

$$T_e = T_0\sqrt{1+\Sigma\left(\alpha_i\frac{\delta_i}{\delta_1}\right)} \tag{2.11}$$

From Eq. (2.2) and Eq. (2.10), it is clear that the eigenvalues of a 2 D.O.F. model and the contracted model are not equal. This difference is caused by the use of the deformation mode in the convenient contraction. In the convenient contraction, the deformation mode is defined by the natural mode that is defined by the initial stiffness of the model. However, the natural mode changes depending on the stiffness deterioration every moment. Then, the difference of the eigenvalues shown in Eq. (2.2) and Eq. (2.10) suggests that the accurate evaluation of the seismic performance becomes difficult in the convenient contraction.

3. Effect of the contraction on 2 D.O.F. model

3.1 Effect of the contraction in the initial stiffness

In this section, on the initial stiffness, the effect of the contraction will be studied by the comparison of the characteristics of the response. In the examination, a 2 D.O.F. model and the contracted model are used. In each model, mass ratio α_i and stiffness ratio β_i are treated as parameters and the damping ratio h is fixed to 5%. The response of the 2 D.O.F. model is the modal response calculated with the first natural mode.

Fig. 3.1 shows the displacement response of the 2 D.O.F. model and the contracted model. In the figure, the horizontal axis is the frequency p normalized by the natural circular frequency ω_0. Fig. 3.2 shows the variation of the maximum magnification of the displacement response of the models, and Fig. 3.3 shows the variation of the excellent frequency.

From Fig. 3.1, it is clear that the response corresponding to the first natural mode become as follows: the response magnification at the second story is almost 12.0, the magnification at the first story is almost 7.0, and the excellent frequency of each story is almost 0.6 Hz. The characteristics of the 2 D.O.F. model and the contracted model are same. Furthermore, from Fig. 3.2 and Fig. 3.3, it is clear that the 2 D.O.F. model indicates the same characteristics with the contracted model in the maximum magnification of displacement response and in the excellent frequency, and these parameters are not affected by the variation of stiffness ratio

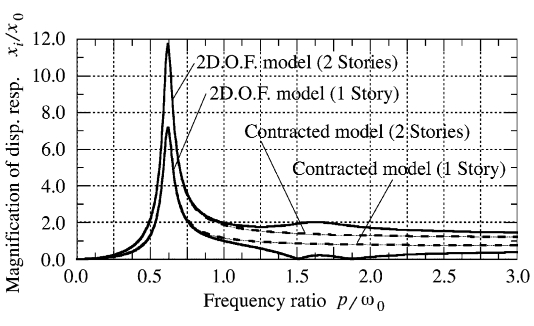

Fig. 3.1 Response displacements of a 2 D.O.F. model and the contracted model

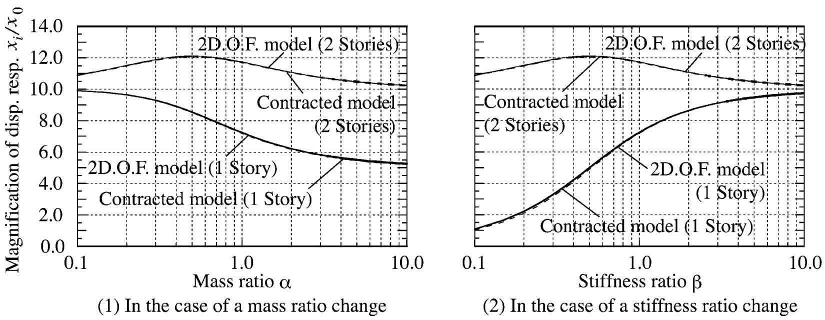

Fig. 3.2　Variation of the maximum magnification of displacement response by the variation of the mass ratio and the stiffness ratio

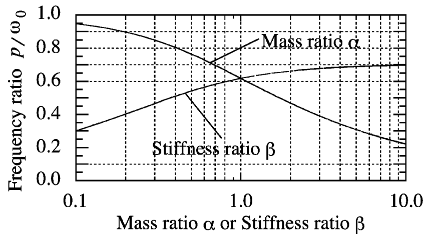

Fig. 3.3　Variation of the excellent frequency ratio by the variation of the mass ratio and the stiffness ratio

and mass ratio.

Than the above, it was confirmed that the contraction, even if it is the strict contraction or the convenient contraction, gives accurate response on the initial state of the model.

3.2　Effect of structural properties on the deformation mode

In the Limit Proof Calculation Method for Wooden Structure, it is considered that the use of the deformation mode in the convenient contraction causes error to the seismic performance evaluation. From the parameter study on the mass ratio α_2 and the stiffness ratio β_2, it was found that the variation of the deformation mode in Eq. (2.7) is classified to three patterns.

Using $R_i^{(n)}$ that means the deformation angle of the i-th story in the n-th step, the patterns are described as follows.

