A study on the effect of wall stiffness on the vibration characteristics of traditional timber frames including *Kumimono*

Iuko TSUWA[1], Mikio KOSHIHARA[2]

ABSTRACT: In this study, shaking table tests with traditional timber frames including *Kumimono* were carried out. In order to clarify how the behavior of the whole frame and *Kumimono* in earthquakes is different by changing the wall stiffness, we used three types of frames with different walls. It is clarified that the modeling method of a frame with the highest wall stiffness differs from one of the other frames. The evaluation method of horizontal load about each frame is discussed.

Key Words: shaking table test, traditional timber frame, *Kumimono,* vibration characteristics

INTRODUCTION

When we build or renovate traditional timber structures such as temples and shrines in Japan, earthquake resistant designed buildings are needed. Therefore the quantitative evaluation of their structural behaviors is indispensable. Experimental and analytical studies about traditional wooden buildings or structural elements in such buildings have increased and the evaluation method of the structure performance about some elements has also proposed. However most of previous studies are carried out individually. Therefore the evaluation method and the vibration characteristics about each structural element in a frame are still not clear sufficiently. Additionally there are few studies about the behavior of traditional wooden buildings in big earthquakes. In this study, shaking table tests were performed with three types of traditional timber frames including bracket complexes called *Kumimono* in Japanese. Each frame had the different wall stiffness. The aim of this research is to clarify the vibration characteristics of the whole frame and elements in each frame against big earthquakes and the effect of wall stiffness on the vibration characteristics of *Kumimono.*

OUTLINE OF EXPERIMENT

Test Specimens

The specimens were the 2/3 scale model of a frame in the *Asuka* style of the five-storied timber pagoda as shown in Figure 1. The span between columns was an outside plane of structure in the first story of the pagoda as shown in Figure 1, in order to clarify the modeling method of the structures consisting of *Nuki*, columns. *Kumimono* modeled the parts of 2 pairs on the central two columns because *Kumimono* in corners is projecting at 45-degree angle in a flat and has complex forms and the aim of this study was to get basic data of each element. A cornerstone was put under each column. They were connected with a dowel. Tree species were yellow cedar.

[1] Graduate student
[2] Associate professor

Three types of specimens were used in the tests as shown in Figure 2. Specimen 1 consisted of columns, *Koshi-nuki*, *Ji-nuki*, *Kumimono*. Specimen 2 was made by adding mud walls between the columns of the Specimen 1. Specimen 3 had plywood walls instead of mud walls. Both walls were put in the both sides.

