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修士論文

Structural Characteristics of Groups of Traditional Wooden Houses in South Nias, Indonesia

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in South Nias, Indonesia

Contents

Chapter 1 Introduction

1.1 Scope

Indonesia consists of many islands and is a multiracial country. Each ethnic group has their own type of traditional wooden houses. Among them, we focus on the village of *Bawomataluo* in South Nias, Indonesia. Most of the traditional timber houses in South Nias have survived against the past large earthquakes in such seismic areas. In the present study, the structural characteristics of traditional wooden houses in South Nias were studied.

We conducted structural survey in the village of *Bawomataluo* in South Nias. In the present survey, micro-tremor measurements were carried out. As results of micro-tremor measurements, the fundamental characteristics of the traditional wooden house were evaluated. However, we found that some timbers were so deteriorated and damaged seriously by termite. These damages might have reduced the original seismic resistance. The climate monitoring was performed to study the effect of temperature and humidity on deterioration of timbers.

As no nails are used to construct the traditional houses, the joints were categorized into four types. Material tests of timbers used for structure were also conducted to examine the strength. With these fundamental characteristics, earthquake response analyses were performed. The coupling effect of *omohada* (houses lined in a row) was indicated by the analysis. Further structural analysis would be needed to study the dynamic behaviors of traditional houses.

1.2 Background

1.2.1 Description of Nias Island[1][6][13]

Nias Island is located to the west of Sumatra Island, shown in Fig.1-2. There are approximately 700,000 people in Nias Island. Although they have dry and rainy seasons, it rains frequently particularly in the center and the north of Nias. The temperature ranges between average day (32℃) and night (22℃).

The architectural style of traditional wooden house is different among North part, central part, and South part (see Photo.1-1～1-3). The traditional style in North Nias has elliptical shape of floor plan, standing independently. On the other hand, the traditional style in South Nias has rectangular plan, standing side by side. In central Nias, the traditional house is middle type between North type and South type.

A lot of trading vessels came to Nias Island at age of discovery. The main trading port was Gunungsitoli at North Nias, while many pirates came to South Nias because it was easy to hide around Telukdalam as second trading port. It can be noticed that the shape of the traditional house is similar to ships. A person who lives in Bawomataluo said that the shape of the traditional house arose from the ships of pirates when a lot of pirates came to Telukdalam.

Approximately 90 percent of Indonesian people are Muslim, while about 10 percent are

Christian. However, they had been native religion with customs of head hunting in the past time, so that the village should be at high place to be defended against other settlement. The village of Bawomataluo is on the top of the hill about 1.3 feet high from sea level. There are only three ways to go up the village with long stone steps. There is a stone stage called jumping stone which is approximately 2 meter in height. A man who jumped over the jumping stone could become a warrior at that time. The jumping stone is performed at traditional ceremonies and at a special accasion reguested by the tourists, nowadays (see Photo.1-5). There is a traditional dance called Lompat Batu (=war dance), which represent heroic attitude facing the enemies as the expression of glory in the war field.

The megalith culture had been developed in South Nias. There are many megaliths still now called *daro-daro* (see Photo.1-7), being shaped rectangular or circular benches or tables. The *daro-daro* is placed in front of water drainage, showing the rank of house owner. It is the physical reminder of past feasts of merit and lasting memorial to those who hosted them.

The village of *Bawomataluo* was constructed between 1863 and 1878 by people who escaped from the old village of *Orahili* after its destruction by Dutch troops. *Omosebua* also built that period in the middle of the village.

On both side of the central paved line called *ewali,* the space is striated by crosswise paths leading to the house. This semi-public area can be classified into two socially significant zones. The area under the eaves is a private area used mainly by woman for domestic chores.
In front of the area, both side of the street, there is water drainage called *elea* slightly sloped towards the end of village (see Photo.1-8).

Fig.1-1 Map of Indonesia

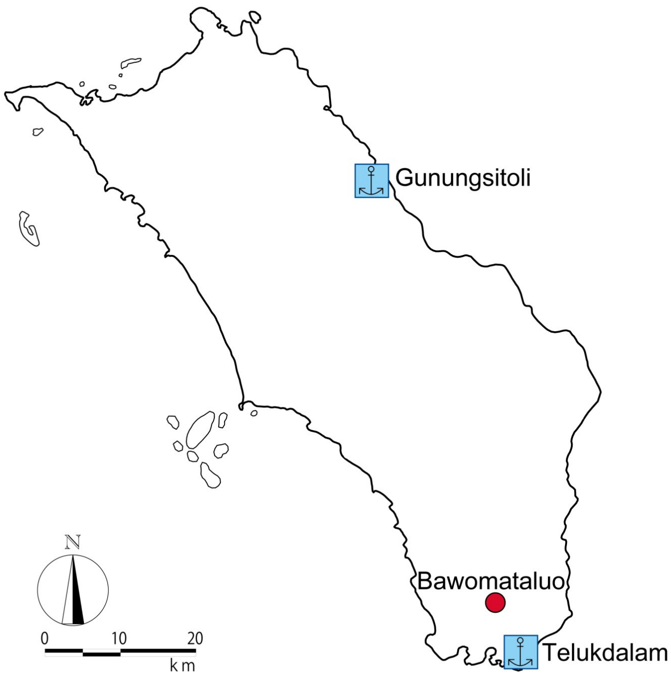


Fig.1-2 Map of Nias Island (source: HIC smatra, OCHA)

Photo.1-1 Traditional house in North Nias

Photo.1-2 Traditional houses in South Nias

Photo.1-3 Traditional house in Central Nias (source: Sato.K)

Photo.1-4 Assembly house

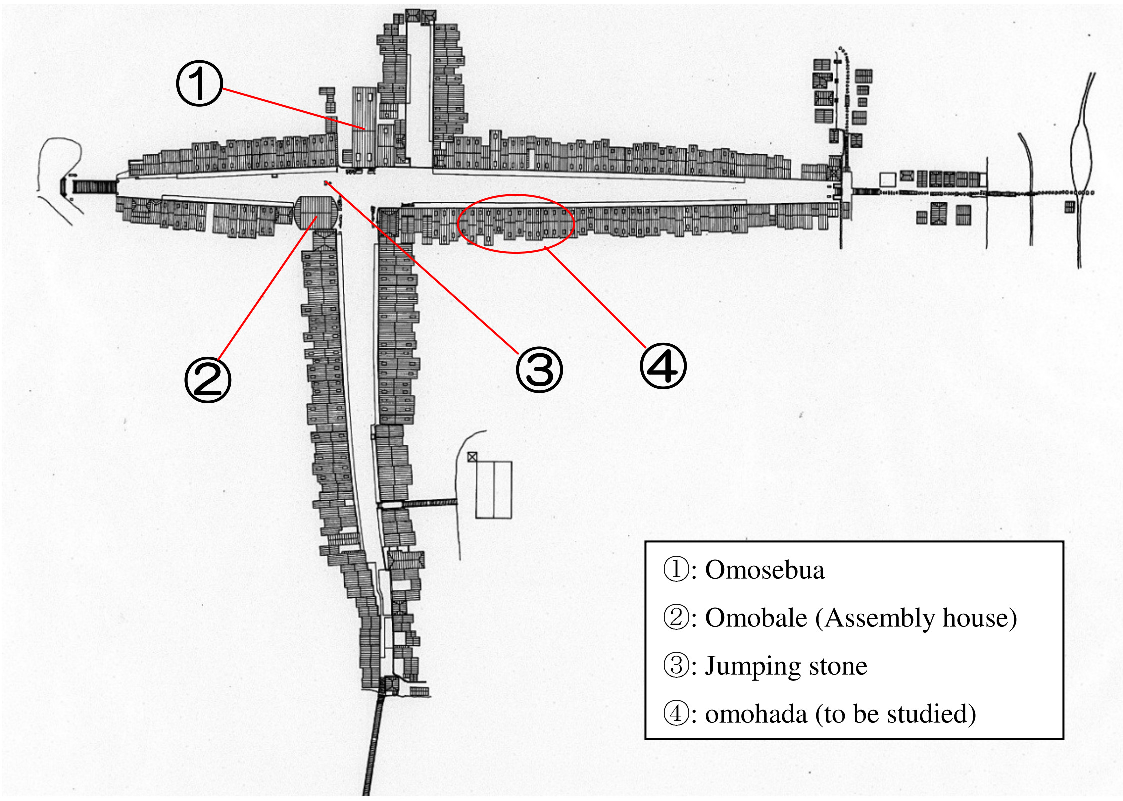


Fig.1-3 Arrangement plan of Bawomataluo (source: Ando.K, Inoue.M)