Pattern A : the story deformation angles keep the relation $R_2^{(n)} < R_1^{(1)}$.
Pattern B : the story deformation angles keep the relation $R_1^{(n)} > R_2^{(n)} > R_1^{(n-1)}$.
Pattern C : the story deformation angles keep the relation $R_2^{(n)} < R_1^{(n)}$.

These patterns are correspond to the regions A, B and C in Fig. 3.4 that are separated by two curves (a) and (b). These curves converge to the stiffness ratio $\beta_2 = 1.0$, if the mass ratio α_2 increases.

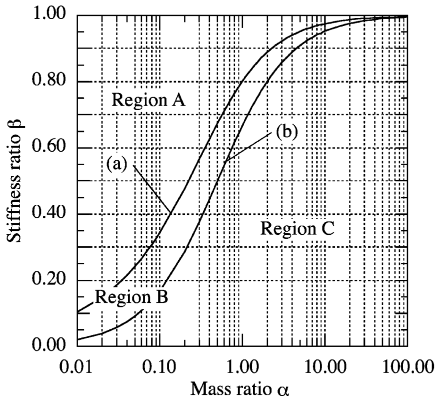

Fig. 3.4 Variation of the deformation modes by the combination of the mass ratio and the stiffness ratio

3.3 Effect of the contraction on the evaluation of the characteristics of the structure that rigidity deteriorated

In the following, in order to clarify the effect that the convenient contraction causes to the evaluation of the characteristics of the structure that rigidity was deteriorated, for each deformation pattern A, B and C, a parameter study will be done. In the examination, the characteristics of the model are defined by the stiffness ratio β_2 and the mass ratio α_2 : β_2 is 1.00, 0.75 and 0.50 for each pattern A, B and C, and α_2 is 1.00 for all patterns. The characteristics of the rigidity deterioration of the model are defined as Fig. 3.5. In order to clarify the effect of the convenient contraction, the result that is obtained by the convenient contraction compared to the result of the 2 D.O.F. model.

The figures from Fig. 3.6 to Fig. 3.8 show, respectively, the variation of the first eigenvalue, the variation of the acceleration response and the variation of the displacement response.

Fig. 3.6 indicates that the eigenvalue error for the 2 D.O.F. model of the contracted model becomes as follows. When the stiffness ratio is constant, namely in the pattern A, the error is almost 22% on the story that deformation angle is 1/30 rad. and the error increases when the rigidity is deteriorated. When the stiffness ratio increases, namely in the pattern B, the error is almost 0% and the error decreases when the rigidity is deteriorated. When the stiffness

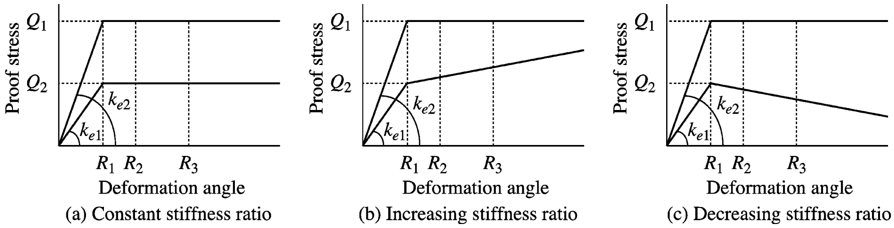

Fig. 3.5 Patterns of the variation of the stiffness ratio β_2 after the rigidity deterioration

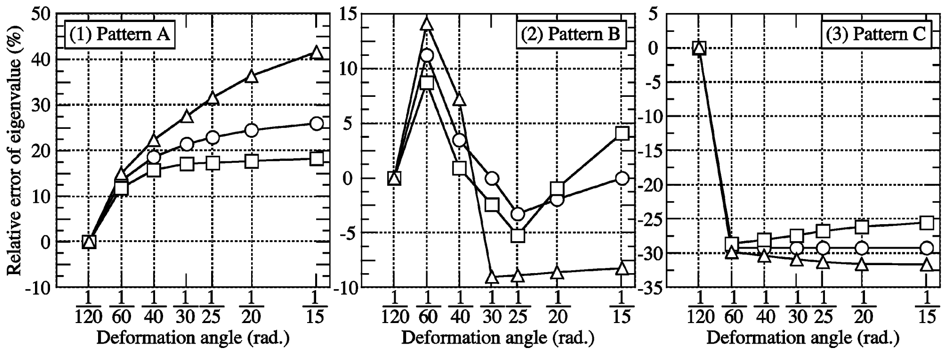

Fig. 3.6　Eigenvalue error by the combination of the variation pattern of stiffness ratio β_2 and the pattern of the deformation mode (symbol ○, □ and △ means, respectively, the case that β_2 is constant, the case that β_2 increases, and the case that β decreases.)

