Development of Earthquake-proof Fittings of Traditional Wooden Frame Structures

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Abstract

There are many old traditional wooden frame buildings which were specified as cultural heritage or will be specified as Japanese important building in the near future. But there are many buildings which do not have good performance against seismic action. The purpose of the investigation is to develop the earthquake proof fittings, and to apply them to the traditional wooden structures. In concrete terms, the types of the earthquake-proof fittings are the Kamachi door, the acrylic door and the hinged wooden door. Strength and rigidity of the earthquake proof fittings were estimated experimentally, and they were applied to reinforce the two old Buddhist temples.

Key words: traditional wooden building, earthquake-proof fitting, shear diaphragm.

Introduction

There are many Buddhist temples and the shrines which do not have sufficient performance against a big earthquake. According to our investigation (Kataoka and Sakurai 1998) about the temples which were damaged by the Nobi-Earthquake (M8.2) in Gifu prefecture of Japan, a percentage of the damaged temples is 57.1% in 140 total number in Gifu prefecture, and 61.7% in 243 total number in Aichi prefecture. In general, the architectural style of the Buddhist temples has been inherited without change of the style, and they have been repaired without reinforcement for seismic action. So, the serious damages may be caused by a big earthquake in the future. On the other hand, it is very important to maintain the traditional style as it was, and we avoid to change the past traditional style in the recondition. In particular, change of the architectural style of the important cultural assets is prohibited in Japan. The purpose of our investigation is to propose the new earthquake-proof fittings. In concrete terms, they are the Kamachi door (Figure 1), the door that transmits light (Figure 4) and the double leaf door (Figure 8).

Development of the Kamachi Hinged Door and the Kamachi Sliding Door

Some of the fittings which are used in the traditional wooden structures are Kamachi doors (Kataoka and Nakayama 2006). The Kamachi door is a proper word of the Japanese traditional wooden fitting, and it is fabricated from a lot of parts shown Figure 1. As they do not have shear strength and shear stiffness, we developed the new Kamachi door which has shear resistance. A detailed drawing is shown in Figure 2. The earthquake-proof doors can be applied to not only the Kamachi door but also the Japanese shoji doors of the indoor side of the building. The earthquake-proof Kamachi door increases lateral strength and spring radius of the building against torsion. This is for the reason that these earthquake-proof doors are mainly arranged in the outer part of the building. The transfer elements of the shear stress from the frame to the door are the upper stopper and the lower stopper at the Kamachi, the hard hinges and the anchor bolts.

We tried a cyclic load test to obtain the lateral behavior of the earthquake-proof Kamachi door subjected to the seismic action. The specimen is composed of the materials shown in Figure 1 and Figure 2. The anchor bolts are installed in the lower both stiles of the vertical Kamachi. The cyclic load is applied at the top of the specimen under the apparent deformation angle, 1/300rad. 1/200rad.1/150rad. 1/75rad. 1/50rad. The maximum lateral load was recorded when the anchor bolts yielded.

The structural plywood, the Japanese cedar, the wood framework and the resorcinol resin that constitute the earthquake-proof door were stable until a last cycle of the lateral loading. Maximum strength of the wooden shear wall is limited under the 14kN/m in the Japanese standard.. As the maximum strength of the Kamachi door is over 14kN/m, it is estimated as the reliable earthquake-proof structural member. But, we estimated the maximum strength of it as 14kN/m according to the standard.

As the experimental result shows a good performance against the shear force, we tried to use the Kamachi doors to reinforce the structure of the Sairaiji temple in Japan. Figure 2 shows the details of the Kamachi door and the wooden frame structure of the temple.