Photo.1-5 Performance of Jumping stone

Photo.1-6 *Omosebua* and *ewali gorahua*

Photo.1-7 *daro-daro*

Photo.1-8 Open space in front of the house

1.2.2 Damages caused by the past Earthquakes

On December 26, 2004, a great earthquake occurred close to Sumatra. Tsunami caused by the earthquake attacked 12 countries. The damages forced people who live in Nias to live in tents or other temporary housing.

On March 28, 2005, another major earthquake occurred near the Nias Island shown in Fig.1-4. As a result, approximately 900 people dead and 70000 houses damaged or destroyed by the earthquake. More than 400 people were dead around the Gunung sitoli (: main city of North Nias), and 50 people were dead in Teluk dalam (: main city of South Nias). Most of masonry houses completely collapsed, which injured many people. In contrast, the traditional wooden houses in South Nias did not completely collapse by the earthquake. Those houses were damaged only the roof-frame particularly in the village of Bawogosari and Hilisimaetano. Some traditional houses leaned to front, being supported by temporary members, shown in Photo.1-9. In consequence, it could be considered that the traditional wooden houses have seismic consideration. The interesting point is why the traditional houses could survive against great earthquakes.

Photo.1-9 Traditional houses damaged by earthquakes leaned to front

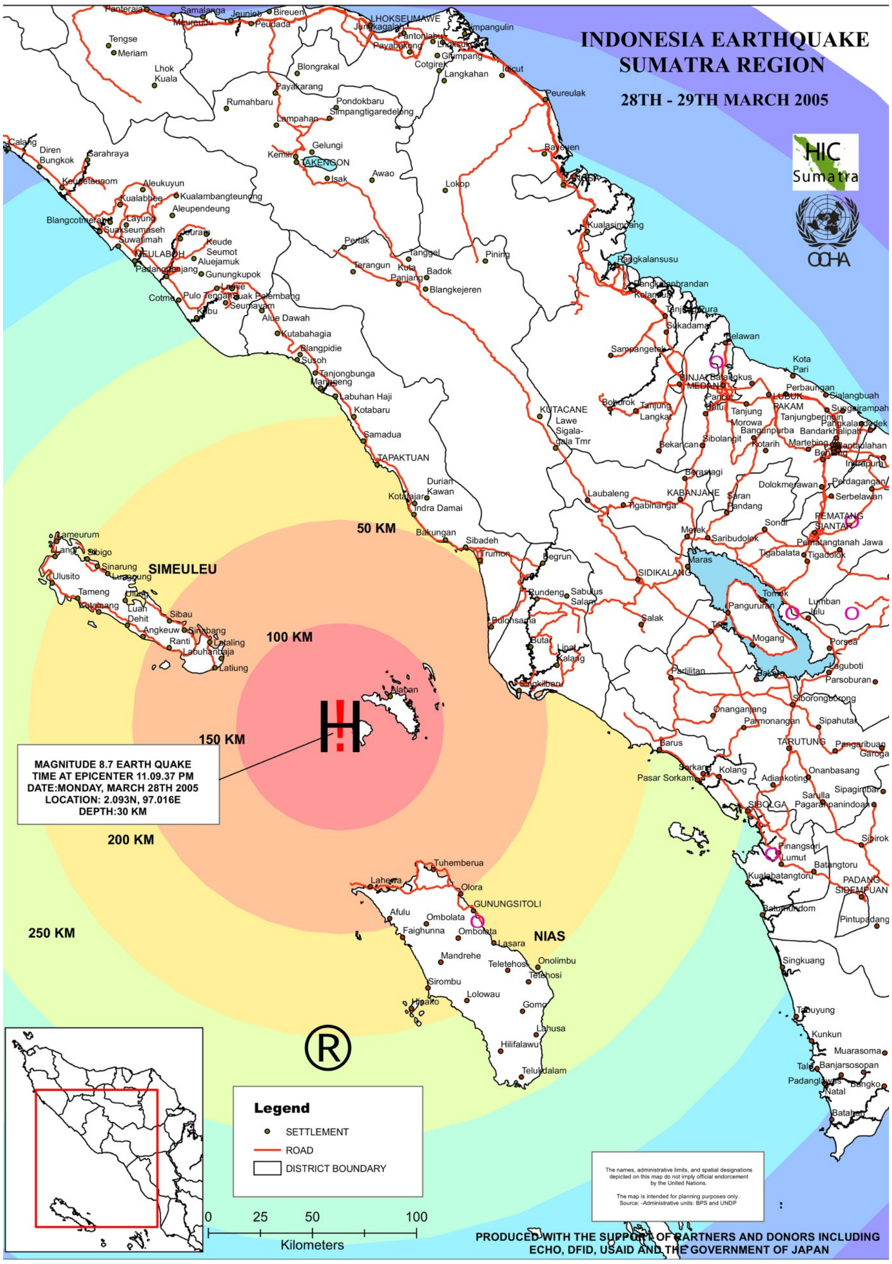


Fig.1-4 Hypocenter of Sumatra earthquake (souse: HIC sumatra, OCHA)

1.3 Purpose

It can be said that there are many cultural things worth preserving in South Nias, being maintained by people themselves. Although there are institutions to conserve cultural assets its self in Indonesia, no institutions have been organized to conserve the group of traditional buildings. The scope of the present research is to develop institutions organized for conservation of those groups as an international cooperation research with Indonesian experts.

In addition, the traditional houses in South Nias have survived against past earthquakes, indicating seismic resistant capacity. The purpose of this study is to clarify the structural characteristics and to evaluate the seismic safety of traditional wooden houses.

1.4 Past Studies

K.Andou and K.Inoue et.al reported the traditional wooden house in South Nias from a cultural point of view. Floor plan, cross section, and elevation of both of omosebua and omohada were drawn in detail by them.

The social structure and settlement pattern of South Nias are studied by them. There were used to be four social classes in traditional society of South Nias as *siule* (noble), *ele* (leader of native religion), *ono mbanua* (general people) and *sawuyu* (slave). The settlement is basically placed high level providing the area, which composed of an Assembly square, an Assembly house, houses, public bath, a Church, a Jumping stone, and public water place. The main road is widen at the center of the settlement for Assembly square, which have a stone called "*fuso newali*" as a navel of village. The houses are ranged both side of main road, which has different size depend on the social class. In particular, *Omosebua* (chief's house) is remarkably large, which is also used for some ceremonies or other public things. The assembly house placed at the center of village is a place for important meeting, which is usually used as community space for men. K.Andou and K.Inoue considered that such occlusive settlement pattern with definite core as this come from custom of head hunting to defend against other settlement, indicating the stratified society of Nias.