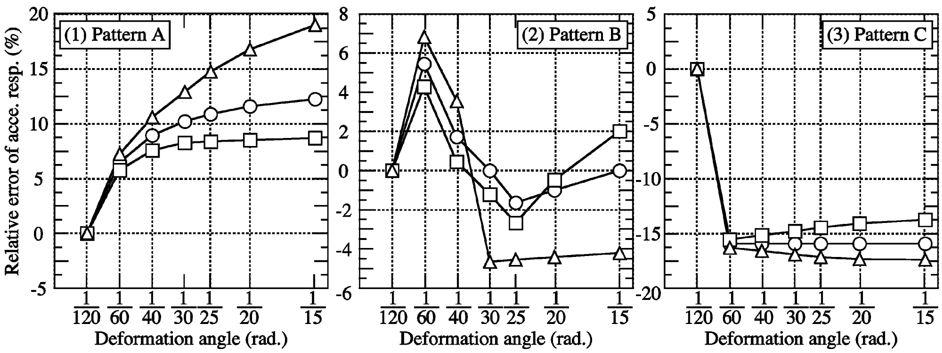

Fig. 3.7　Acceleration response error by the combination of the variation pattern of the stiffness ratio β_2 and the pattern of the deformation mode (on the symbols in the figures, see the caption of Fig. 3.6)

decreases, namely in the pattern C, the error is almost −30% and the error is constant even if the rigidity is deteriorated. When the stiffness ratio increases, the error becomes smaller, in each level of the story deformation angle, than the case that the stiffness ratio is constant. On the other hand, when the stiffness ratio decreases, the error becomes greater, in each level of the story deformation angle, than the case that the stiffness ratio is constant.

Fig. 3.7 indicates that the acceleration response error for the 2 D.O.F. model of the contracted model becomes as follows. When the stiffness ratio is constant, the error of acceleration response, on the story that deformation angle is 1/30 rad., is almost 10% and the error increases with the rigidity deterioration. In the pattern B, the error is about 0% and the error decrease when the rigidity was deteriorated. In the pattern C, the error is almost −17% and the error is constant even if the rigidity was changed. When the stiffness ratio decreases, the error becomes greater than the error of the case that the stiffness ratio is constant.

The result shown in Fig. 3.8 indicates that the displacement response error has similar properties to the acceleration response error.

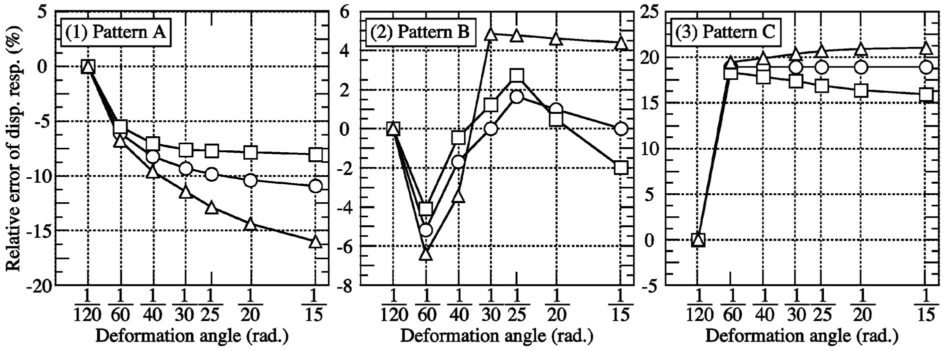

Fig. 3.8 Displacement response error by the combination of the variation pattern of the stiffness ratio β_2 and the pattern of the deformation mode (on the symbols in the figures, see the caption of Fig. 3.6)

By the figures shown from Fig. 3.6 to F. 3.8, the relation between the error and the pattern of the deformation mode is summarized as follows: in the patterns A and C, the error increases, and, in the pattern B the error decreases. Furthermore, the relation between the error and the variation of the stiffness ratio after the rigidity deterioration is summarized as follows: the error decreases when the stiffness ratio increases, and, the error increases when the stiffness ratio decreases.

3.4 Effect of the convenient contraction on the seismic performance evaluation

In this section, it is studied on the effect that is caused by the convenient contraction. In the examination, the 2 D.O.F. model is used, and the seismic performance evaluated by the convenient contraction is compared with the seismic performance that was evaluated by the strict contraction. The parameter study will be done on the patterns A and C which the error increases. In the pattern A, the stiffness ratio β_2 is defined as 1.00, and the pattern B the stiffness ratio β_2 is defined as 0.50. The other parameters are set as follows: the value of the natural period of the first story is set the value that is longer than 0.64 s, the ground is category I, earthquake zone factor Z is 1.0, height of each story is 3.0 m and the mass ratio α_2 is 1.00.

Fig. 3.9 is the response deformation angles of the 2 D.O.F. model that were evaluated by the Limit Proof Calculation Method. Table 3.1 is a summary of the evaluated seismic performance.

In the pattern A, for all variation patterns of the stiffness the response deformation angle obtained by the convenient contraction is 1/21 rad., and the angle obtained by the strict contraction is 1/23 rad.. This result suggests the following matters: the use of the deformation mode gives safety evaluation, and the variation of the stiffness ratio caused by the rigidity deterioration does not affect to the seismic performance. On the other hand, in the pattern C, the response deformation angle obtained by the convenient contraction is 1/28 rad., and the response deformation angle obtained by the strict contraction is 1/24 rad..