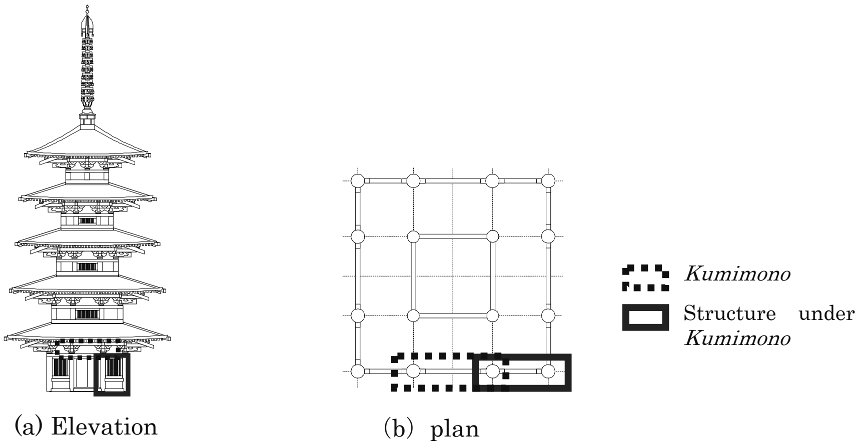

Figure 1. Subject plane of the structure

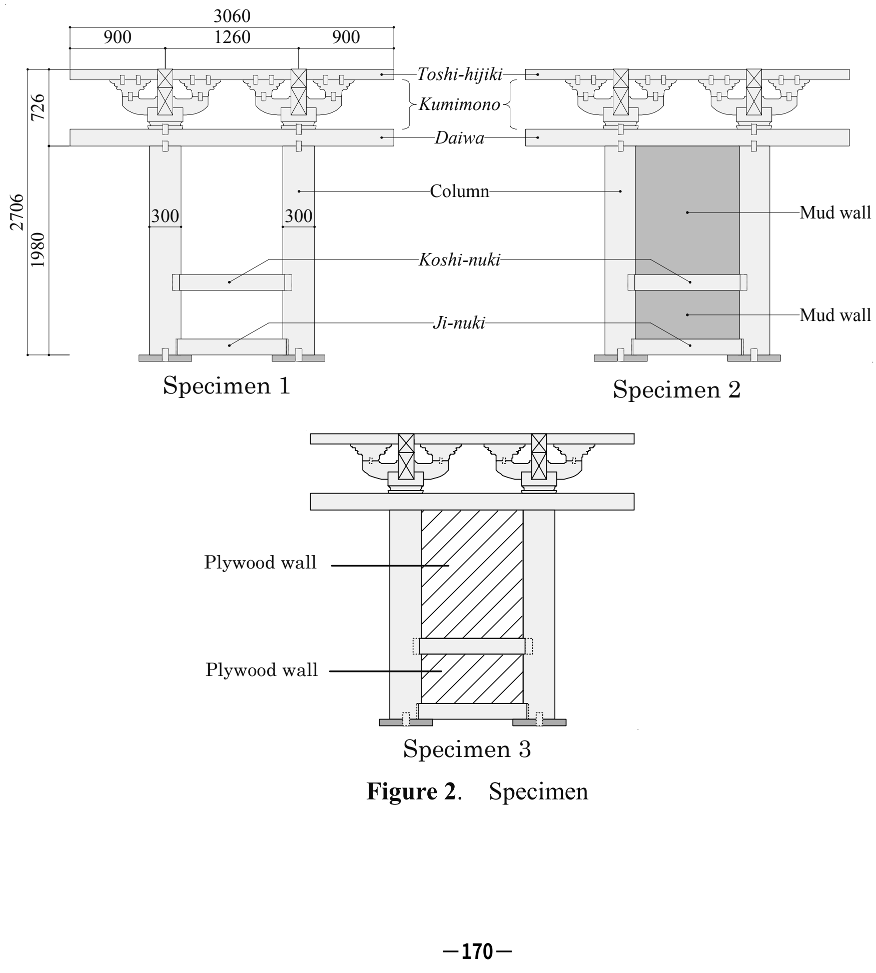

Figure 2. Specimen

Experimental method
The shaking table tests were carried out at the shaking table of *Chiba* Experiment Station in Institute of Industrial Science. Horizontal unidirectional shaking was conducted. Figure 3 shows the experimental method. The vertical load of 39.9kN made of steel frames and lead was put on each specimen. A load cell to measure axial force and shear force was placed under each column. The acceleration, displacement and the strain of specimens were measured using about 75 devices.

BCJ-L2, the level 2 of a simulated wave provided from the building center of Japan, was used as a large input motion. In the tests of Specimen 1, the maximum input acceleration was increased by 10% from 10% to 100%. In the tests of Specimen 2 and 3, one input with BCJ-L2 20% and two inputs with BCJ-L2 100% were carried out.

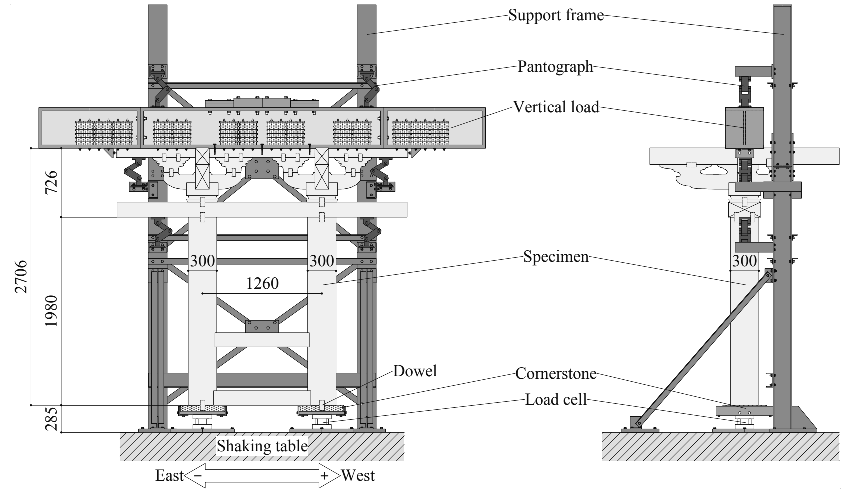

Figure 3. Experimental method

EXPERIMENTAL RESULTS

In a previous paper (Kato et al, 2008), we described the outlines of results from Specimen 1 and 2. In this report, we present the results of Specimen 3 and the comparison of three specimens gotten from the first input of BCJ-L2 100% mainly.

The relationship between load and displacement
Figure 4 shows the relationship between load and displacement from each Specimen. The maximum shear force was 26.4kN at the test of Specimen 3. It was 2.5 times higher than Specimen 1 and 2.0 times higher than Specimen 2. The maximum displacement of the top was 191mm, 1/17rad deformation angle at the height of columns. It was almost same with Specimen 1 and 2. The plywood walls did not collapsed like mud walls. However the shear force came down after about 25mm displacement. The hysteresis curve of Specimen 3 differs from Specimen 1. It can be assumed because the rocking of the whole frame was seen in the test of Specimen 3, however the phenomenon did not appeared in the test of Specimen 1. From the comparison of three specimens, the negative gradient appeared in the deformation from the maximum to the origin point in every specimen.

