Seismic Performance Evaluation of Temple Traditional Building Reinforced by Restoring Force due to Column Rocking

Tatsuru Suda
Kanazawa institute of Technology, Japan

Yoshiyuki Suzuki and Kyosuke Mukaibo
Ritsumeikan University, Japan

Yasuhiko Tasiro
Nikken Sekkei LTD., Japan

SUMMARY
As a seismic reinforcement method for tradition wooden buildings such as temples, an improvement method of restoring force due to column rocking by making a cross-section of column bottom larger is presented. To verify the effect of the seismic reinforcement, static tests and shaking table tests using a full-scale model were carried out. It is found that the restoring force due to column rocking is improved especially for large deformation by comparison with that of unreinforced wooden frame. It is then confirmed that the traditional wooden frame has high performances of deformability and restoring force by the seismic reinforcement. The restoring force characteristics for a seismic design are examined from the static tests. The application of the presented reinforcement method is attempted to the reinforcement design of an existing temple in Kyoto. The seismic performance of the temple is estimated by a seismic response analysis, and it is confirmed that the reinforcement method is effective in the seismic reinforcement for traditional wooden buildings with large diameter columns.

Keywords: traditional wooden building, seismic reinforcement, seismic design, restoring force characteristics

1. INSTRUCTION

Many traditional wooden buildings such as temples and shrines exist in Japan. They often do not satisfy the required seismic performance because the traditional wooden structures have heavy roofs and their base shear coefficients are usually low. The seismic reinforcement techniques suited to traditional wooden structures are desired. In this study, as a seismic reinforcement method for a temple tradition wooden building, the method improving restoring force due to column rocking is proposed by increasing a cross-section of column bottom by fitting a reinforcement member up a column bottom.

2. STATIC LATERAL LOADING TESTS

2.1. Specimen of traditional wooden frame

To clarify the restoring force due to column rocking of traditional wooden frame and to verify the effect of the reinforcement method, static lateral loading tests using a full-scale model were conducted. The specimen of traditional wooden frame is shown in Figure 2.1. The specimen consists of four circular columns, floor tie-beams, mid-wall tie-beams, pillow blocks, girders as shown in Figure 2.1. The columns are set on base stones without any connectors. Two precast concrete (PC) panels of total weight 109.6kN were set on the girder as weight equivalent to a roof. The roof weight of specimen is increasing from 109.6kN to 148.9kN and 188.1kN by steel panels.

2.2. Seismic reinforcement method

The reinforcement members are constituted by four wooden parts, and the reinforcement members are fitted up the column bottom of the specimen, as shown Figure 2.2. The component parts of a reinforcement members are shown in Figure 2.3(a) and (b). In the test of first period, as shown in Figure 2.3 (a), the slot cut for steel ring was processed to the reinforcement members. The steel ring was inserted in the slot in order to prevent movement of a reinforcement member. The cross-section size of the column bottom is increasing from 300mm in the diameter to 500mm by this reinforcement method. The reinforcement members were made by the Japanese cypress. Figure 2.3 (b) shows the component parts of improved reinforcement member. In the test of the second period, in order to prevent movement of a reinforcement component, the slot cut for a wooden dowel was processed in the side of the reinforcement members further. In addition, the split tensile of the lower part of a reinforcement member reinforced on the screw. The cross-section size of the column bottom is increasing from 300mm in the diameter to 400mm and 500mm by this reinforcement method. The reinforcement members were made by a Japanese cypress and Afzelia (Zelkova from Africa).