They indicated the basic consideration of spaces (see Fig.1-5) that it goes more private space one after another from main street to back of a house (in order from the main street : front garden, stylobate, space under the eaves, dwelling, cattle shed , and kitchen garden) . The dwelling is divided into front room and back room. Front room is used for customers or bedroom for men as common space and back room is used for cooking, taking a meal, and bedroom for women as private room. There is tiered space (which called *Bato, Danedane*) where people spend their time freely seeing the main street through the opening. Nowadays, most of all traditional wooden houses are extended to back space for removing the kitchen.

On construction method of traditional wooden houses in Bawomataluo, they presented that the traditional house can be divided into three parts; under floor space, living space, and roof frame. *Nuki* and *Kashira-nuki* supported under-floor frame rigidly with braces. At the living space, beams and walls of front and back connected two parts of thick walls in ridge direction as a BOX. The roof frame structure is relatively light, consisting of braces in span direction. The beams connect three triangular frames of roof structure. Two openings at the roof, which can be adjusted the opening level, are so effective in getting light and ventilation. [2,3, and 4]

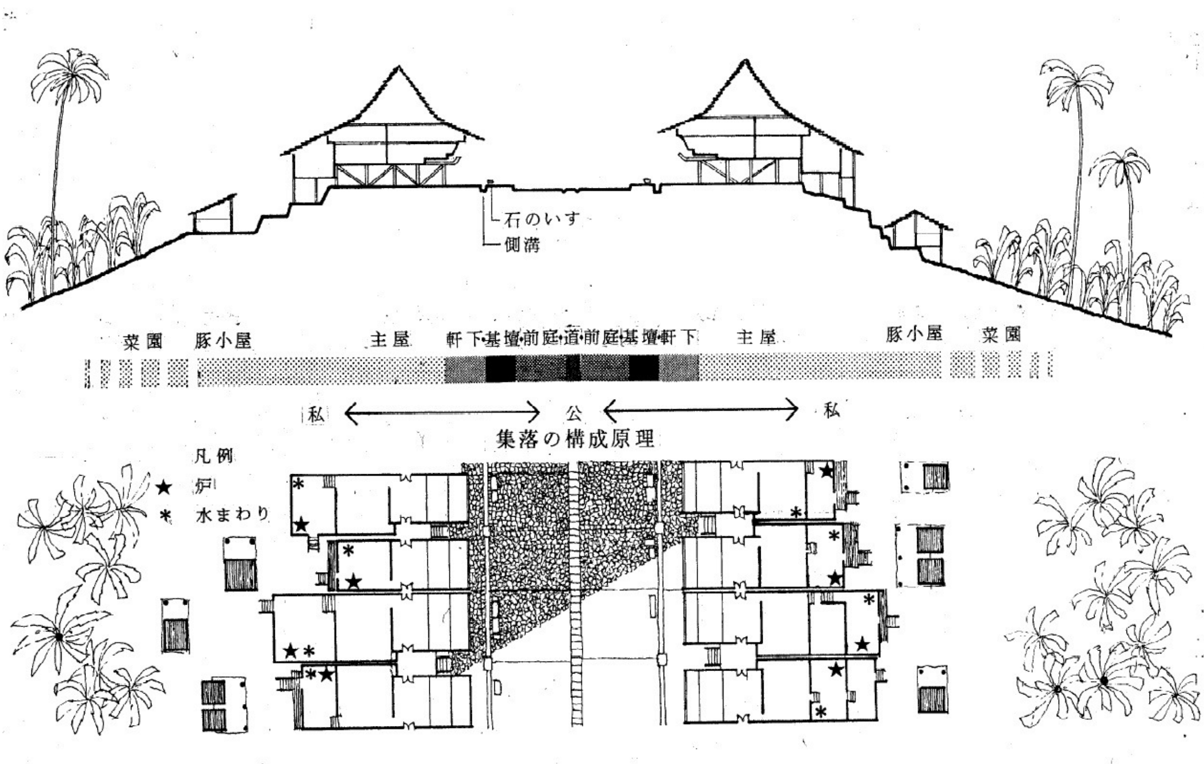


Fig.1-5 The basic consideration of spaces

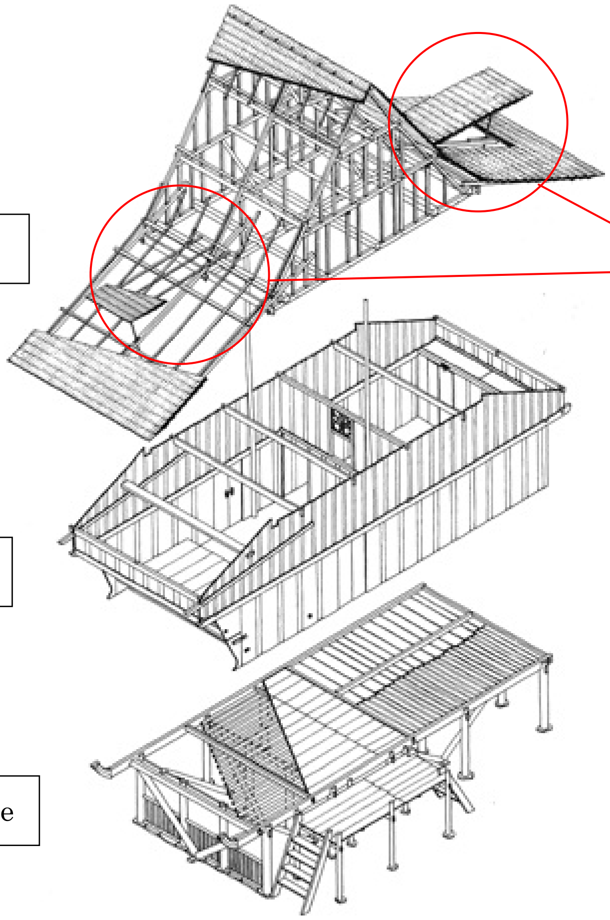


Fig.1-6 Three parts of traditional wooden house

M.Sato reported the process of transformation of traditional wooden houses in Nias. Many houses are roofed with GI sheets or other steel sheet instead of traditional Sago leaves. These new material could keep good condition longer than Sago leaves without rain leaking through the roof, so that a number of people changed roof material from Sago leaves to GI sheets. However, those materials raised temperature of the space in the roof because of high thermal conductivity. As a result, some people started to use the space under the floor, making concrete walls with concrete blocks between columns instead of the braces. Thus the space under the floor becomes living space, using several kinds of door including glasses.

As living space was changed from on the floor to under floor, some people build a low house of one story instead of traditional wooden house. Some people built houses of two stories with balcony to make more floor space for bedroom.

Sato. M also presented the ornament and sculptured parts of a building in Indonesia.

He considered that the traditional style would disappear when people change their life style by changing roof material from Sago leaves to GI sheets. He was afraid that yang generation should go outside of the village for long time to earn money in order to live in their traditional house comfortably.[5]

K.Sato studied wooden houses in Southeast Asia and Oceania from the point of prototype and development. He categorized those houses by 7 points; 1.The name of house, 2.Cross beam or beam structure, 3.Elevated floor style, 4.Basement, 5.Expansion, 6.Roof construction and 7.Mixed style. The prototype of the short pillar style is elevated floor supported by four short pillars which arranged in a square. Short pillar – roof style is the first type which has only roof. It developed as Short pillar – wall style which has side walls and posts supporting the ridge directly from the floor. The style of traditional wooden house in South Nias is included in the category of Short pillar – wall style with gable roof. The granary of Toraja-Sa'dan (Serebes), the house of Toraja-Sa'dan, the house of Lio (Flores), and the long house of Dayaks (Borneo) are in same category.[7]

Chapter 2 Microtremor measurement

2.1 Introduction

We conducted micro-tremor measurement at both Omosebua (; a headman lived in formerly) and Omohada (; common people live here). (see Photo.2-3 and 2-4) Those heritage structures have two kinds of roof materials; GI sheets and sago leaves.