The relationship between load and displacement of Kumimono
Figure 5 shows the relationship between load and displacement of *Kumimono* for all specimens from

the tests of BCJ L2 100%. The displacement of *Kumimono* was calculated by subtracting that of *Daiwa* and the horizontal displacement occured by the rotation of *Daiwa* from that of *Toshi hijiki*. The horizontal load was the sum of shear forces from the load cel under columns because we assume that *Kumimono* was connected a frame under *Daiwa* with a series spring. The horizontal displacement of *Kumimono* in Specimen 3 was the highest of all specimens. We can see the tendency that the higher the rigid of walls is, the more the horizontal displacement is. However a part of the hysteresis curve from Specimen 3 is different from the hysteresis curve of Specimen 1 and 2. Therefore we need to examine the hysteresis curve of *Kumimono* in conjunction with that of a whole frame.

Characteristics of deformation

Figure 6 shows the characteristics horizontal deformation of each specimen in the range of the maximum amplitude from the test of BCJ-L2 100%. The deformation of *Daiwa* and the top of each specimen were described in order to see how the parts of *Kumimono* and the structure under them behaved. The behavior of the Specimen 3 differed from that of the others. In the test of Specimen 3, the whole frame including *Kumimono* was rocking, but only columns was rocking in the test of the others.