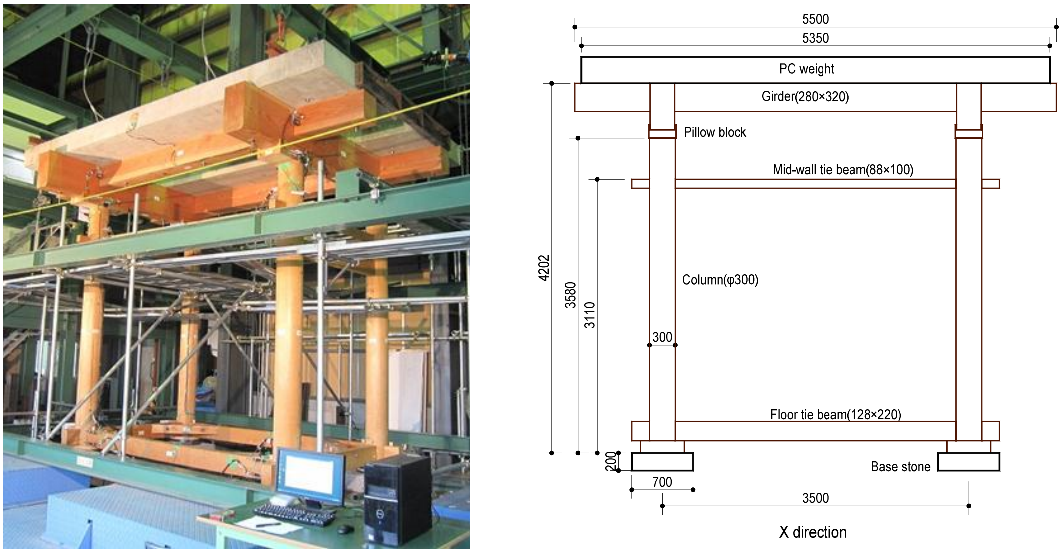


Figure 2.1. Overview and elevation plan of specimen

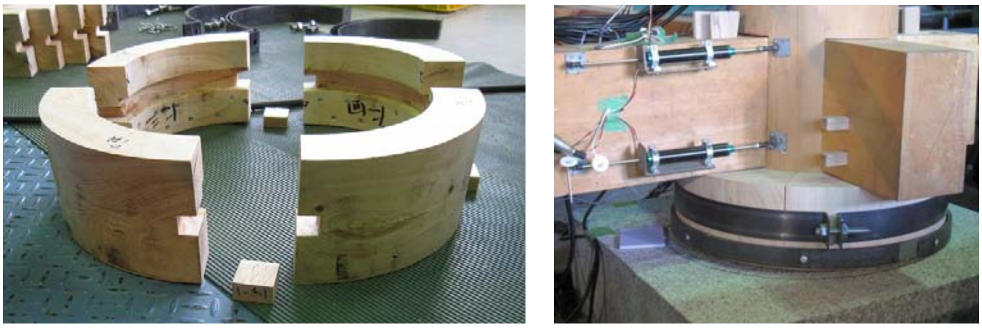
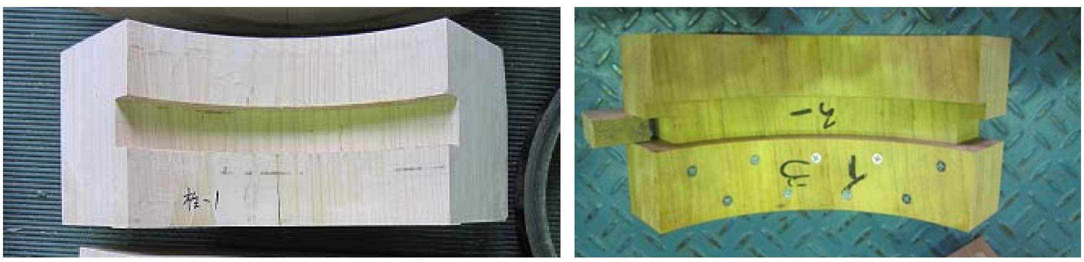