The Earthquake-proof Acrylic Door

The glass doors are arranged at the periphery of the Buddhist temples and the shrines which need natural light in the room. If some of them have shear resitance, the ability of building to withstand earthquake increases. In general some of them are always shut, they are opened very occasionally. Then, we developed the earthquake- proof acrylic door instead of the glass door, which can transmit the light from outdoor to room (Sirai *et al*. 2010). They are fabricated by using the lattice stainless plate, the Japanese cypresses, the acrylic plates, the adhesives and the tap screws. The specimen of the sliding door and the fundamentals of the structural element are shown in Figure 4. The earthquake-proof acrylic door is not only the fitting but also the structural element. The thin stainless grid plate is resistless against the lateral buckling. But as the Japanese cypresses are rigidly attached by glue to the both surfaces of the stainless plate, the strength and the rigidty of the stainless grid increase. Figure 5 shows the details of the relationship between the earthquake-proof sliding door and the frame. The shear connectors between the door and the door frame are the compressed dowel which is made from the Japan cedar. The acrylic sliding doors are fixed with the stoppers (lateral restraint members) and the locks. We conducted strength tests of the acrylic door subjected to the lateral cyclic load. Figure 6 shows that the relationship between the lateral load and the deflection angle. The lateral behavior is linear, and it is similar to the behavior of the steel structure. The reason why the structural characteristics are similar to the steel structure is that the acrylic door is fabricated with the stainless grid plate, the acrylic plates and the wood grid member. We fixed the points of intersection of the vertical rails and the horizontal rails by using the tap screws to protect a brittle fracture of the resin. As the results, the curve in Figure 3 shows the flexible behavior after yielding.

Earthquake-proof Hinged Wooden Door

There is a wide room behind the main Buddhism room, and the two rooms are partitioned with the wall which is constitutes of the mud wall and the hinged wooden doors (Konuta *et al*. 2010). They can not resist against the big earthquake. That is the reason why the hinged doors do not have the mechanics of the shear diaphragm. In other words, the hinged door can not transfer the shear force from the mud wall to the sill.