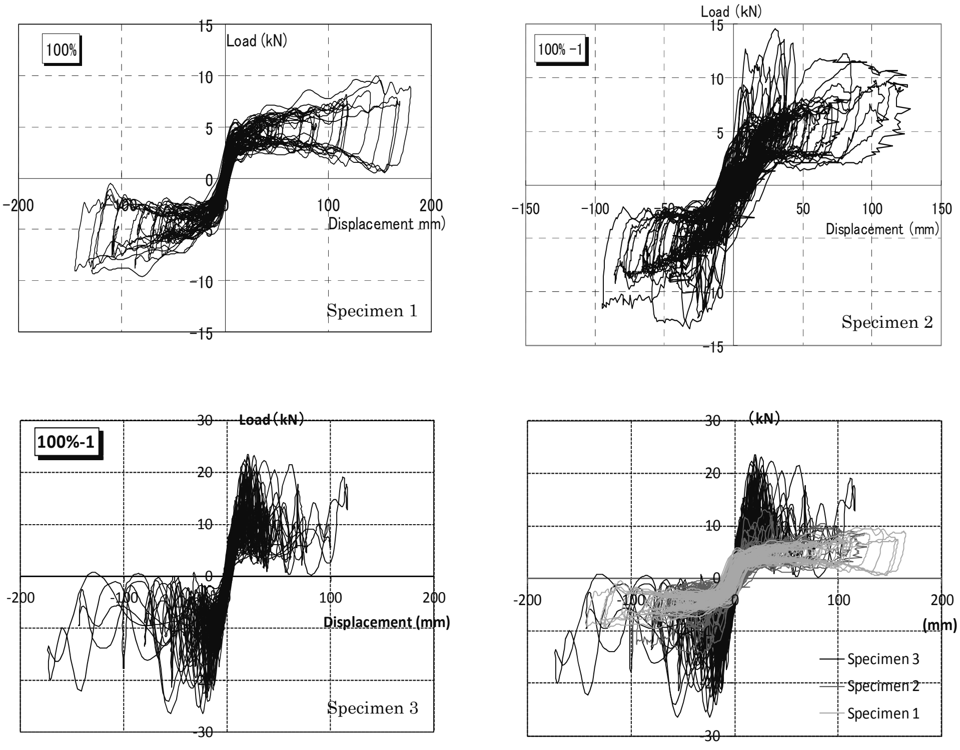

Figure 4. The relationship between load and displacement

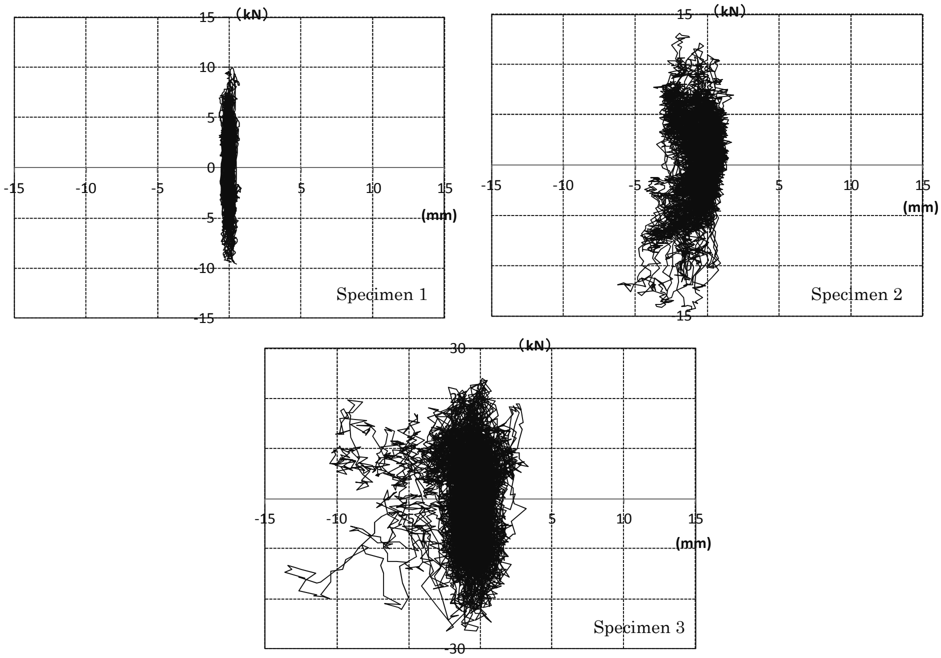

Figure 5. The relationship between load and displacement of *Kumimono*

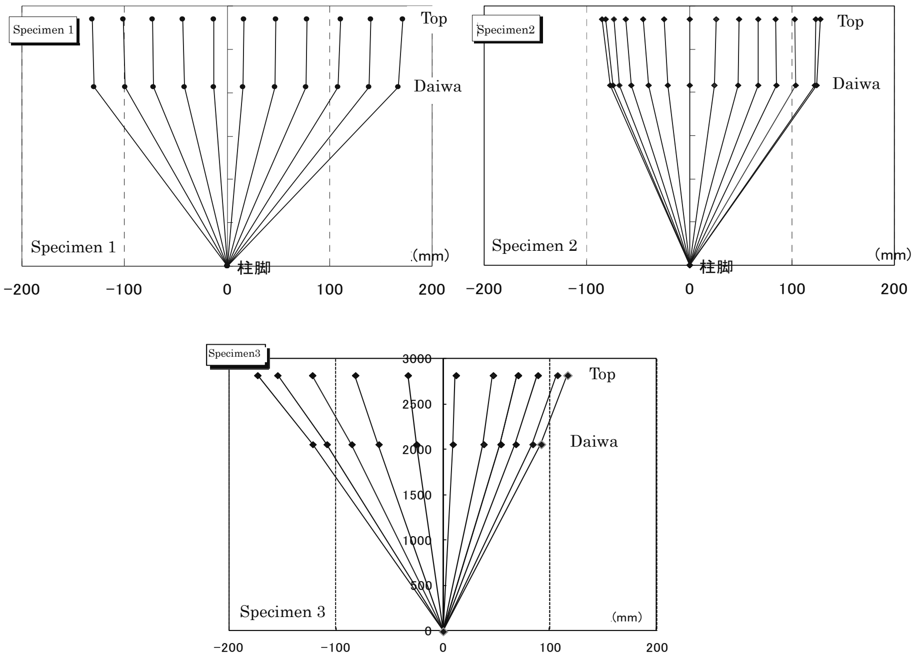

Figure 6. Characteristics of deformation

Bending moment of Column-Koshinuki joint

When columns inclined, the rotation motion occurred at the joints of columns and *Koshinuki*. By the motion, the compressive strains inclined to the grain of members came up and bending moment happened at *Koshinuki*. Figure 7 shows the relationship between the bending moment and rotation angle of a joint of a column and *Koshinuki* from each specimen. The graph shows values from each column-joint. The rotation angle of Specimen 3 was smaller than the other specimens. It can be seen because the rotation at the joints was not occurred like Specimen 1 and 2. It can be assumed from the behavior of the specimen.

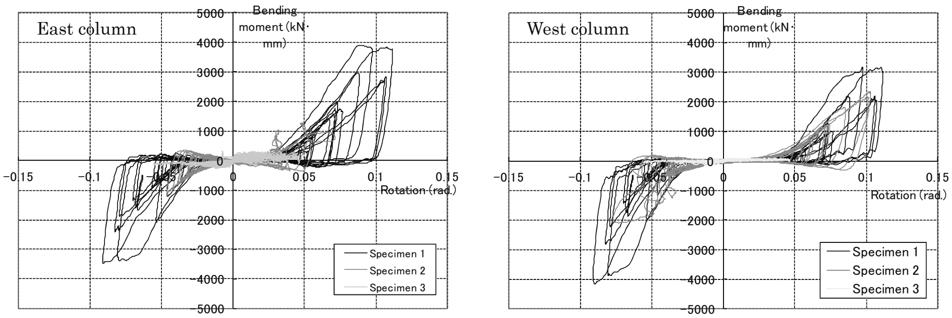

Figure 7. The relationship between bending moment and rotation angle of a joint of columns and *Koshinuki*

DISSCUSSIONS

We discuss about the resistance structural elements under *Daiwa* against horizontal load and whether all elements are summed or not. Column, and the joint of column and N*uki*, mud walls, and plywood walls are considered as the structural elements. The characteristics of restoring force for each element were defined as follows.