Measurements of micro-tremor were carried out by using 6 micro-tremor sensors, shown as Fig.5. Sampling duration was 60 seconds for each record with sampling frequency of 100 Hz using a portable monitoring equipment of SPC-51A (Tokyo Sokushin Co., Ltd.). We carried out the measurement in 18 cases including manpower excitation tests in both span and ridge directions (see Table 2-1). Fig.2-1～2-14 show arrangement of the sensors for each measurement case. One sensor was placed on the base, while the other sensors were arranged on the structure for calculation of transfer function to evaluate the natural frequency and the vibration mode.

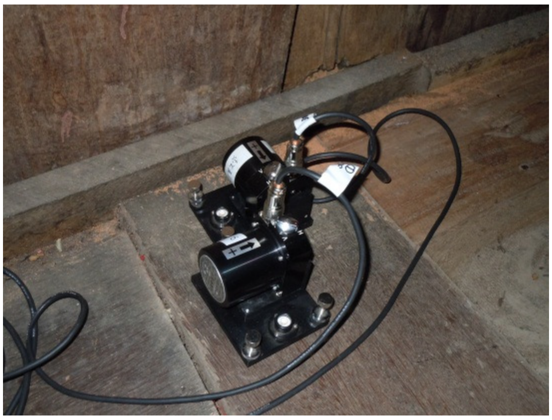


Photo.2-1 Sensors

Photo.2-2 micro tremor measurement

Photo.2-3 Omohada

Photo.2-4 Omosebua

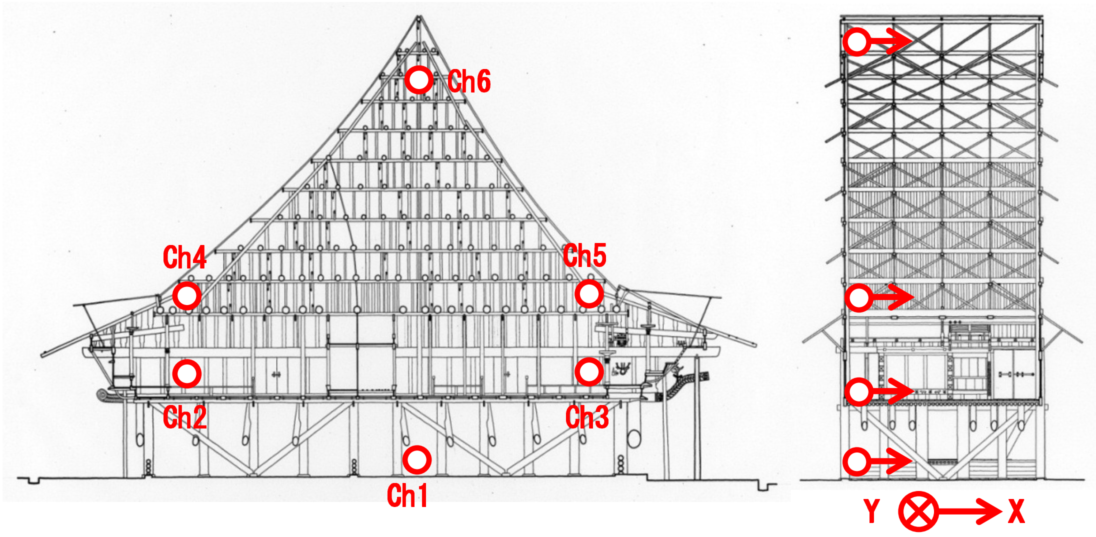


Fig.2-1 Arrangement for case 1-1

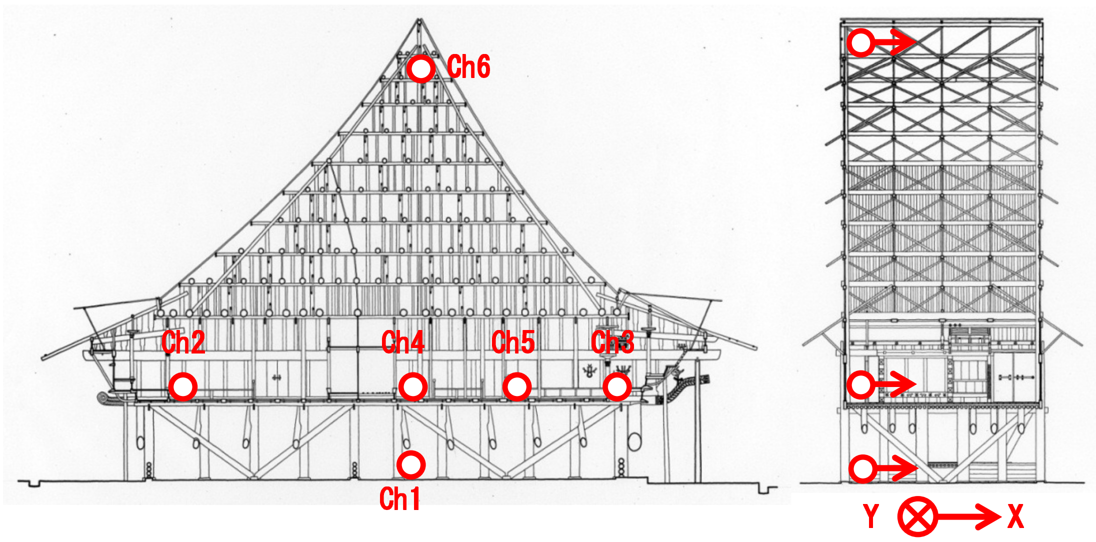


Fig.2-2 Arrangement for case 1-1’