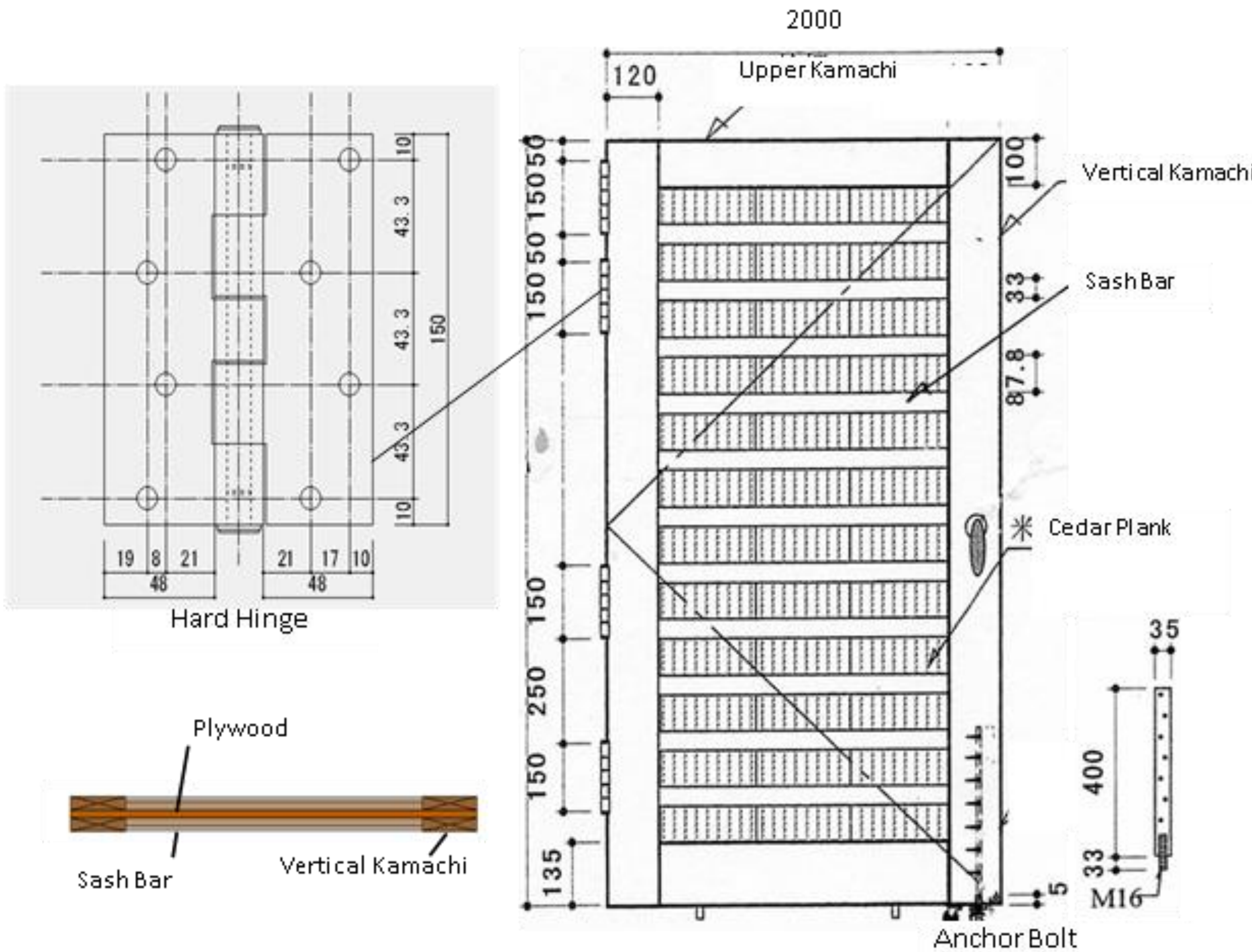


Figure 1. Details of earthquake-proof Kamachi Door.