From the above, it was clarified that there is a case in which the response deformation

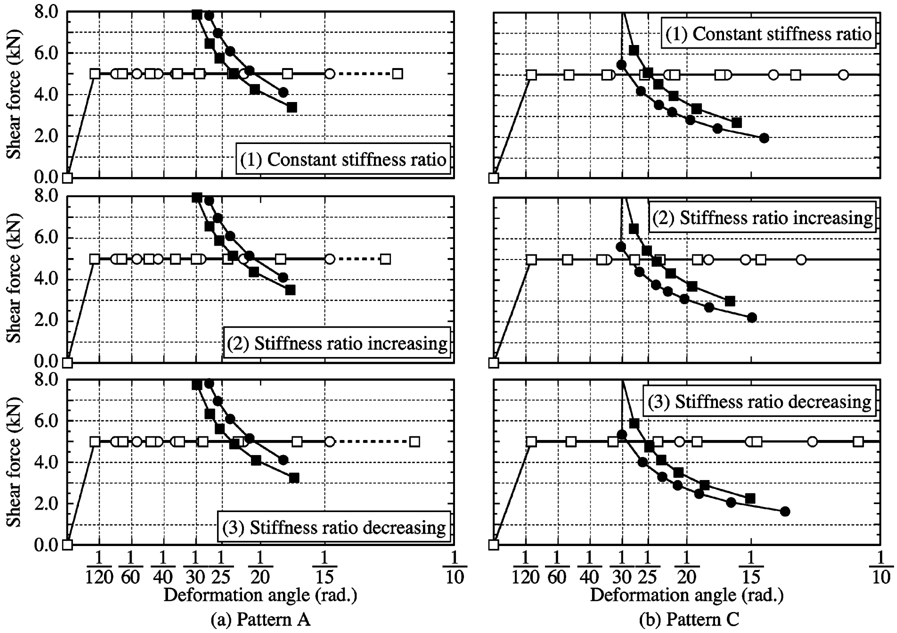

Fig. 3.9 Comparison of the response deformation angles of the 2 D.O.F. model that were calculated by the convenient contraction and by the strict contraction (Symbols ○ and □ mean the restoring force characteristics, and ● and ■ mean the response. Furthermore, ○ and ● are the results calculated by the convenient contraction, and □ and ■ are the results calculated by the strict contraction.)

Table 3.1 Summary of the evaluated seismic performance of the 2 D.O.F. model

Stiffness ratio	Contraction method	Pattern A	Pattern C
Constant	Strict contraction	1/23	1/24
	Convenient contraction	1/21	1/28
Increasing	Strict contraction	1/22	1/23
	Convenient contraction	1/21	1/27
Decreasing	Strict contraction	1/24	1/25
	Convenient contraction	1/21	1/29

angles calculated by the convenient contraction become smaller than the angles calculated by the strict contraction.

4. Effect of the contraction in 3 D.O.F. model

4.1 Relation between eigenvalue and stiffness ratio

In this section, it is studied on the effect of the convenient contraction to the seismic performance evaluation of multi D.O.F. model. To clarify the effect of the increment of the degree of freedom of the model, a 3 D.O.F. model is used.

In order to compare the results of the 3 D.O.F. model with the results of the previous 2

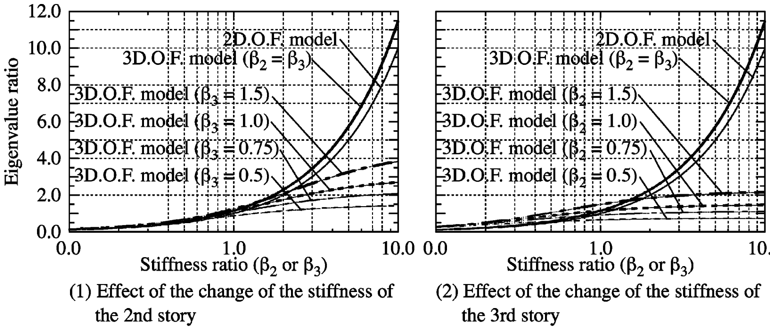

Fig. 4.1 Relation between the eigenvalue ratio F_i and the stiffness ratio β_i

D.O.F. model, the eigenvalue ratio F_i is defined. In the following, F_2 means the eigenvalue ratio of a 2 D.O.F. model, and F_3 means the eigenvalue ratio of a 3 D.O.F. model : F_2 is the ratio of the eigenvalue of the second story to the eigenvalue of the first story, and F_3 is the ratio of the first eigenvalue of the upper two stories to the eigenvalue of the first story. The eigenvalue ratio of a 3 D.O.F. model is defined as the ratio of the first eigenvalue of the upper two stories to the eigenvalue of the first story. Here, the eigenvalue of the upper two stories is calculated by the Static Reduction Method that was shown in Fig. 2.3.