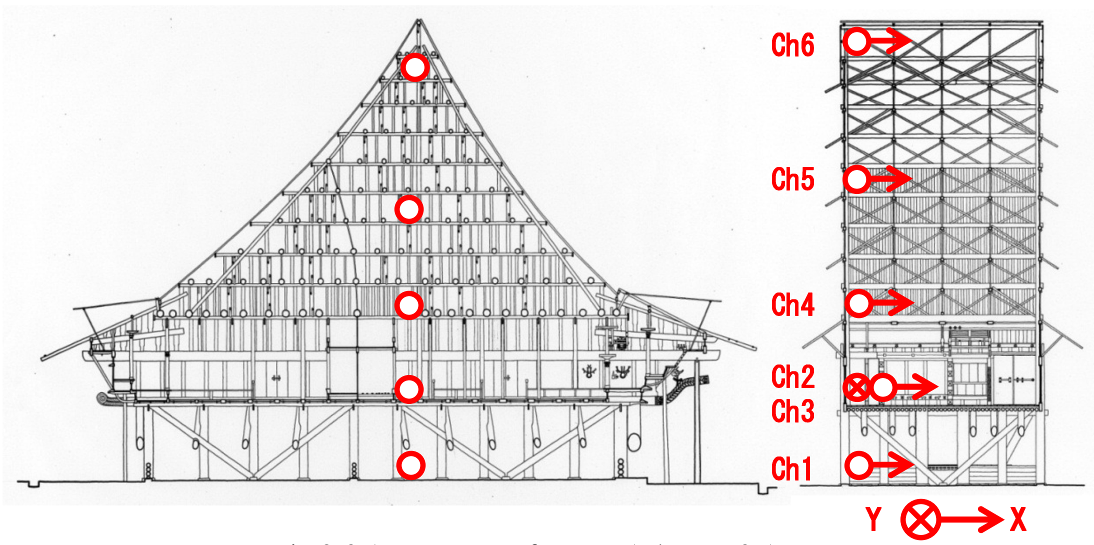


Fig.2-3 Arrangement for case 1-4, case 3-1

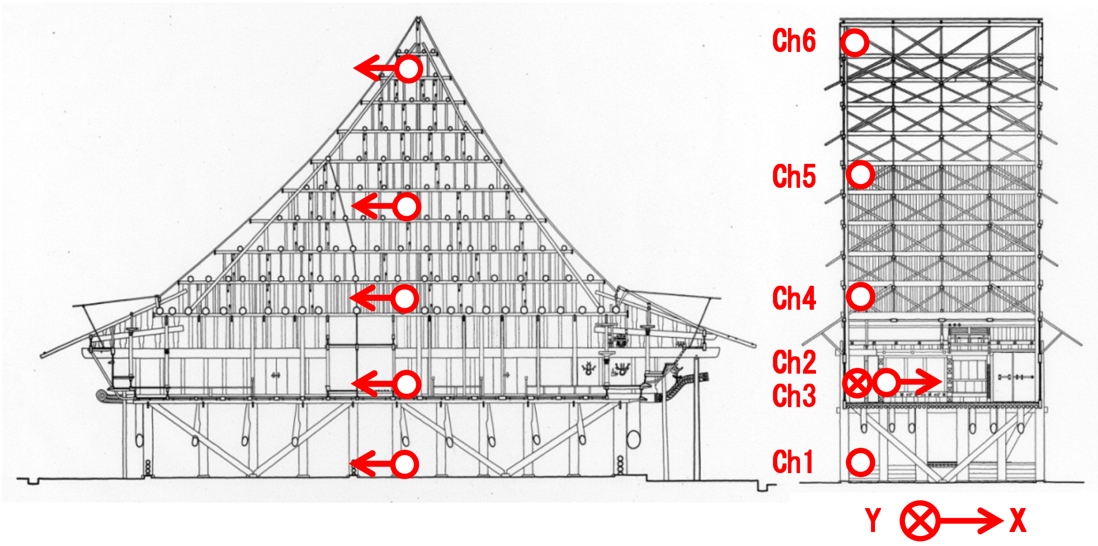


Fig.2-4 Arrangement for case 1-3, case 3-2

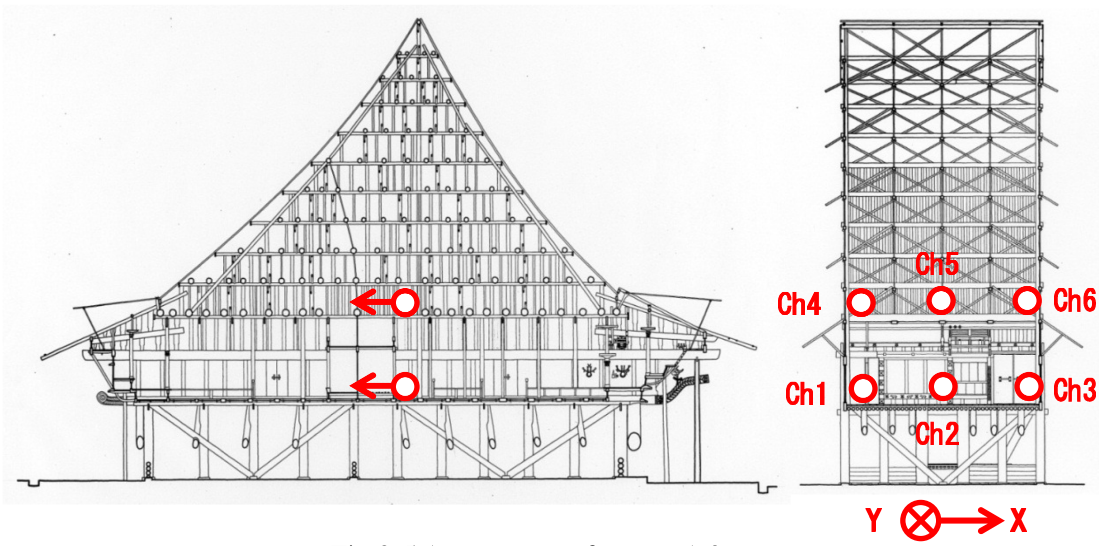


Fig.2-5 Arrangement for case 1-2

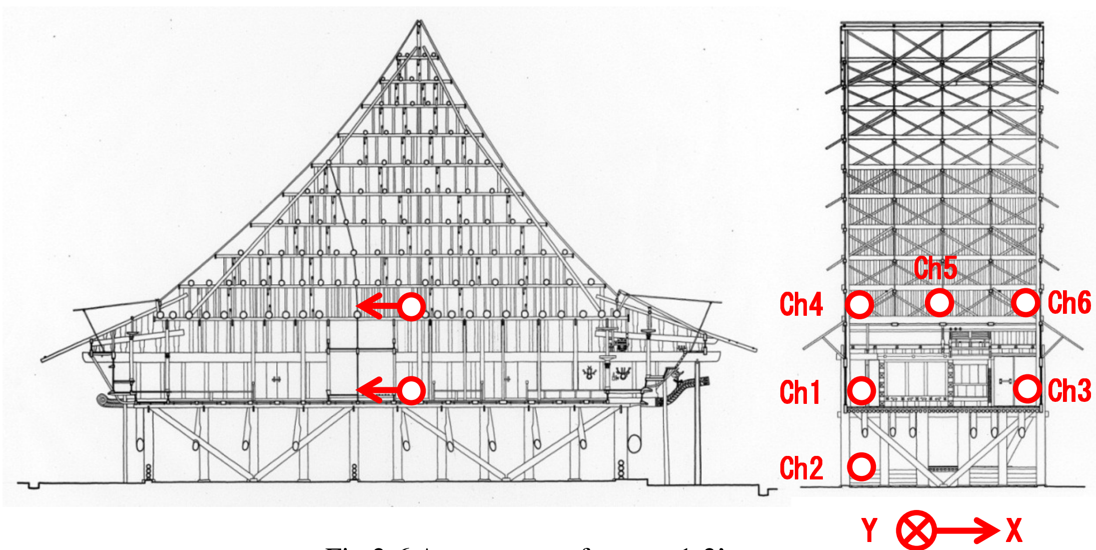


Fig.2-6 Arrangement for case 1-2’