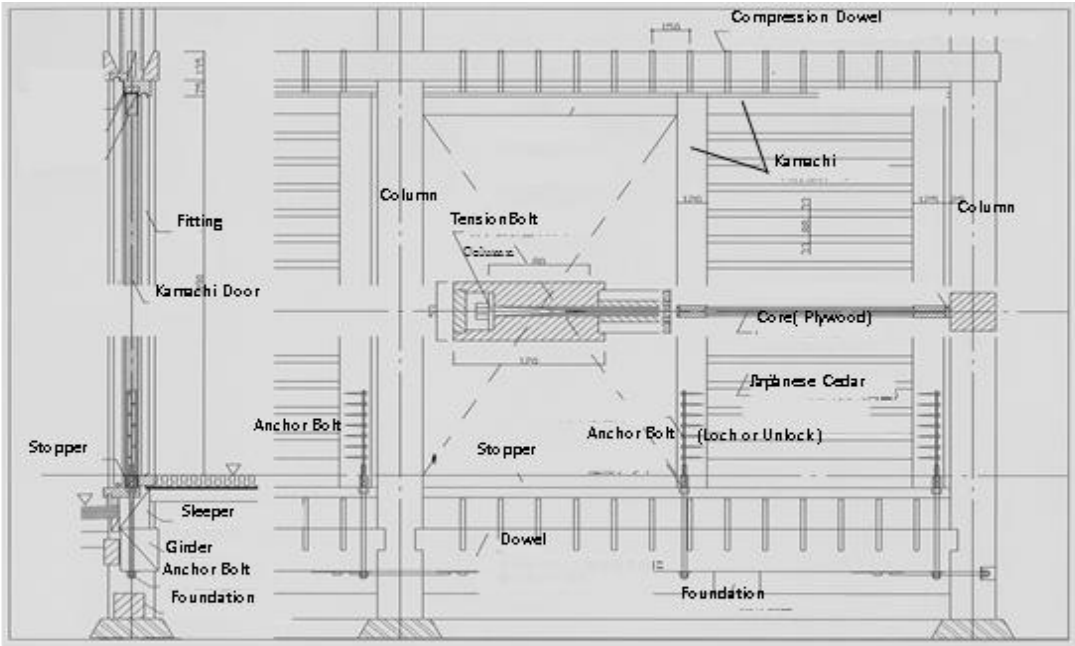
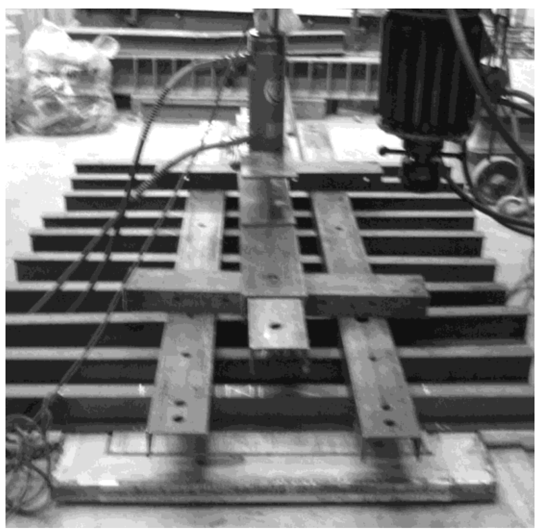