The ratio F_2 and the ratio F_3 are described by Eq. (4.1) and Eq. (4.2) respectively, where β_2 is the stiffness ratio defined in Fig. 2.2.

$$F_2=\frac{\omega_2^2}{\omega_1^2}=\beta_2 \tag{4.1}$$

$$F_3=\frac{{}_U\omega_1^2}{{}_L\omega_1^2}=\frac{3}{2}\left(2\beta_3+\beta_2-\sqrt{4\beta_3^2+\beta_2^2}\right) \tag{4.2}$$

Fig. 4.1 shows the relation between the eigenvalue ratio F_i and the stiffness ratio β_i. From the figure, it is clear that the eigenvalue ratio F_3 increases with increasing β_i, and that thevariation of the eigenvalue ratio F_3 is similar to the variation of F_2.

On the other hand, when the stiffness ratio of the second story β_2 is not equal to the stiffness ratio of the third story, the variation of the 3 D.O.F. model becomes different from the variation of the 2 D.O.F. model. From this result, it is estimated that the convenient contraction affects to the result of the seismic performance evaluation.

4.2 Effect of the contraction in the initial stiffness

The deformation mode of a 3 D.O.F. model is calculated from the first natural mode by Eq. (2.7). This procedure is the same as the procedure of a 2 D.O.F. model. Then the contraction method, even if it is the convenient contraction, does not affect to the evaluation of seismic performance on the initial stiffness.

4.3　Effect of the contraction in the rigidity deteriorating process

In this section, in order to clarify the effect of the contraction to the 3 D.O.F. model that the rigidity was deteriorated, an examination will be performed with the parameters β_2 and β_3; the stiffness ratio β_2 of the second story takes values 0.50, 0.75, 1.00 and 1.50, the stiffness ratio β_3 of the third story takes values 0.50, 0.75, 1.00 and 1.50, and the mass ratios of the second story and the third story are set to 1.00.

Fig. 4.2 shows the first natural modes that were calculated in each case of the combination of the stiffness ratio β_2 and β_3. The figures from Fig. 4.3 to Fig. 4.5 show the effect of the rigidity deterioration. Each figure shows the first eigenvalue, the acceleration response and the displacement response, respectively.

From Fig. 4.3, the effect of the convenient contraction is summarized as follows. When the stiffness ratio of the second story is 0.50, the error ratio of the first eigenvalue is less or equal to almost −42% for all stiffness ratio β_3. In the case β_2 is 0.75, the error ratio is almost in the range from −10% to −25%, for all β_3. In the case β_2 is 1.00 or 1.50, the error ratio for $\beta_3=0.50$ is almost in the range from 0% to 5%, and the error ratio on the other β_3 exceeds almost 10%. From the above, it is clear that the combination of β_2 and β_3 causes similar effect to the natural period.

From Fig. 4.4, the effect on the acceleration response is summarized as follows. When the stiffness ratio β_2 is 0.50, the error ratio is less or equal to about −20%, for all β_3. In the case β_2 is 0.75, the error ratio is almost in the range from −% to −13%, for all β_3. In the case β_2 is 1.00 or 1.50, the error ratio for $\beta_2=0.50$ is almost in the range from −4 % to 0%, and the error ratio for the other β_3 becomes greater or equal than almost 5%.

From Fig. 4.5, it is clear that the effect on the displacement response shows similar

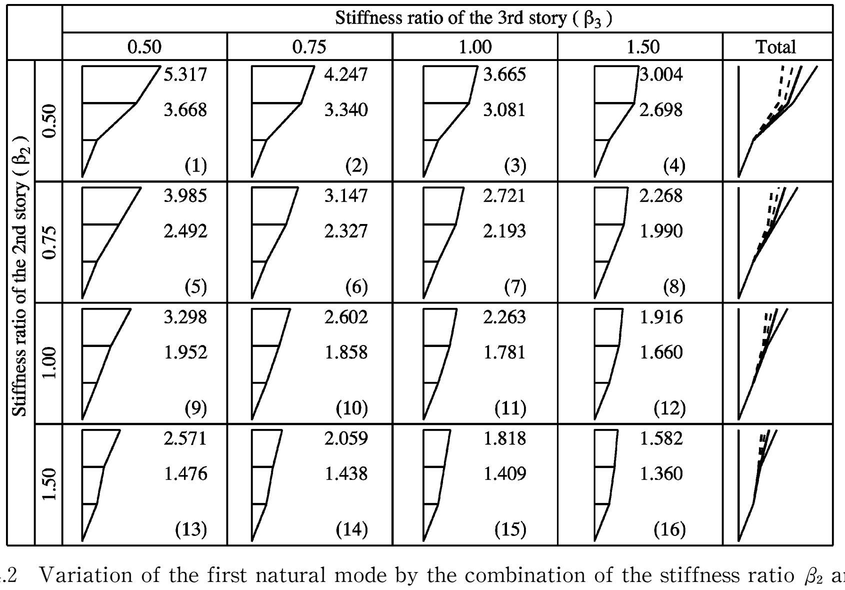

Fig. 4.2　Variation of the first natural mode by the combination of the stiffness ratio β_2 and β_3