Column: They have restoring force occurred by column rocking. The force was defined using Equation (1) (Ban 1942 and Kawai 1999) as follows:

$$H = H_0 \left\{ 1 - \frac{\delta}{b} + 0.99625 e^{-7.5675\frac{\delta}{b}} - \frac{1.9963}{(25\frac{\delta}{b} + 1)} \right\} \qquad (1)$$

where H: restoring force, H_0: restoring force for rigid body $= \frac{Pb}{h}$, P: vertical load, b: the diameter of column, h: the height of column, and δ: horizontal displacement.

The maximum restoring force can be estimated 80% of H_0. The displacement occurred at that time is 0.088 times as much as the diameter of column.

The joint of the column-*Koshinuki*: we estimated bending moment at the joints from the experimental results.

The joint of the column-*Jinuki*: The value of the compressive strains at the joints was not measured in experiment. Therefore we estimated the compressive strains inclined to the grain of members using *Merikomi* theory (Inayama 1991).

Mud walls: Material tests for wall pieces made by the same specification were carried out. The restoring force was evaluated from the tests. (Tsuwa 2008)
Plywood walls: The restoring force is estimated by calculating the sum of the shear forces for nails used at the surface of walls and the wooden framework for walls. (Murakami 1999, JHWTC 2008)

The envelope curve for each characteristic of restoring force and the curve of the sum of elements are shown in Figure 8. However the rocking of the whole frame was distinguished in the test of Specimen 3. Therefore we assumed that there were no compressive strains at the joints of clumn-*Nuki* and the resistance force was only by plywood walls. The sum of the whole frame was calculated by subtracting the frame rocking force from the forces of plywood walls. The slope in the deformation from the maximum to the origin point in the results of every specimen was almost same with the restoring force of one column. It can be seen that it is possible to sum the restoring force of each element in the structure under *Kumimono* at the range of loading in Specimen 1 and 2. About Specimen 3, the theory corresponds to the experimental results at the range of initial rigid. The theory for negative slope after the maximum resistance force differs from the experimental result.

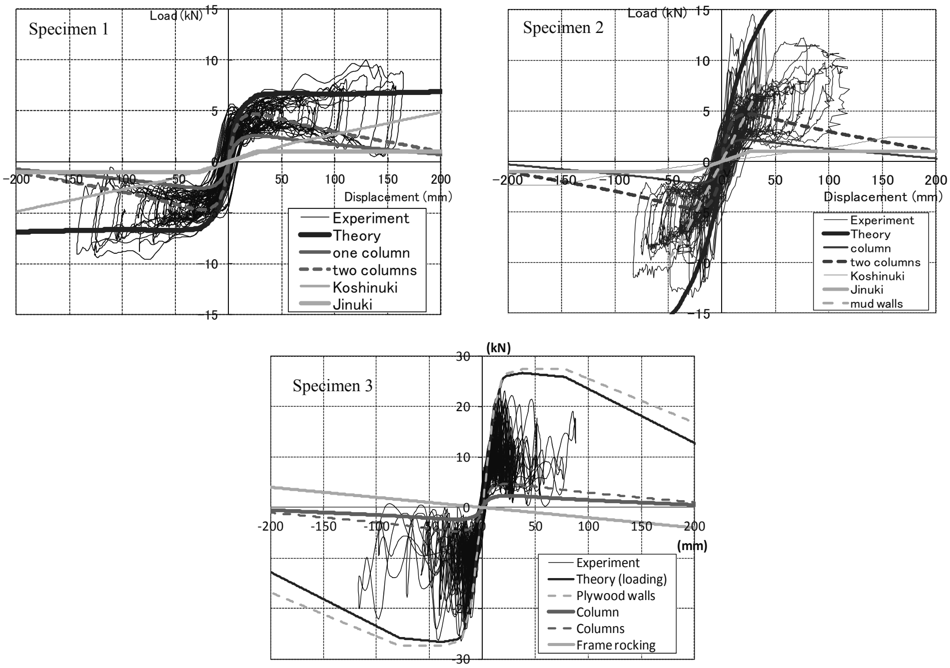

Figure 8. The comparison of experiment and theory

CONCLUSIONS

The shaking table tests were carried out using three kinds of plane of traditional timber structure with three types of wall having different rigid. Each result was compared. The evaluation of the horizontal resistance force of each structural element under *Kumiono* was discussed. The results could be summarized as follows.