Figure 2. Details drawing of Kamachi Door.



(Adhesion Works)

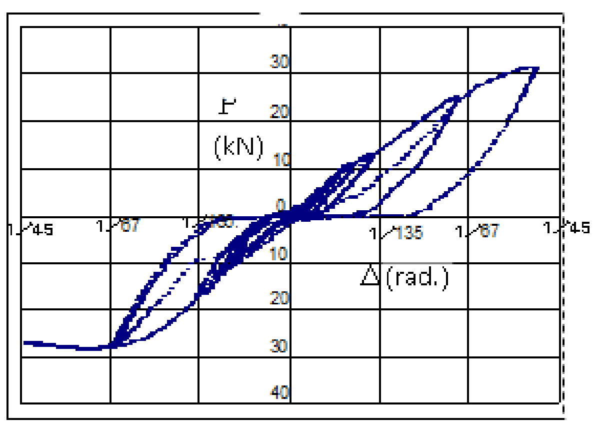


Figure 3. Lateral behavior of Kamachi Door.

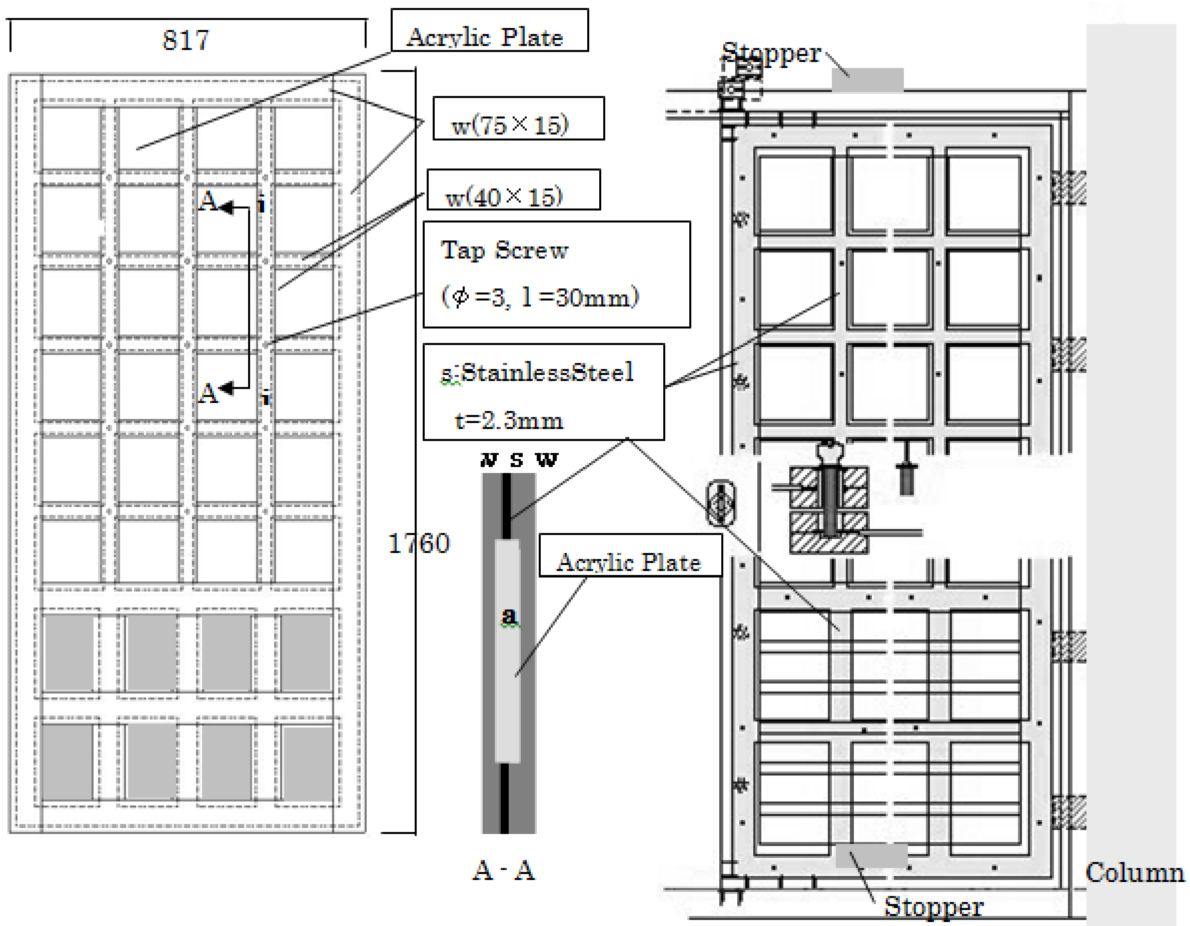


Figure 4. Details of the earthquake-proof Acrylic Door. w:Japanese Cypresses, s: Stainless Steel t=2.3mm, a: Acrylic Plate t=5mm. Elements< Adhesive>: Wood and Stainless Steel<Urethane Resin>, Wood and Acrylic Plate<Resorcinol Resin>, Stainless Steel and Acrylic Plate<Urethane Resin>.

Then, we developed a hinged door which possesses the structural performance. The specimen and the fundamentals of the structural element are shown in Figure 8. Figure 9 and Figure 10 show the lateral behavior of the specimen subjected to the lateral cyclic load. The shear connectors between the door and the door frame are made of the dowel of the compressed Japanese cedar. Figure 9 shows that initial stiffness and strength are very low. That is due to clearance between the door frame and the dowel of the compressed Japan cedar. As the result, the low rigidity means that the door is not effective as the shear diaphragm. Therefore, we improved the constitution of the specimen. We nailed down the door frame and the rails. Figure 10 shows the hysteresis loops of the improved double hinged door.

It shows a good performance as a shear diaphragm. We applied the earthquake-proof hinged door to reinforce the structure of the Buddhist temple in Nagoya of Japan. As the result, the performance of the building against the big earthquake was improved than the original state.

Conclusions

The development of the earthquake-proof Kamachi doors, the acrylic door and the double hinged door reached the stage for practical use. All the materials which were used in the experiments are in the market. The experimental results show the actual situation and the performance of the earthquake-proof fittings. It is evident that the more work (Kataoka et al. 2010) by different approaches is necessary to assure their structural performance, and to lead to the general use.