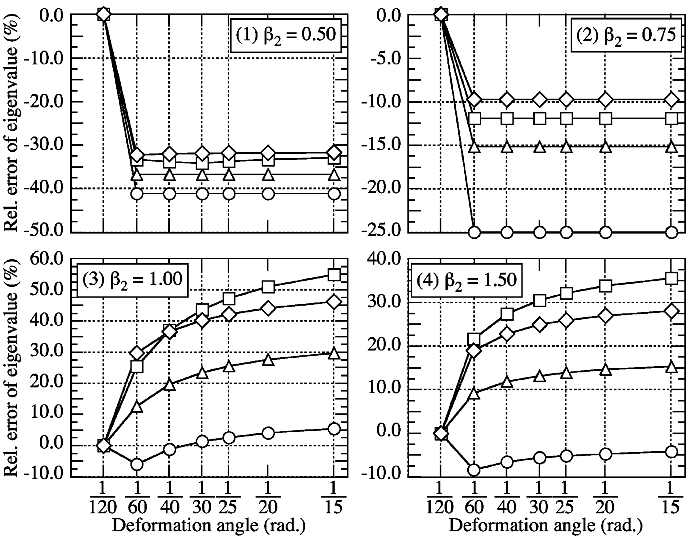

Fig. 4.3 Variation of eigenvalue by the rigidity deterioration (β_2 and β_3 are the stiffness ratios defined in Fig. 2.2. Symbols ○, □, △ and ◇ means the value of β_3 is 0.50, 0.75, 1.00, and 1.50, respectively.)

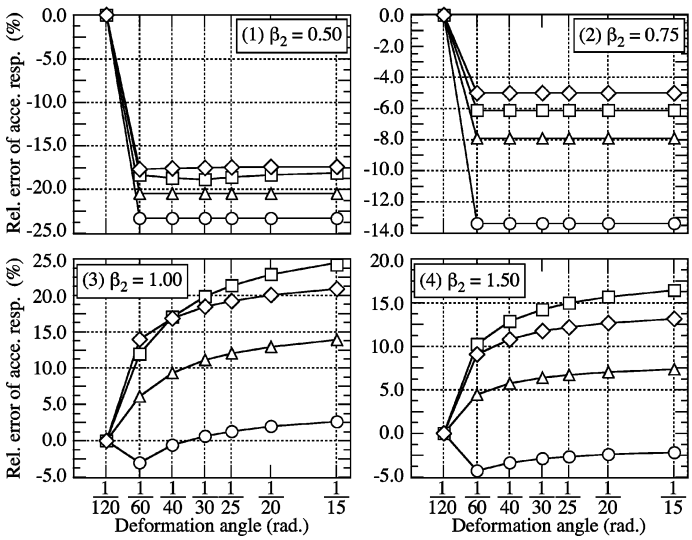

Fig. 4.4 Variation of acceleration response by the rigidity deterioration (The meanings of β_2 and β_3 is the same as Fig. 4.3.)

tendency to the acceleration response in the combination of the stiffness ratio β_2 and β_3.

From the above results on the 3 D.O.F. model, it was clarified that there are many combinations of the stiffness ratio β_2 and β_3 where the error ratio exceeds 10%. And in all case, the error of the 3 D.O.F. model exceeds the error of the 2 D.O.F. model. And in all case,

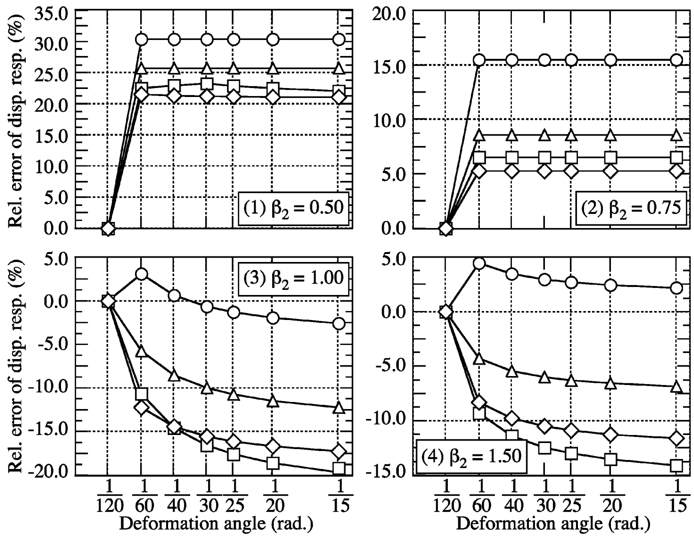

Fig. 4.5 Variation of displacement response by the reduction of rigidity deterioration (The meanings of β_2 and β_3 is the same as Fig. 4.3.)

the error of the 3 D.O.F. model exceeds the error of the 2 D.O.F. model. In the 3 D.O.F. model, the deformation mode pattern that increases error of the 2 D.O.F. model, namely the pattern A and C, are corresponds to the combination of the stiffness ratio $\beta_2=\beta_3=0.50$, 1.00, 1.50. The combinations of stiffness ratio $\beta_2=\beta_3=0.50$, 1.00 and 1.50 correspond to the pattern A or C, too. In these cases, the error of the 3 D.O.F. model exceeds the error of the 2 D.O.F. model. However, in the case where the stiffness ratio $\beta_3=0.75$, the case corresponds to the pattern B that decreases error on the 2 D.O.F. model, then the error decreases in the 3 D.O.F. model.