Figure 2.2. Reinforcement members and Situation of reinforced column bottom



(a) Type A (b) Type B

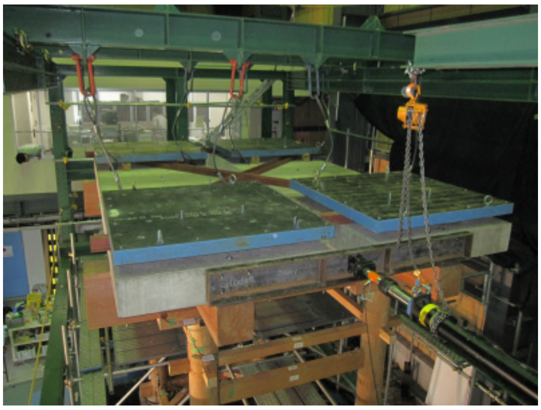
Figure 2.3. Component parts of the reinforcement member

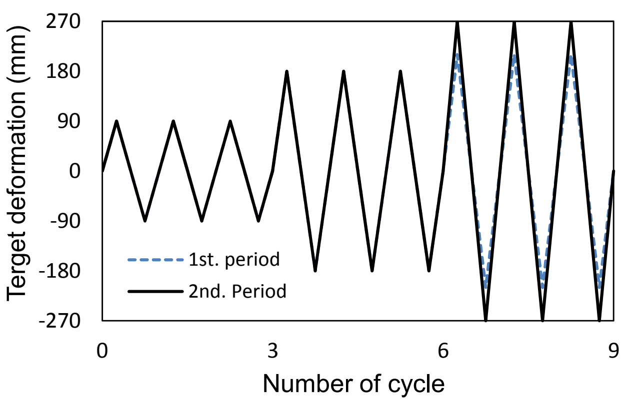
2.3. Parameters and Loading system

The parameter of a specimen and a test is shown in Table 2.1. The testing parameters were the weight of dead load, the cross-section size of column bottom, the wooden material of reinforcement members, and the processing method of reinforcement members. The symbol of a specimen indicates the weight of dead load, the wooden material, the cross-section size of column bottom, and type of reinforcement member, respectively. The static lateral loading tests were carried out for the specimen. The static horizontal forces were applied at the level of PC panels by using an actuator under displacement control, as shown in Figure 2.4 (a). As a program of static lateral loading test, the loadings are repeated three times until each specified deformation amplitude in both positive and negative directions. In the test of the first period, the displaced target points were programmed at 90 mm, 180 mm, and 210 mm. In the test of the second period, the maximum displaced target point was programmed at 270 mm. The displacement program of a test is shown in Figure 2.4 (b).

Table 2.1. Parameters of static lateral loading test

Specimen	Weight of dead load (kN)	Cross-section size of colum bottom (mm)	Reinforcement member: Wooden material	Reinforcement member: Type
A-H500A	109.6	500	Japaneses cypress	A
B-H500A	148.9	500	Japaneses cypress	A
C-H500A	188.1	500	Japaneses cypress	A
C-N300	188.1	300	Without reinforcement	
A-H400B	109.6	400	Japaneses cypress	B
A-A400B	109.6	400	Afzelia	B
A-H500B	109.6	500	Japaneses cypress	B
A-A500B	109.6	500	Afzelia	B
A-N300	109.6	300	Without reinforcement	


(a) Loading set



(b) Loading program

Figure 2.4. Method of static lateral loading test

2.4. Effects of reinforcement method

The horizontal load of specimen, the relative story displacement, and the bending moment of the tie-beams were obtained from the static lateral loading test. The relation between the whole restoring force and the story deformation is shown in Figure 2.5. The whole restoring force consists mainly the bending moments of tie-beams and the restoring forces due to rocking columns. The bending moments of the two tie-beams were calculated from strains measured on them. The restoring force due to column rocking shown in Figure 2.6 is evaluated by using test data. Figure 2.7 (a) shows the effect of reinforcement of the restoring force due to column rocking by comparison between with and without the reinforcement. It is found that the deformable performance of specimen increases by the reinforcement. And, it is found that the deformable performance of specimen increases as the cross-section size of column increase. However, the maximum restoring force of a specimen is almost the same in all the cases about the test as the parameter of cross-sectional size. The effect of the weight of dead load about a restoring force due to column rocking is shown in Figure 2.7 (b). It is found that the maximum restoring force of specimen increases as the weight of dead load increase. About the effect of the wooden materials, the Afzelia of performance is more effective than the Japanese cypress.