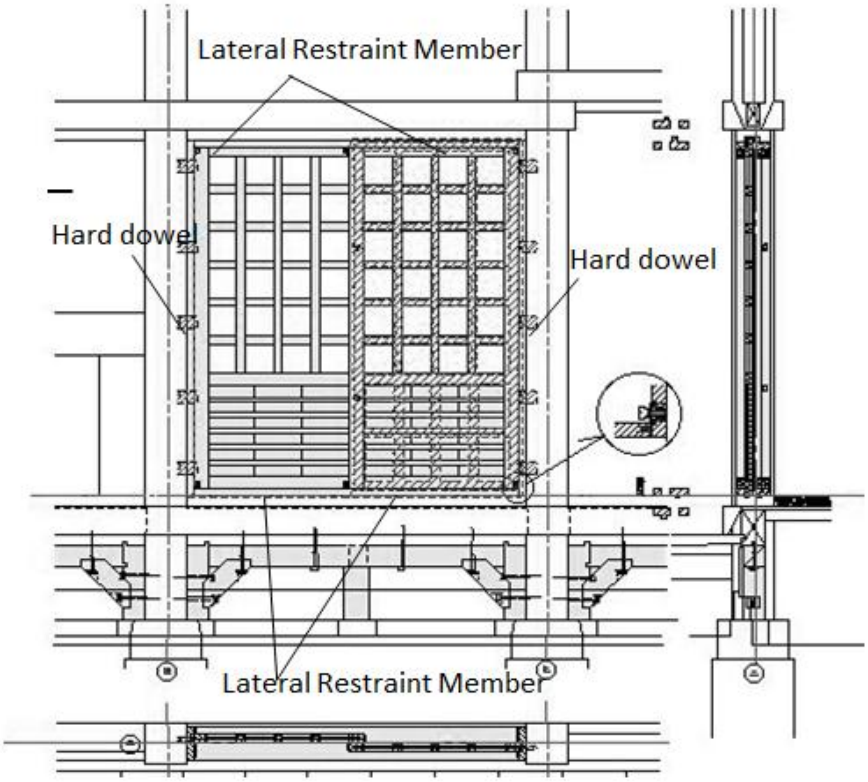


Figure 5. Composition of Acrylic Door and the frame.

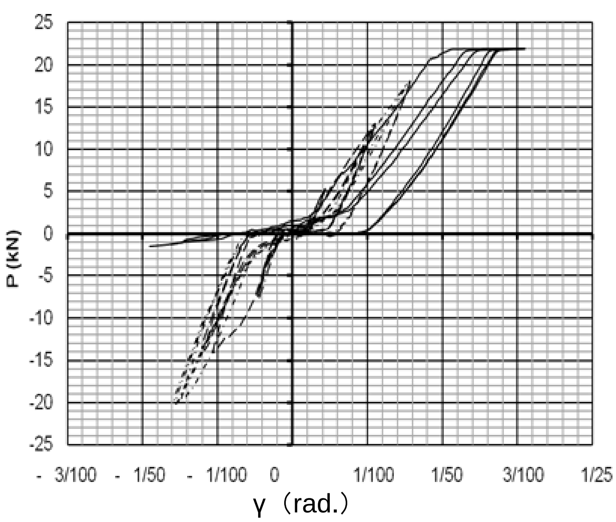
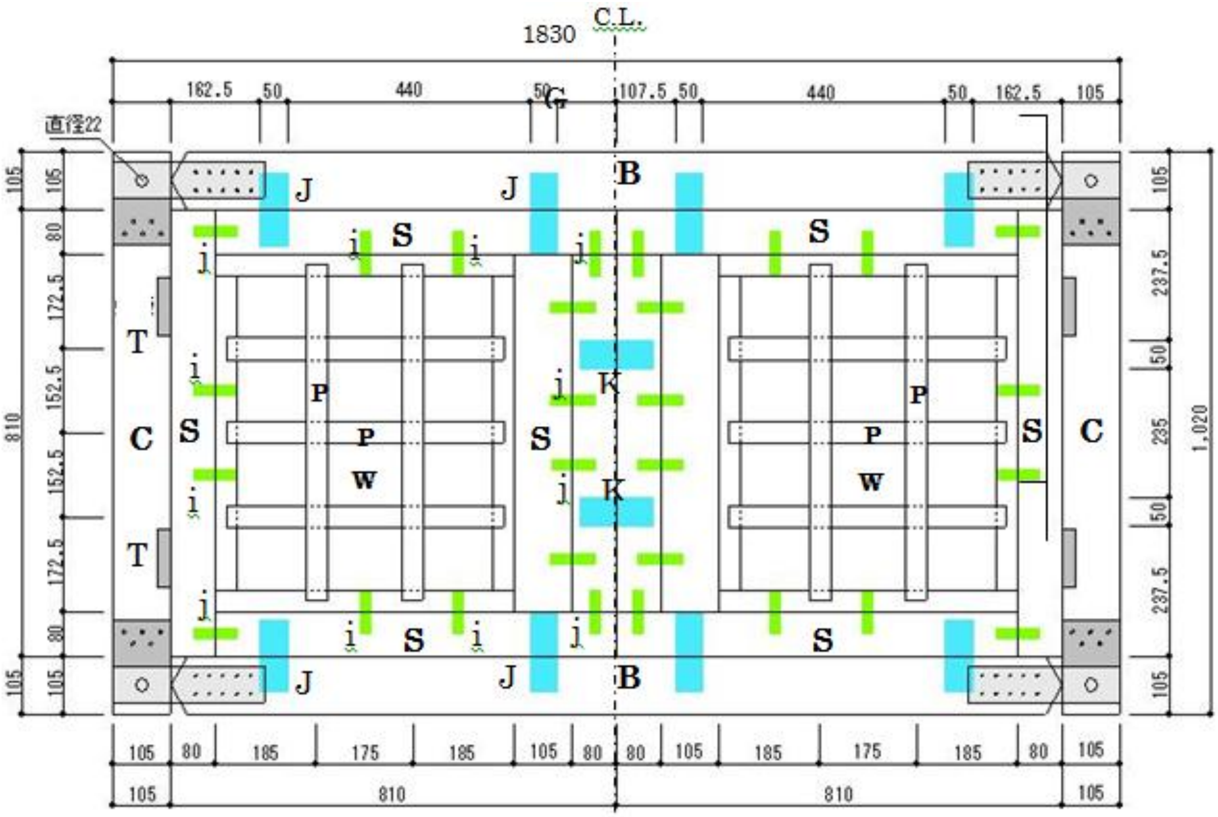