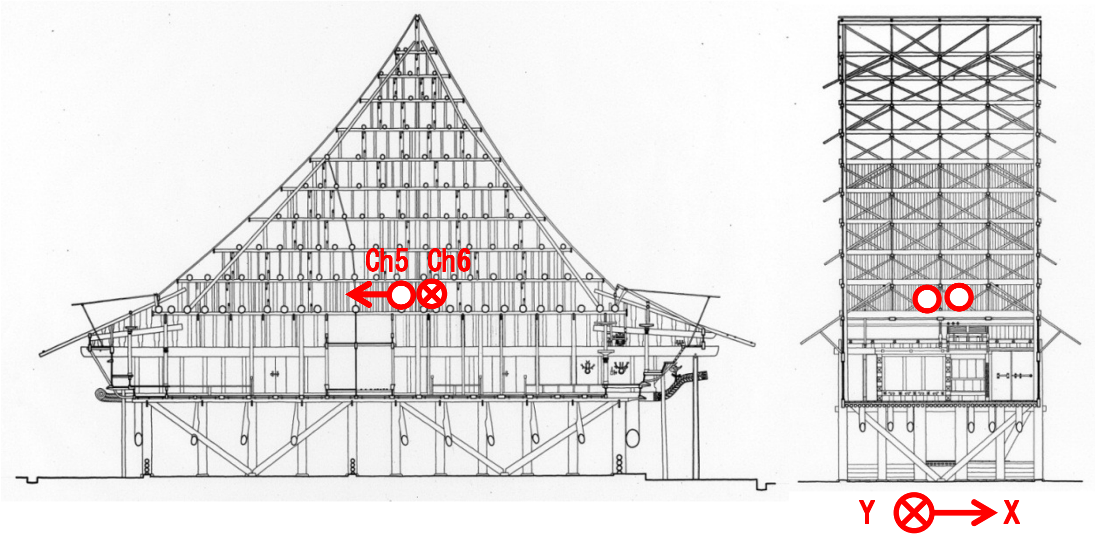


Fig.2-7 Arrangement for case 1-6

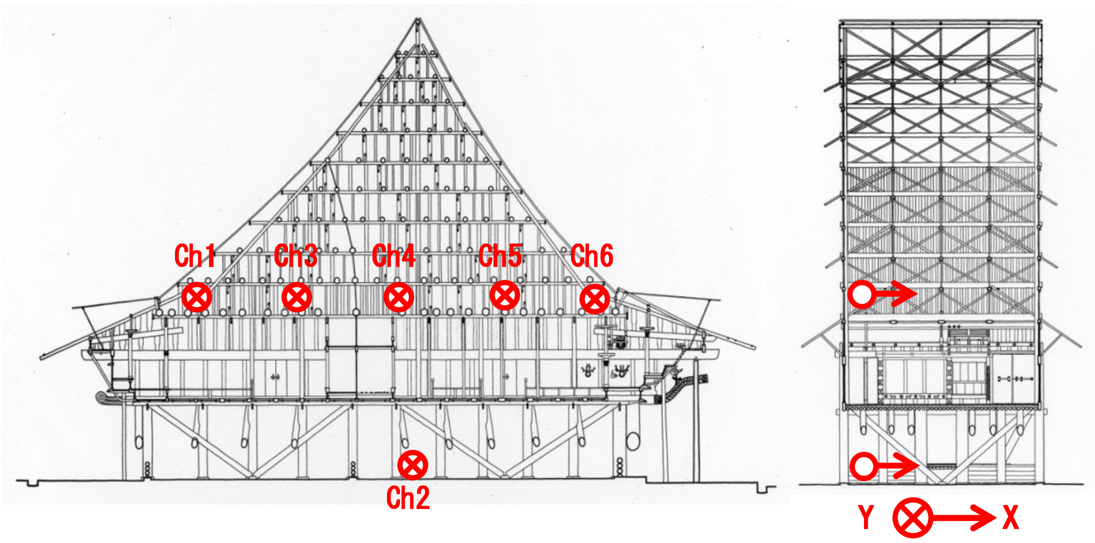


Fig.2-8 Arrangement for case 1-7

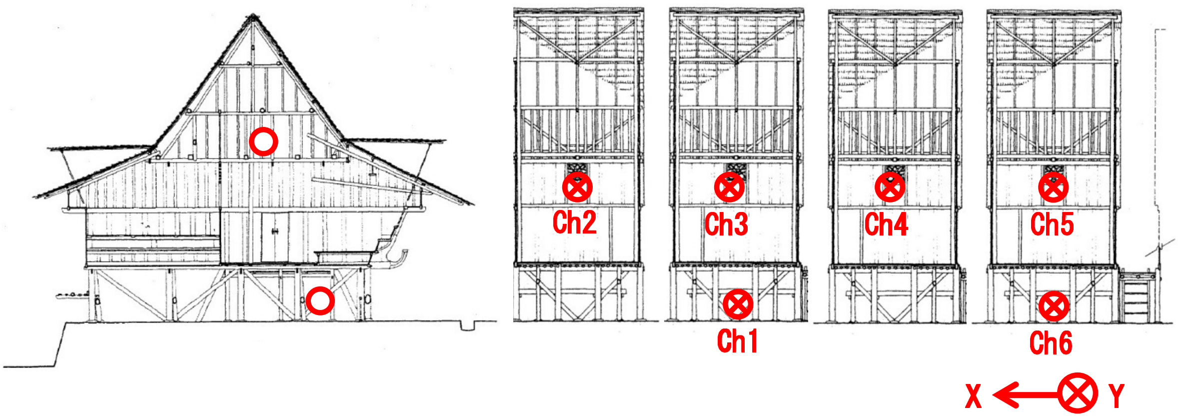


Fig.2-9 Arrangement for case 2-4, case 2-4’

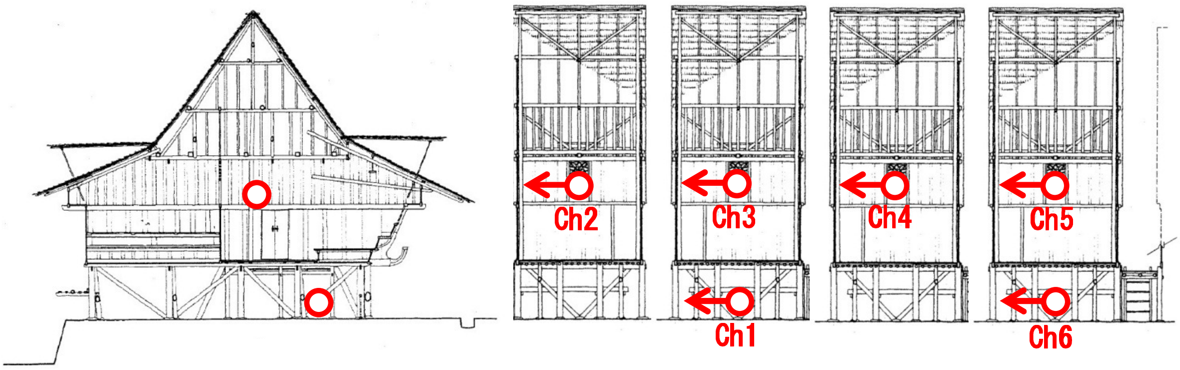


Fig.2-10 Arrangement for case 2-3, case 2-3’