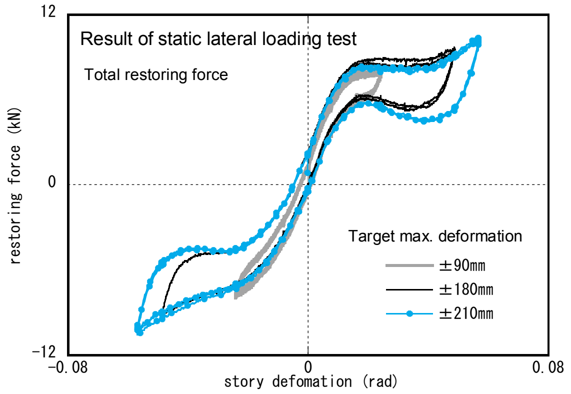


Figure 2.5. Relation between the whole restoring force and the relative story displacement

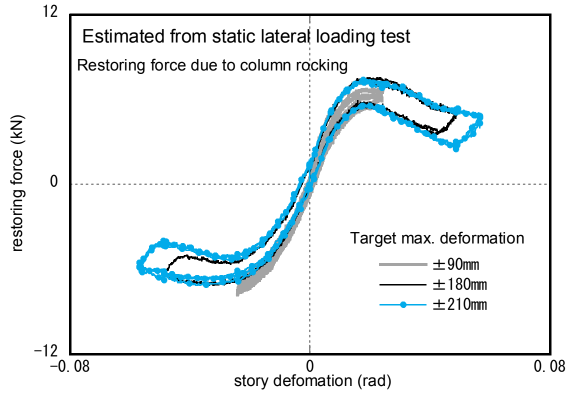
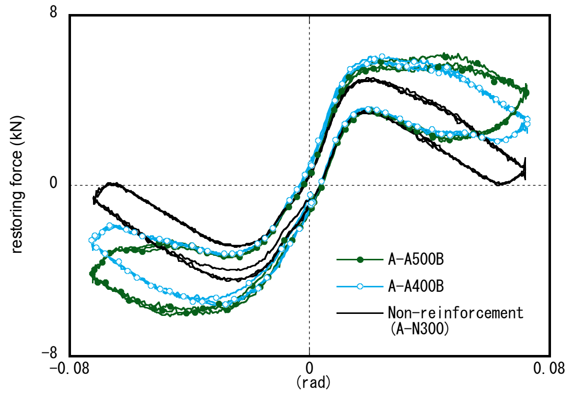
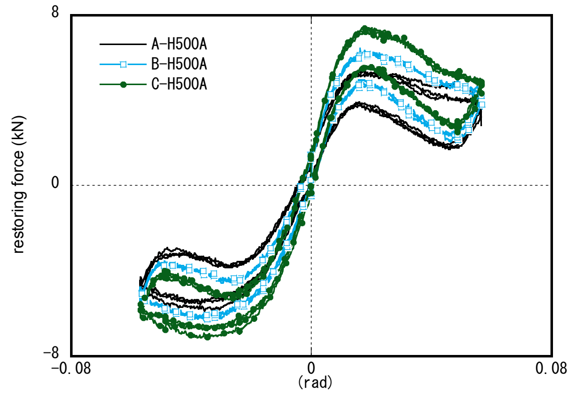