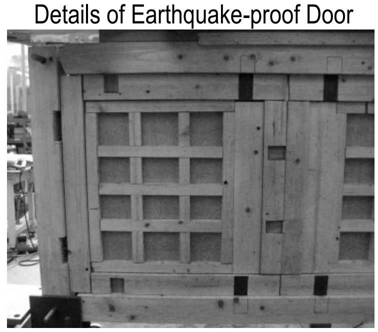
Figure 6. Relationship between lateral loads and deformation angle of Acrylic Door.

Figure 7. Example of the arrangement of Earthquake-proof Door.



Details of Earthquake-proof Door

Mud Wall and Fittings



Earthquake Proof Door

＜COMPONENTS＞
B: Girder (105×105)
C: Column (105×105)
S: Horizontal Kamachi(85×105)
P: Rail (45×45)
W: Plywood (t=9)
J1: Flat Dowel (50×20)
J2: Movable Dowel (50×20)
K: Flat Dowel (50×20)
T: Hard steel Hinge (50×20, t=3)

Figure 8. Details of the Earthquake-proof Hinged Door.

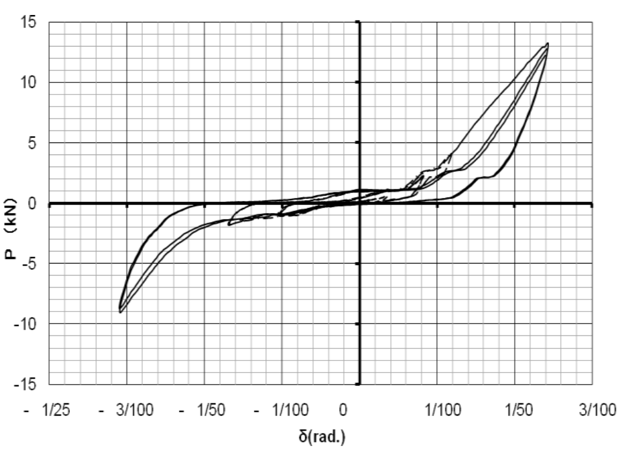


Figure 9. Relationship between lateral Load and deformation angle(Type A).