1) Adding mud walls or plywood walls in a frame caused a large horizontal resistance force and high

stiffness compared with a frame without walls.

2) The frame including plywood walls was rocking dominantly.

3) It is clarified that the relationship between load and displacement of a frame like Specimen 1 and 2 can be evaluated by adding the restoring force characteristics of each structural element in the frame. However, when the stiffness of the structural elements under *Kumimono* is high like Specimen 3, the behavior of the whole frame can vary from a frame like Specimen 1 and 2, and the evaluation method of each structural element can be different.

ACKNOWLEDGMENT

The specimens used in the tests were made by master carpenter Mr. Yasugoro Kaneko of Fudosyaji. The tests were performed with Assistant Yosuke Simawaki, Koshihara Laboratory, Mr. Hideo Otsuka, a Technical Staff of Koshihara Laboratory, Ms. Tomoka Takase, an undergraduate student of Isoda Laboratory at Shinshu University and members of Koshihara Laboratory. The authors wish to express their sincere gratitude to all of people above for their generosity and help without which this experiment could not be accomplished.

REFERENCES

Ban, S. (1942). "A study on the determination of the stability about main hall structures, Vol. 3: a mechanical study on the Japanese Traditional Frame, 1, the stability restoring force of a column." March, 252-258.

Inayama, M. (1991). "The theory of compression perpendicular to the grain in wood and its application." Phd Thesis of the University of Tokyo, March.

Kawai, N. (1992). "A study on the structural stability of traditional timber structures." The technical report of the Building Center of Japan.

Kato, K., Tsuwa, I., and Koshihara, M. (2008). "Shaking table tests of traditional timber frames including *Kumimono*, Part 1 Experimental outline and results." Summaries of technical papers of annual meeting Architectural Institute of Japan, C-1, Structures III, 43-44.

Tsuwa, I., Kato, K., and Koshihara, M. (2008). "Shaking table tests of traditional timber frames including *Kumimono*, Part 2 Modeling of horizontal resistance force and the analysis." Summaries of technical papers of annual meeting Architectural Institute of Japan, C-1, Structures III, 45-46.

Murakami, M., Inayama. M. (1999). "Formulae to predict the elastic and plastic behaviour of sheathed walls with any nailing arrangement pattern." Journal of structural and construction engineering, No.519, 87-93.

Japan Housing and Wood Technology Center, (2008). "The allowable stress design of conventional post and beam and structures."

A Study towards the Formation of Disaster Management Planning Process with Past Disaster Lessons

Taiki KOU[1], Shinya KONDO[2], Mehedi Ahmed ANSARY[3] and Kimiro MEGURO[4]

ABSTRACT: *Formation and revision process of disaster management plan has not been fully described even though the methodology of analyzing past disaster management operations has developed. In this paper, we described a model of formulating disaster management plan based on the theories of public policy. Following this, we applied the model to the actual revision process of disaster management plan, Standing Orders on Disaster, in Bangladesh. Through the analyses of this revision process, we extracted several on-site agendas. To fortify the accuracy and concreteness of this proposed model, further theoretical and practical analyses would be imperative.*

Key Words: Disaster, Cyclone, Flood, Bangladesh, Disaster Management, Operation, Policy Agenda, Revision of Disaster Management Plan, Policy Planning

INTRODUCTION

The main part of the revision process of disaster management plan has been "qualitatively and quantitatively analyzing past lessons of disaster management operation and reflecting them into the revised plan". However, if we extend the coverage of organization into larger ones such as prefectural or national level, the revision process comes to be not just a feedback process discussed only within the related people but a policy process in which several actors who hold different interests involve. In earlier discussions of disaster management, this policy process part has not been fully deliberated even though this part affects the effectiveness of disaster management policy. Therefore in this study, firstly we aim to implement modeling of revision process of disaster management plan, and secondly aim to clarify the agendas of the revision process in the context of consecutiveness and reciprocity by using a case study. That can provide a foundation for the total disaster management planning process from the extraction of past disaster lessons to finalize effectuating the policy. With that, we aim to reduce the uncertainty of revision process of disaster management plan.

To develop the theoretical framework and crystallize the agendas of revision process, we will analyze the revision process of Standing Orders on Disaster in Bangladesh that is the national disaster management plan and firstly revised in 2010 as a case study.

MODELING THE DELIBERATION PROCESS OF DISASTER MANAGEMMET PLAN

Formation of policy agendas and breaking the agendas into some patterns

In this section, we will conduct a modeling of formation of policy agendas by introducing several

[1] Graduate Student, The University of Tokyo
[2] Project Researcher, ICUS, IIS, The University of Tokyo
[3] Director/Professor, BNUS, Bangladesh University of Engineering and Technology
[4] Director/Professor, ICUS, IIS, The University of Tokyo

theories which have been developed in the field of Public Policy.