Figure 2.6. Restoring force due to column rocking

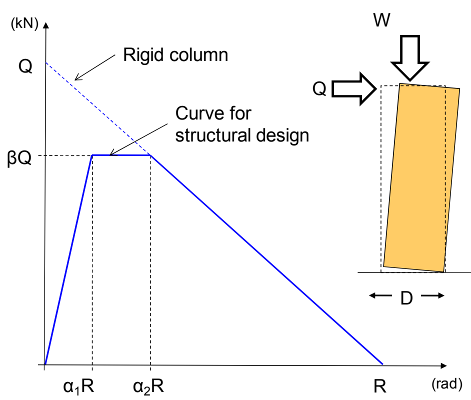


(a) Cross-section size of column bottom

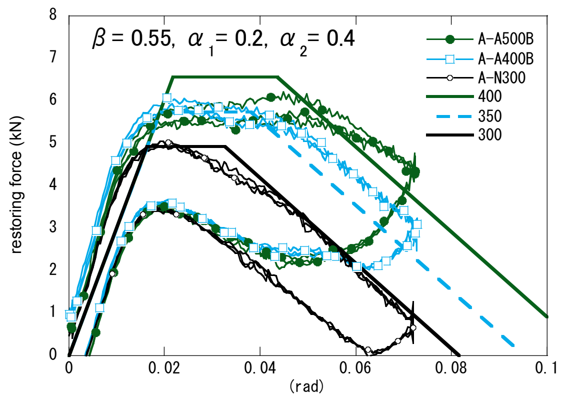


(b) Weight of dead load

Figure 2.7. Effect of parameters about restoring force due to column rocking



(a) Model



(b) Test data

Figure 2.8. Restoring force due to column rocking for seismic design

Here, Q (= W * D / h): restoring forcer, R (= D / h): deformation angle, W: vertical load, h: height of the column, D: diameter of the column.

The characteristics of restoring force due to column rocking have been proposed by some researchers. The characteristics of restoring force due to column rocking based on the past researched results are shown conceptually in Figure 2.8 (a). The curve shown in Figure 2.8 (a) is applied as a characteristic of restoring force due to column rocking for a practical seismic design in Japan, coefficient is $\alpha1$=0.1, $\alpha2$=0.2 and β=0.8. It is thought that the cross-section size of a column effective for a restoring force characteristic is the value which averaged the column top and the column bottom. Therefore, the value which averaged the cross-section size of a column top and the cross-section size of a column bottom is indicated on explanatory note of Figure 2.8 (b). As shown in Figure 2.8 (b), the coefficients $\alpha1$=0.2, $\alpha2$=0.4 and β=0.55 are proposed from the test result of the tradition wooden building using the circular section column at this study.

3. SEISMIC PERFORMANCE EVALUATION

3.1. Amida-do in HigasiHonganji

As an application of the proposed reinforcement method, a seismic reinforcement of a temple building is considered. The building shown in a Figure 3.1 is Amida-do, in HigashiHonganji, built in Kyoto. Amida-do was rebuilt in about 1895 after collapsing by a massive fire. In order to clarify seismic performance of Amida-do, structure investigations were conducted since 2000. The building of Amida-do is typical Japanese traditional wooden structure, and is one story structure, 38.7 m in width, 33.8 m in length, 26.3 m in height as shown in Figures 3.2 and 3.3. The building consists of seventy circular columns, floor tie-beams, mid-wall tie-beams, pillow blocks and girders. The diameter of a column section is from 515 mm to 750 mm, and an average is about 640 mm. The columns are set on base stones without any connectors. The roof is a hip-and-gable roof and is tiled with roofing mud as a bond.