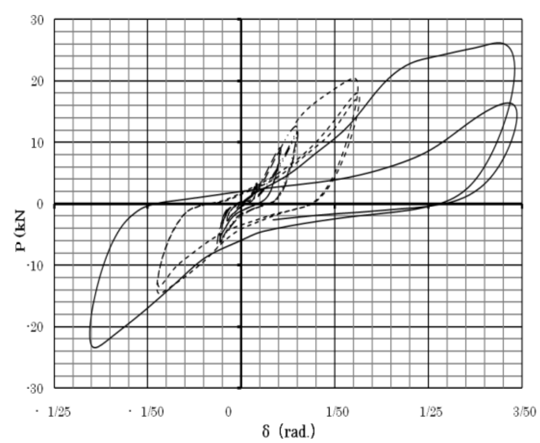


Figure10. Relationship between lateral Loads and deformation angle(Type B).

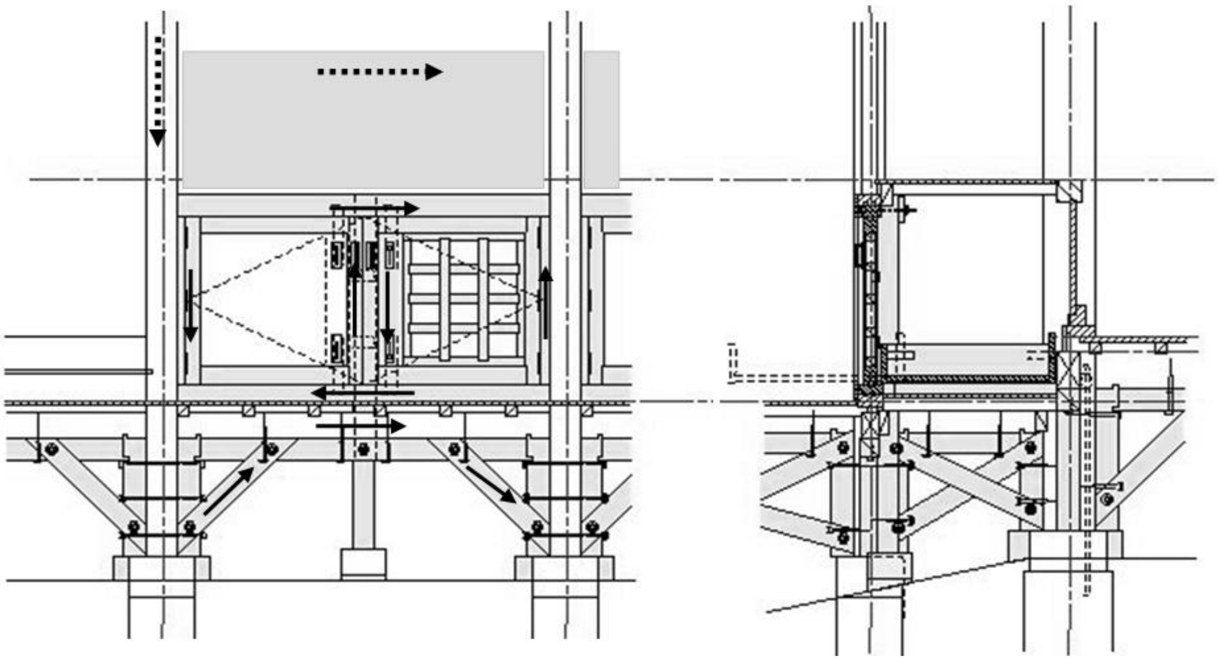


Figure 11. Details of stress transmission from the Hinged Door to the foundation.

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