We set three elements as what affect the formation of policy agenda (**Figure 1**). The first element is past disaster lessons (based on Punctuated Equilibrium (PE) Theory, Advocacy Coalition (AC) Theory, and Multiple Streams (MS) Theory). The Second element is newly recognized issue (based on AC Theory). This is raised because of the changing of organization's norm derived from an environmental change or the newly recognized risk which had not existed in the past. The third element is disruptive issue which suddenly occurs and totally changes the current standing point of the policy (based on PE theory). Based on these three elements, disaster management related policy agenda will be formulated.

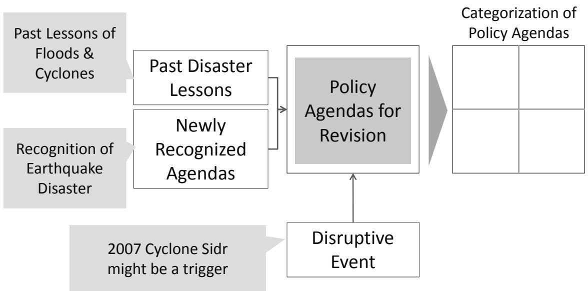

Figure 1. Formation of disaster management related policy agenda

Modeling the deliberation, approval effecting processes

In the last section, we did the modeling of formation of policy agenda. Following that part, we would implement modeling of deliberation, approval, and publication process of disaster management plan. Especially, we would like to discuss the type of participant of revision process, details of deliberation contents among the participating organizations.

In **Figure 2**, a deliberation process of revision of disaster management plan is described. In this model, following flow is anticipated.

1. Disaster management related information is provided from policy formulating organization(s) to policy implementing organization(s)
2. Implementing organization plans own disaster management plan based on the information
3. Disaster management operation related concessions are exchanged between formulator and executor, and the consensus is secured
4. Revision process is finalized by the approval of a certain committee
5. Revised policy will be published and issued to each policy implementing organization

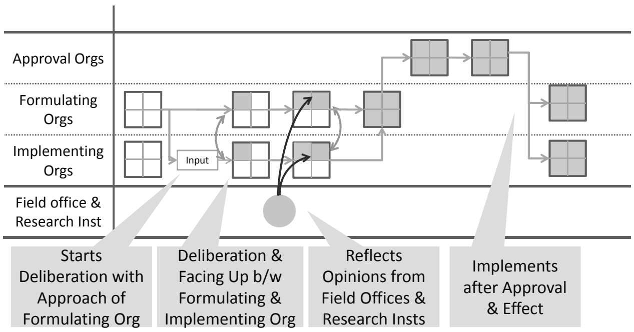

Figure 2. Deliberation process of disaster management plan

CASE STUDY: REVISION PROCESS OF NATIONAL PLAN IN BANGLADESH

Procedure of analyses

In this chapter, we would like to discuss the revision process of national disaster management plan

“Standing Orders on Disaster (SOD)” in Bangladesh, which had firstly published in 1997, and firstly revised in 2010. SOD is the national disaster management plan for all the organizations related to disaster management in Bangladesh. The procedure of the analysis is following. Firstly, we would describe the disaster management related topics in Bangladesh along with a timeline. Secondly, the analyses of revision process will be implemented. These analyses are fortified by the interview surveys toward disaster management related organizations in Bangladesh, e.g. Disaster Management Bureau (DMB), Comprehensive Disaster Management Programme (CDMP), Fire Service & Civil Defense (FSCD), Oxfam Bangladesh, etc. Finally, agendas of the revision would be described. These agendas are mentioned in the context of formulation of policy agendas and of the revision process itself.

Descriptions of disaster related topics in Bangladesh

We would like to briefly overview the disaster related topics in Bangladesh. In 1997, the first SOD was formulated after Cyclone Gorky (1999) as the lesson. In 1998, 2002 and 2004, there were several floods more than a hundred people died. In 2007 and 2009, Bangladesh experienced two cyclones: Cyclone Sidr and Aila. Besides, around 2008, the revision process of SOD gained its momentum. Outside the country, there was Sumatra Earthquake and Tsunami disaster in 2004. Based on the lessons in 2004, a global framework for disaster reduction strategy “Hyogo Framework for Action (HFA)” was formulated in 2005.