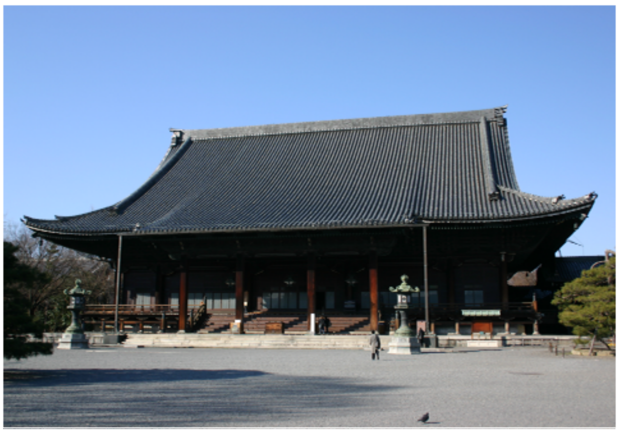


Figure 3.1. Amida-do temple

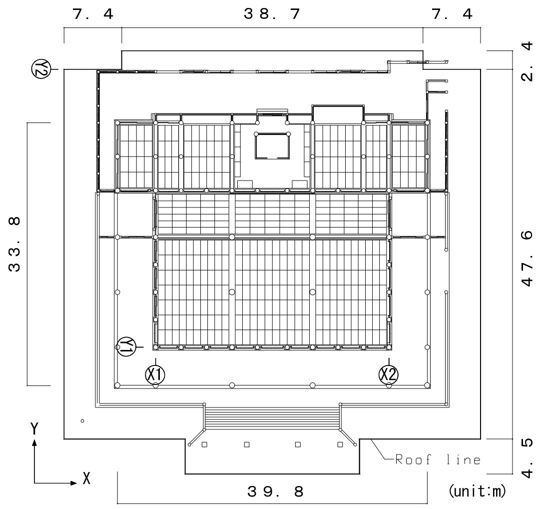


Figure 3.2. Floor plan

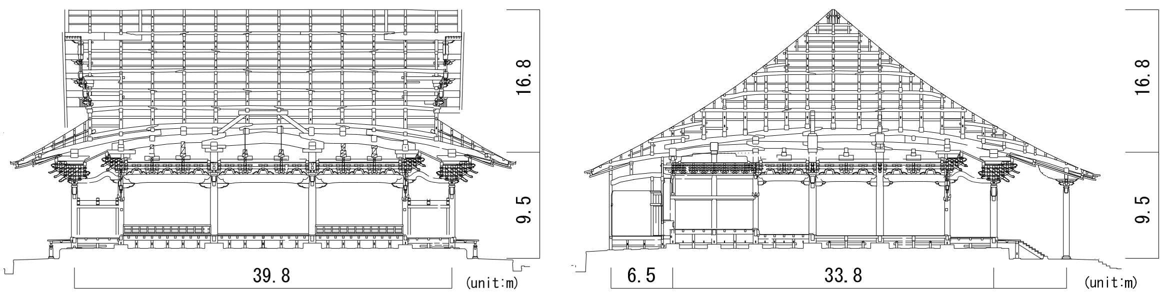


Figure 3.3. Sectional plan (L: X direction, R: Y direction)

3.2. Restoring force characteristics

In order to evaluate the seismic performance of the building, the restoring force characteristics of structure are estimated. The restoring force characteristics as a whole are constituted by the restoring force characteristics of structural elements. Their restoring force characteristics are bending strength of tie-beams, shear strength of mud-plaster walls and shear strength of wooden board walls. The mud-plaster wall is arranged only at the Y2 frame in the rear of building. The wooden board walls are arranged in X1, X2 and Y1 frames as shown in Figure 3.2. The maximum strength of each structural element was estimated according to each specification. The maximum strength of each structural element is shown in Table 3.1. Generally, the deformation angle of a yielding point is about 1/30 rad as for traditional wooden frames. The restoring force characteristic of each structural element is configured as shown in Fig. 3.4. The maximum strength shown in Fig. 3.4 corresponds to the value of Table 3.1.

Table 3.1. Maximum strength of each structural element (kN)

	X	Y
Bending strength of tie-beams	1090	810
Shear strength of mud-plaster walls	390	0
Shear strength of wooden board walls	590	1080
Total	2070	1890