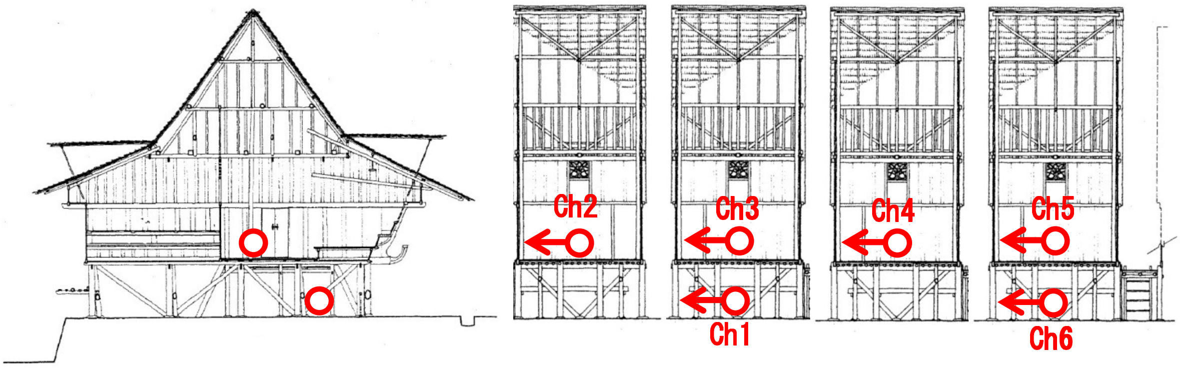


Fig.2-11 Arrangement for case 2-1

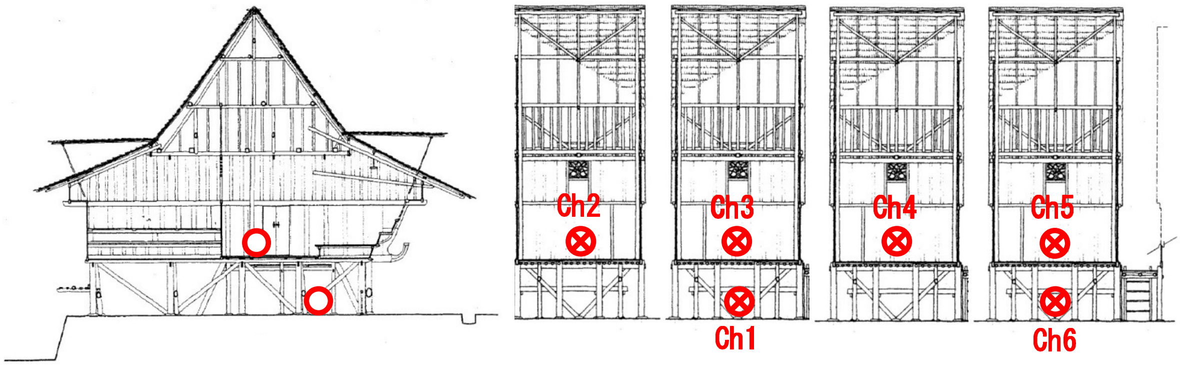


Fig.2-12 Arrangement for case 2-2

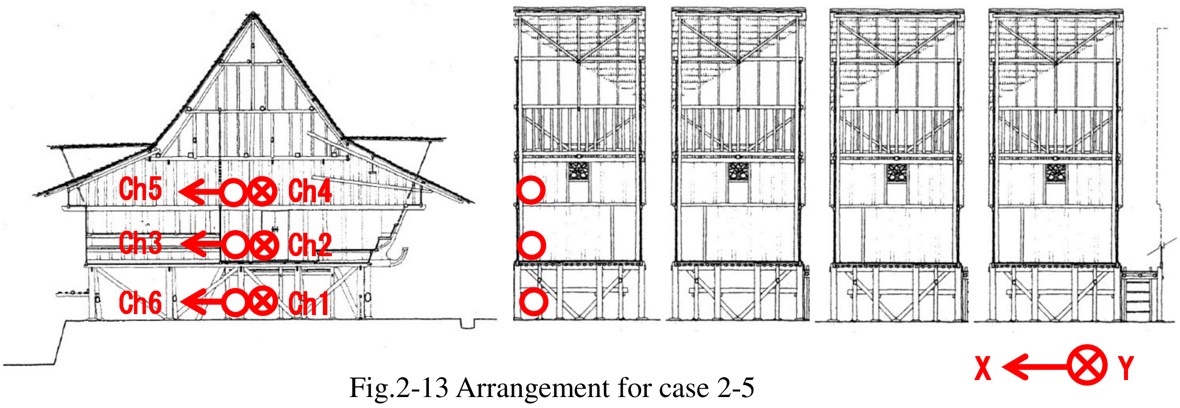


Fig.2-13 Arrangement for case 2-5

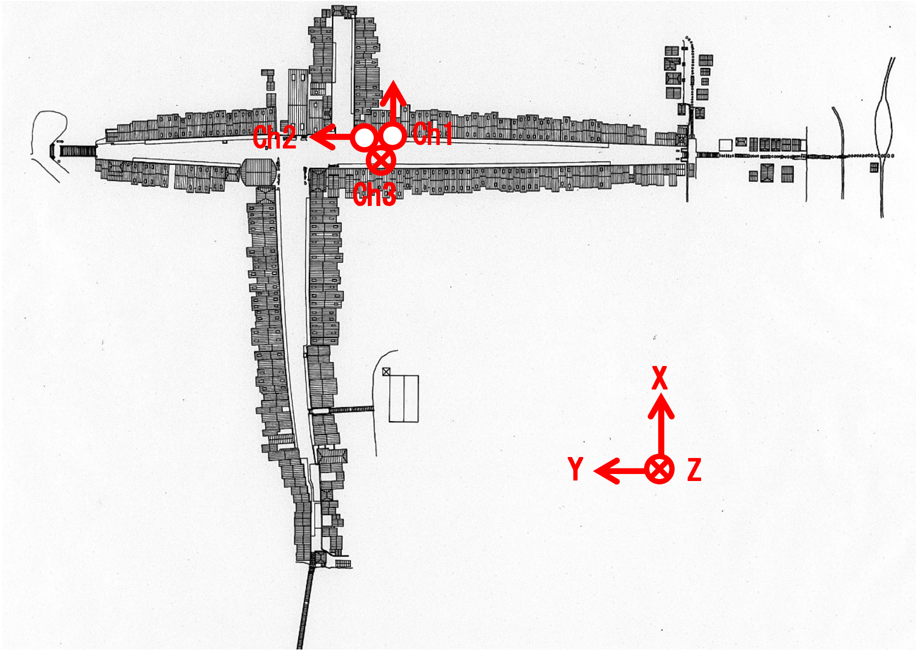


Fig.2-14 Arrangement for case 1-5

Table 2-1 Series of micro tremor measurements

	case No.	Sensor point and direction
omo sebua	case1-1	Span direction
	case1-1'	Span direction (in-plane on the floor)
	case1-4	Span direction for vibration mode
	case3-1	Span direction for manpower excitation
	case1-3	Ridge direction for vibration mode
	case3-2	Ridge direction for manpower excitation
	case1-2	Ridge direction (in-plane without basement)
	cese1-2'	Ridge direction (in-plane)
	case1-6	Beam level for orbit
	case1-7	Span direction (in-plane on the beam level)
	case1-5	ground
omo hada	case2-1	Span direction on the floor level
	case2-2	Ridge direction on the floor level
	case2-3	Span direction on the beam level
	case2-3'	Span direction for manpower excitation
	case2-4	Ridge direction on the beam level
	case2-4'	Ridge direction for manpower excitation
	case2-5	For vibration mode and orbit

2.2 Omo sebua

Transfer function calculated from the micro tremor records revealed that the natural frequency was 2.0 Hz and 3.1 Hz for X direction (=span direction) and for Y direction (=ridge direction), respectably at *Omosebua*. (see Fig.2-15～2-19)

The amplitude shown in Fig.2-20 is average of the measurement of case1-4 and 1-3. Traditional houses structurally consist of three parts; roof structure, middle structure for living space and understructure. The under-structure is so stiff in both directions because of thick braces, while there was a difference in stiffness at middle structure (living space) between span and ridge directions. The vibration mode in span direction indicated that the large displacement was caused in span direction at the middle structure, so that this layer is weak against earthquake loads in span direction. The large displacement might be caused by different shear wall quantity between span and ridge directions.

Fig.2-22 and 2-23 show the vibration mode in horizontal in-plane of floor level and beam level calculated from the amplitude of the transfer function measured in case1-1', 1-2', and 1-7. It seems that the large displacement at middle structure in Y direction (=ridge direction) is caused by thick walls. On the other hand, there are differences in vibration mode between floor level and roof level in X direction (=span direction). It can be considered that horizontal in-plane rigidity of the floor was insufficient. The vibration mode of beam level was affected by walls in span direction at backside of omosebua. However, further study should be needed to evaluate the differences between floor level and roof level.

The damping factor was calculated from the free vibration test. Those tests showed the damping factor of 2.5% and 2.1% in span direction and in ridge direction, respectively. Fig.2-21 shows free vibration waveforms produced by man power. It can be considered that the damping factor is slightly lower than that of Japanese traditional wooden houses.