From these results, it was confirmed that the variation of the error of the 3 D.O.F. model is similar to the variation of the 2 D.O.F. model.

4.4 Effect of the contraction to the seismic performance evaluation

To clarify the effect of the contraction on the 3 D.O.F. model, the seismic performance is evaluated on the following conditions: the natural period of the first story is longer than 0.64 s, the ground is category I, earthquake zone factor Z is 1.0, the height of each story is 2.5 m, the mass ratios β_2 and β_3 are 1.00, and the stiffness ratios β_2 and β_3 take values 0.50, 0.75, 1.00 and 1.50.

The figures from Fig. 4.6 to Fig. 4.9 indicate the response deformation angle in the case of $\beta_2=0.50$, 0.75, 1.00 and 1.50, respectively. Table 4.1 is a summary of the results. In the case β_2 is 0.50 (Fig. 4.6), the response deformation angle calculated by the deformation mode is 1/27 rad., and the angle calculated by the strict contraction is 1/23 rad.. In the other case of β_3, the deformation angle calculated by the covenient contraction is 1/24 rad., and the angle calculated by the strict contraction is 1/22 rad.. Then it is clear that the later case gives poor

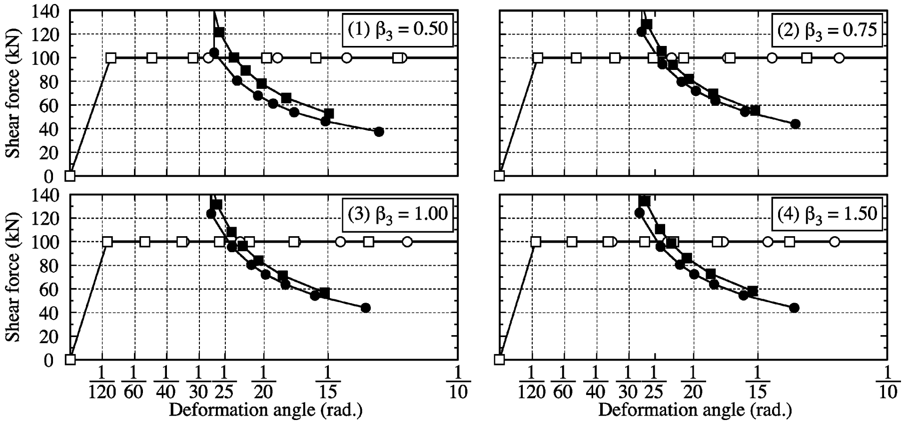

Fig. 4.6 Response deformation angles of the 3 D.O.F. model of the case of $\beta_3=0.5$ (The meanings of the symbols are the same as the symbols of Fig. 3.9)

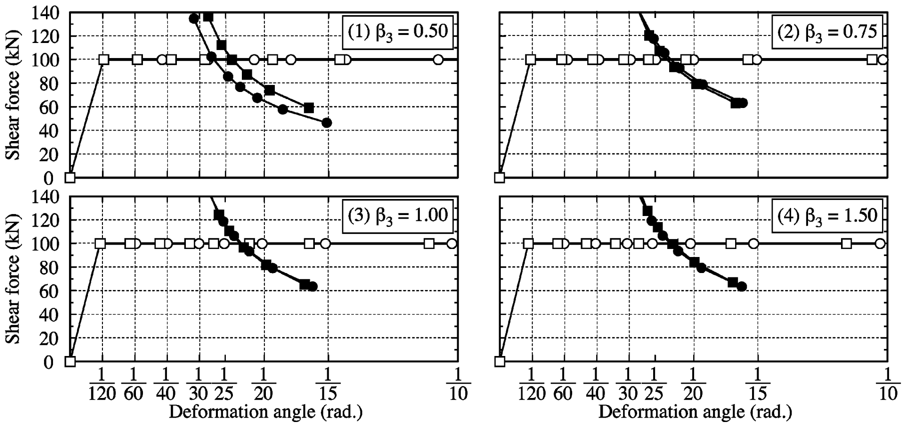

Fig. 4.7 Response deformation angles of the 3 D.O.F. model of the case of $\beta_3=0.75$ (The meanings of the symbols are the same as the symbols of Fig. 3.9)

result on the seismic performance. In the combinations of β_2 and β_3, for example, 0.75 and 0.50 (Fig. 4.7), 1.00 and 0.50 (Fig. 4.8), 1.50 and 0.50 (Fig. 4.9), the response deformation angle calculated by the convenient contraction is small than the angle calculated by the strict contraction.