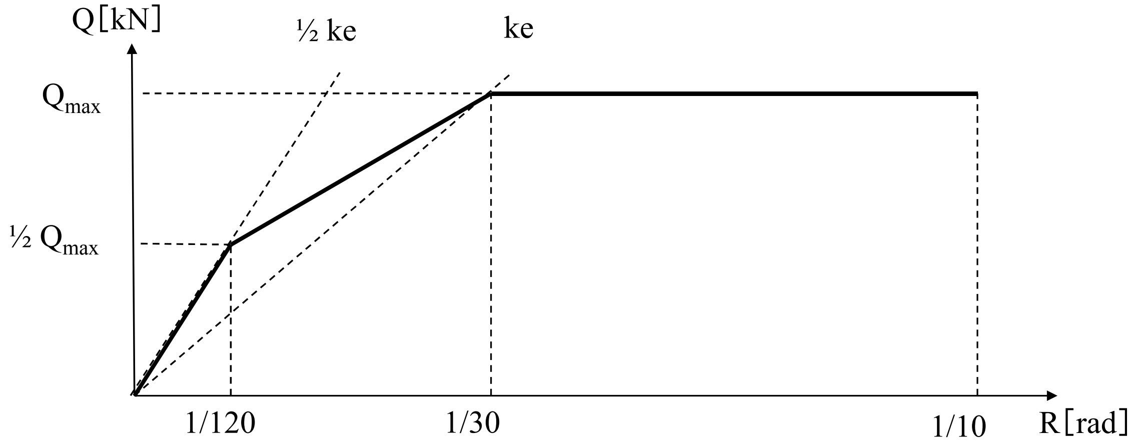


Figure 3.4. Restoring force characteristics of structural element

3.3. Seismic response analysis

The seismic performance of Amida-do evaluated by a response-limit capacity analysis which is an approximate seismic response analysis, is shown in Figure 3.5. In this analysis, acceleration response spectra were used for the cases of Types II in the soil category by the Building Standard Law Enforcement Order. The restoring force of the structure is calculated by summing those of structural elements. The maximum response is approximately obtained at the cross point of two lines. The dead load for seismic design is approximate calculated by summing weights of structural members as show in Table 3.2. As a result of response analysis, the seismic performance of Amida-do is shown in Figure 3.6. Because the maximum response deformation angle is over 1/10 rad, it is point out that the risk of collapse from severe earthquake is high. The seismic performance after the reinforcement by the proposed reinforcement method is shown in Figure 3.7. It is assumed that the bottoms at forty columns are fitted up by reinforcement members. The maximum response deformation angle can be, then, decreased to 1/15 rad. In addition to the proposed reinforcement of restoring force due to column rocking the seismic performance of the building is expected to be better by reinforcing wooden board walls on three sides of the building.