Analysis of formation of policy agendas phase

In this section, we would like to clarify the root causes of the formation of policy agendas related to disaster management. Firstly, there was little opportunity to hold a feedback workshop after the flood disasters which we described in the former section. In addition, after 2007 Cyclone Sidr, 2days workshop was held by the leading organization of disaster management: DMB and CDMP on the purpose of summarizing several lessons of disaster management operations. However, there was no direct linkage between the workshop and the revision of SOD according to the interview survey toward DMB. On the other hand, formation of HFA played a significant role to implement the revision of SOD. According to DMB and CDMP, Risk Reduction related descriptions were newly introduced to SOD based on the strategic framework for risk reduction described in HFA.

Analysis of the deliberation process

We would like to describe the agendas along with the procedure. Firstly, shortage of manpower for the policy formation organization was pointed out. Secondly, insufficient coordination was pointed out. Policy formulator implemented deliberation with implementing organizations, respectively. However, there was little opportunity to implement multi-organizational deliberation. Thirdly, there was little room for external specialized organizations such as universities or research institutes to participate in the deliberation process directly. They were only able to get involved in when the framework of the revision had almost formulated. Finally, regarding the approval and publication process, absence of detail implementation plan for SOD, insufficient system of budget allocation and incentive design to implement the revised orders were pointed out. Except some categories, detailed implementation plan of SOD is limited. In addition, still obscure borderlines of authority are remained to implement operation, e.g. who is in charge of rehabilitation of water well which had been developed by the poverty reduction program in normal times, etc.

Discussion

In this section, we would like to discuss the results of analyses.

Firstly, we would like to point out the basic principles of the revision of disaster management plan in Bangladesh. As illustrated above, this revision was mainly and strongly affected by the disruptive event of global disaster reduction. In addition, there was little cohesion among past disaster lessons even though some post-disaster lessons were held to summarize the lessons. From here, we can extract two points. The first point is that global strategic framework of disaster management, such as HFA was able to be an efficient trigger of revision in Bangladesh. The second point is that disasters which almost annually affect Bangladesh cannot be a big trigger of the revision. However, it was true that fatality in 2007 Cyclone Sidr was the drastic decrease compared to ones in 1970 or 1991. These factors are development of early warning system for cyclone preparedness and the activities of aid agency such as NGO and international organizations. Therefore, there can be still significant room to improve disaster management operations implemented by public organizations. We strongly believe that the establishment of continual revision system of disaster management plan based on past disaster lessons is required in Bangladesh, in addition to the foundation for the revision based on a disruptive change.

Secondly, we would like to describe the agendas of deliberation process. The agendas can be broken down into two points. The first point is the necessity of input of disaster lessons related knowledge to the implementing organizations. In the last revision, policy formulating organizations sent their officers to each implementing organization. However, it was very difficult for the organizations to exhaustively summarize own organization's lessons. Therefore, knowhow of consolidating past disaster lessons and appropriate input of revision related information are required at the beginning. The second point is the necessity of policy deliberation process in which several organizations involve. In the last revision, deliberation among multi-organization was rarely implemented even though several operations are anticipated to do so. However, there is little progress even DMB has taken the shot to the issue. Therefore, as a proposal, introducing a deliberation system by utilizing the current international assistance framework called "cluster" can be one of the foundations.

As a summary of this chapter, we would like to strongly note the importance of human resources development in the field of disaster management in Bangladesh. As we have seen, the trigger of this revision was an external disruptive change. For the continual revision of the disaster management plan in Bangladesh, the revision cycle should be organized and implemented within the country. To achieve that, human resources who can analyze past disasters and accumulate the lessons, who can raise the lessons as policy agendas, and who can handle the deliberation process and issue the new orders are required. In other words, disaster management specialized persons are required for each level of organizations from the field to the center of the government.

CONCLUSIONS

We have seen the overview of revision process of disaster management plan with the case study of SOD in Bangladesh. Firstly, we set a model of revision process with utilizing the theories of public policy. Through the modeling, we were able to figure out one possible procedure of revision. To fortify the model, further accumulation of knowledge both theoretically and practically will be indispensable. Secondly, we analyzed the actual case in Bangladesh. The procedure was overviewed and the agendas were pointed out. Establishing a foundation for accumulating disaster lessons within the country with nurturing the professionals in the several levels of organizations will contribute to minify the agendas.

ACKNOWLEDGMENT

We would like to express our sincere gratitude for the cooperation of DMB, CDMP, other public agencies & INGOs, and Bangladesh University of Engineering and Technology (BUET).

REFERENCES

Davi, A. Rochefort and Roger W. Cobb. (1993: Spring). "Problem Definition, Agenda Access, and Policy Choice." *Policy Studies Journal*, 21:1, p56-71.

Sabatier, P. A. (2006). "The Advocacy Coalition Framework, in Sabatier, ed.," Theories of the Policy Process, Chapter 6.

True, J. K. et al. (2006). "Punctuated-Equilibrium Theory: Explaining Stability and Change in American Policymaking, in Sabatier, ed.," Theories of the Policy Process, Chapter 5.