From the parameter study, in the combination of the stiffness that ratio β_2 or β_3 have the value 0.50, it was clarified that the use of the convenient contraction gives lower seismic performance than the case of the 2 D.O.F. model.

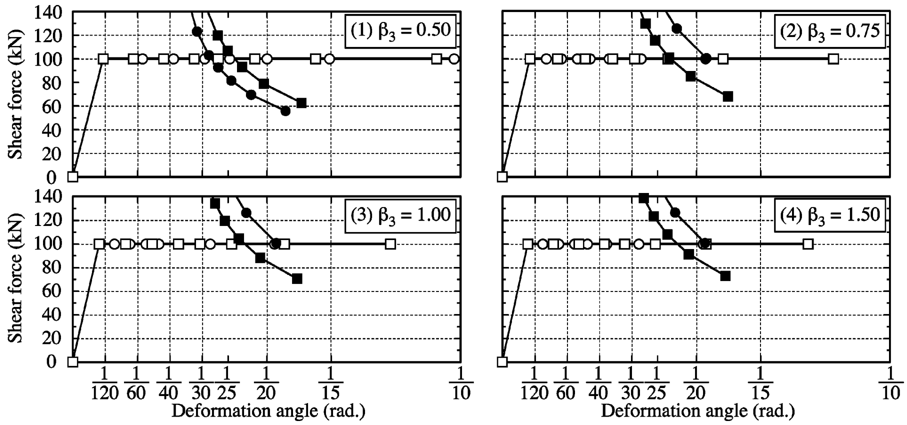

Fig. 4.8 Response deformation angles of the 3 D.O.F. model of the case of $\beta_3=1.0$ (The meanings of the symbols are the same as the symbols of Fig. 3.9)

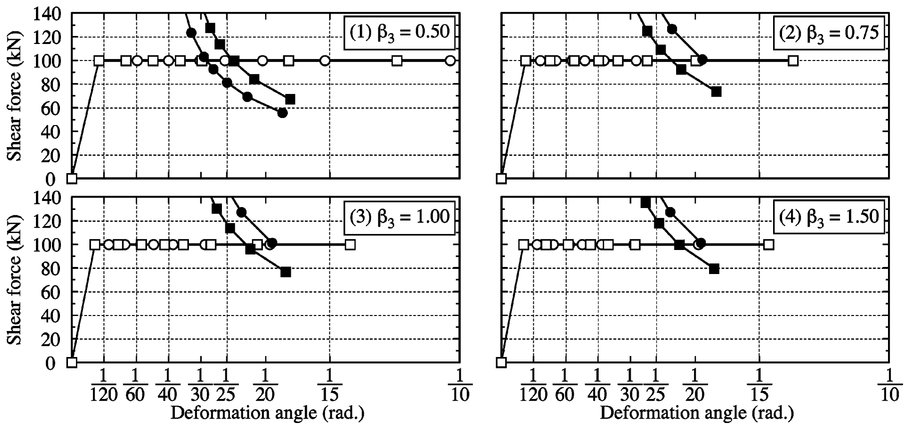

Fig. 4.9 Response deformation angles of the 3 D.O.F. model of the case of $\beta_3=1.5$ (The meanings of the symbols are the same as the symbols of Fig. 3.9)

5. Conclusions

In the study, it was examined on the effect that will be caused by of the use of the deformation mode instead of the accurate natural mode in the Limit Proof Calculation Method for Wooden Structure.

From the analytical study by a 2 D.O.F. model on the contraction that uses the deformation mode, the following became clear : the deformation modes vary by combination of the stiffness and the mass, and the variation pattern of the deformation mode is classified to three patterns. From the numerical study by a 2 D.O.F. model on the variation pattern of the deformation mode, the following became clear : two of the patterns increases the error of the seismic

Table 4.1 Summary of the seismic performance of the 3 D.O.F. model
(β_2 and β_3 are the stiffness ratios defined in Fig. 2.2)

β_2	β_3	Convenient contraction	Strict contraction
0.50	0.50	1/26	1/24
	0.75	1/24	1/23
	1.00	1/24	1/23
	1.50	1/24	1/23
0.75	0.50	1/28	1/24
	0.75	1/23	1/23
	1.00	1/22	1/22
	1.50	1/22	1/22
1.00	0.50	1/28	1/24
	0.75	1/19	1/23
	1.00	1/19	1/23
	1.50	1/19	1/22
1.50	0.50	1/29	1/24
	0.75	1/19	1/23
	1.00	1/19	1/22
	1.50	1/19	1/22

performance evaluation and the other pattern decreases the seismic performance evaluation. Furthermore, from the numerical examination by a 3 D.O.F. model, it was found that the error of the seismic performance evaluation of the 3 D.O.F. model becomes larger than the error of the 2 D.O.F. model.

From the above, in the use of the Limit Proof Calculation for Wooden Structure, the mechanical properties, namely the stiffness and the mass, of the structures should be examined carefully because there are cases that increase the error of the seismic performance evaluation.

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