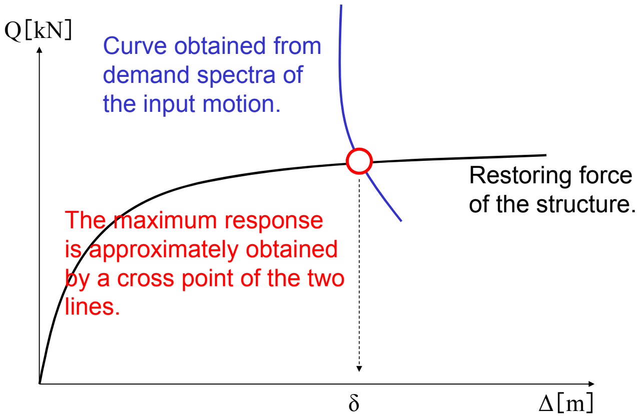


Table 3.2. Weight for seismic design

	Weight	Dead load
Roofing tiles	6430	28800
Roofing mud	5570	
Wooden members	16800	

Figure 3.5. Response-limit capacity analysis

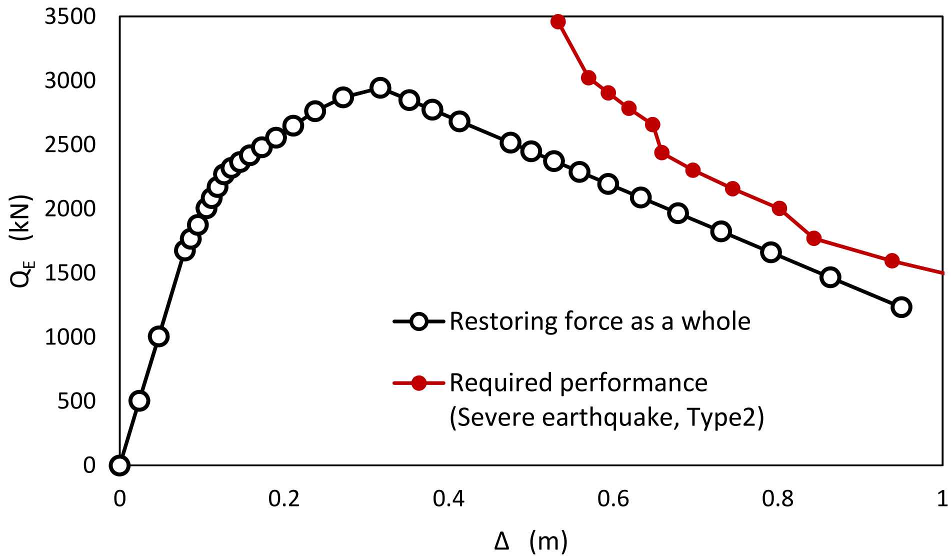


Figure 3.6. Seismic performance of X direction for Amida-do

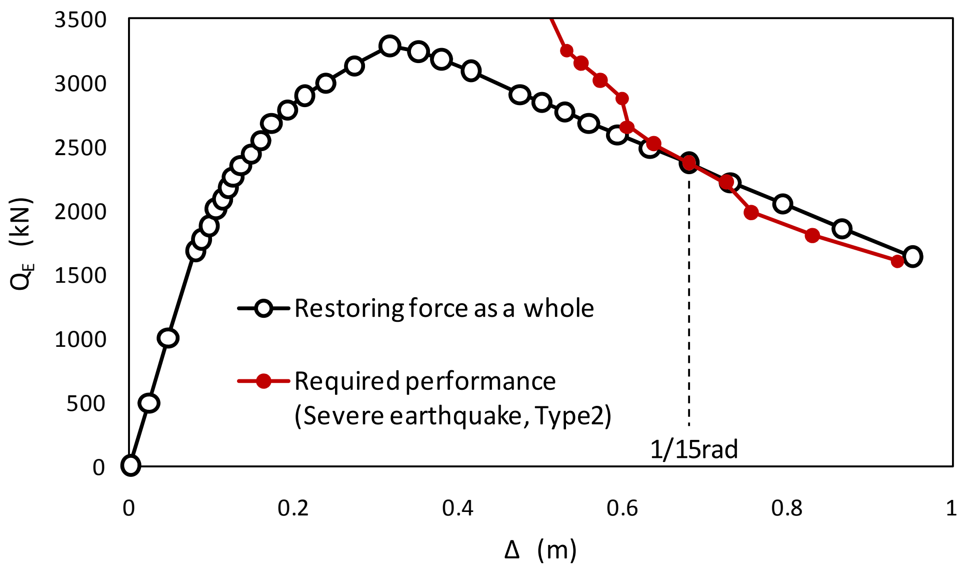


Figure 3.7. Seismic performance of X direction after reinforcement

4. CONCLUTION

As a seismic reinforcement method for traditional wooden buildings, the improvement method of restoring force due to column rocking by making a cross-section of column bottom larger is presented. From the static lateral loading tests using a full-scale specimen of traditional wooden frame, it is found that the restoring forces due to column rocking is improved especially for large deformation by the proposed reinforcement method. It is also confirmed that the reinforced traditional wooden frame has the high performance of deformability as well as the restoring force. The effect of the seismic reinforcement for the temple traditional wooden building in Kyoto is showed analytically. The specification of reinforcement members suitable for the column bottoms is also verified analytically. The proposed reinforcement method is therefore useful as the seismic reinforcement for traditional wooden structures with large diameter columns.

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