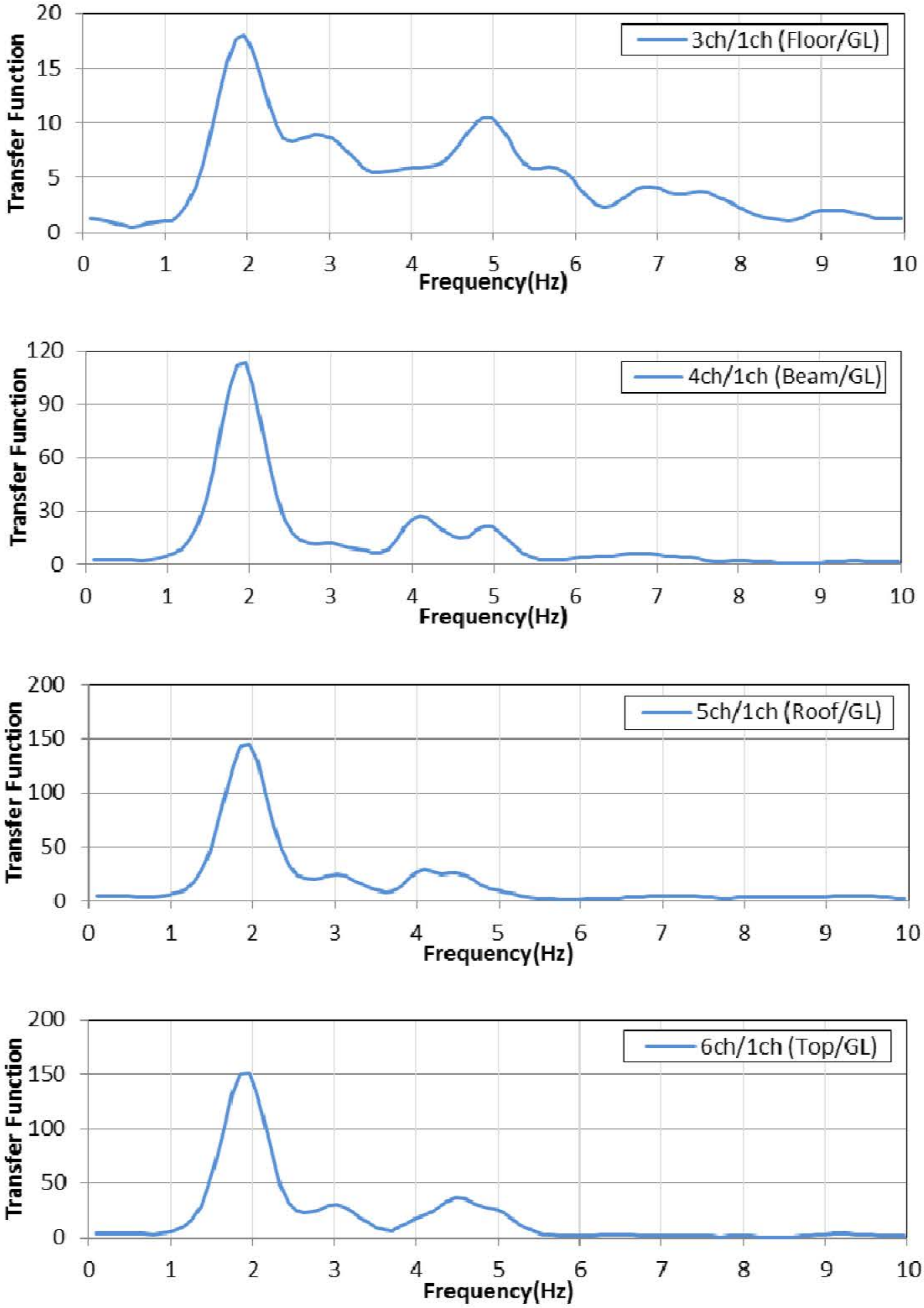


Fig.2-15 Transfer Function measured in case 1-4 (span direction)

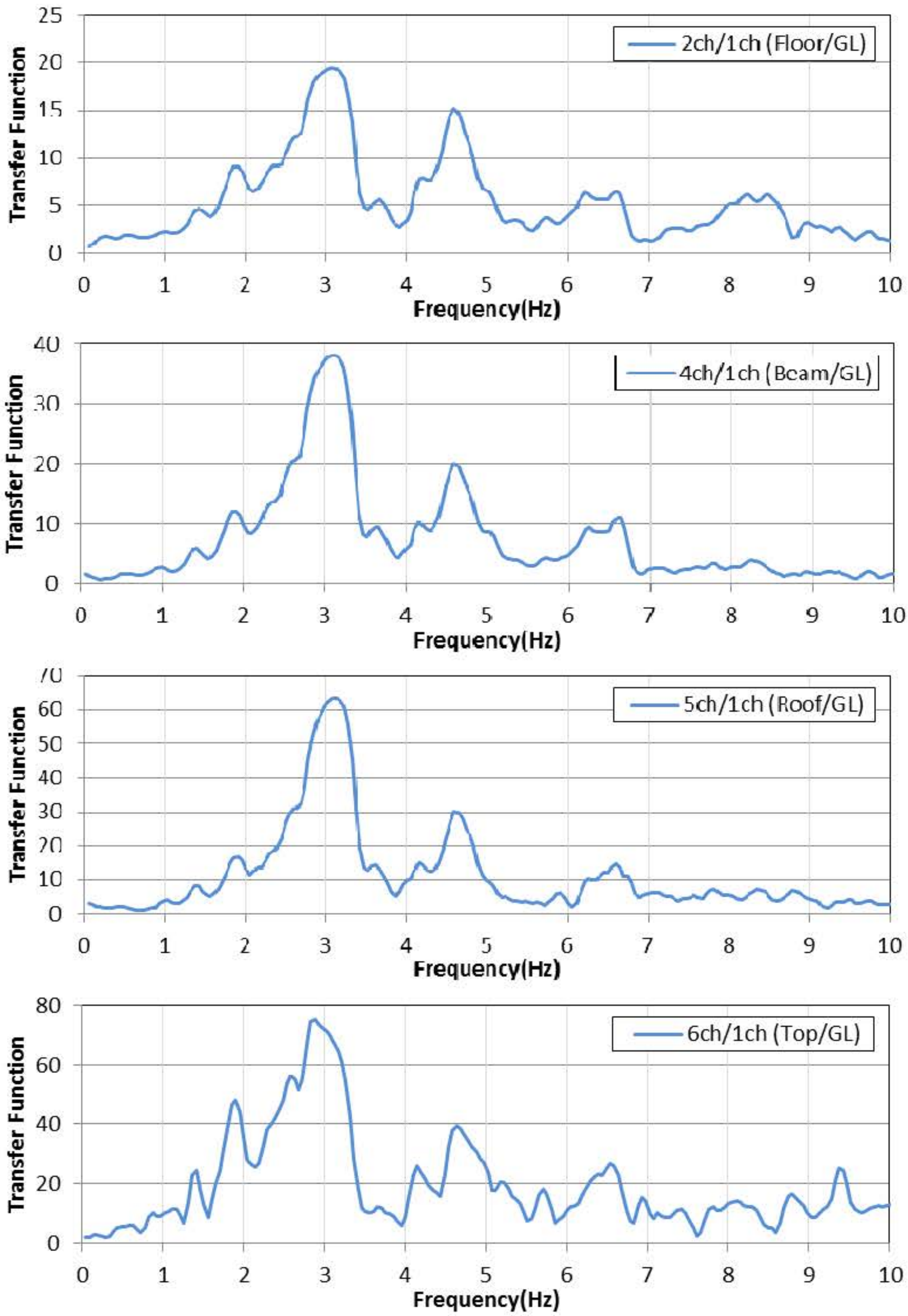


Fig.2-16 Transfer Function measured in case 1-3 (ridge direction)

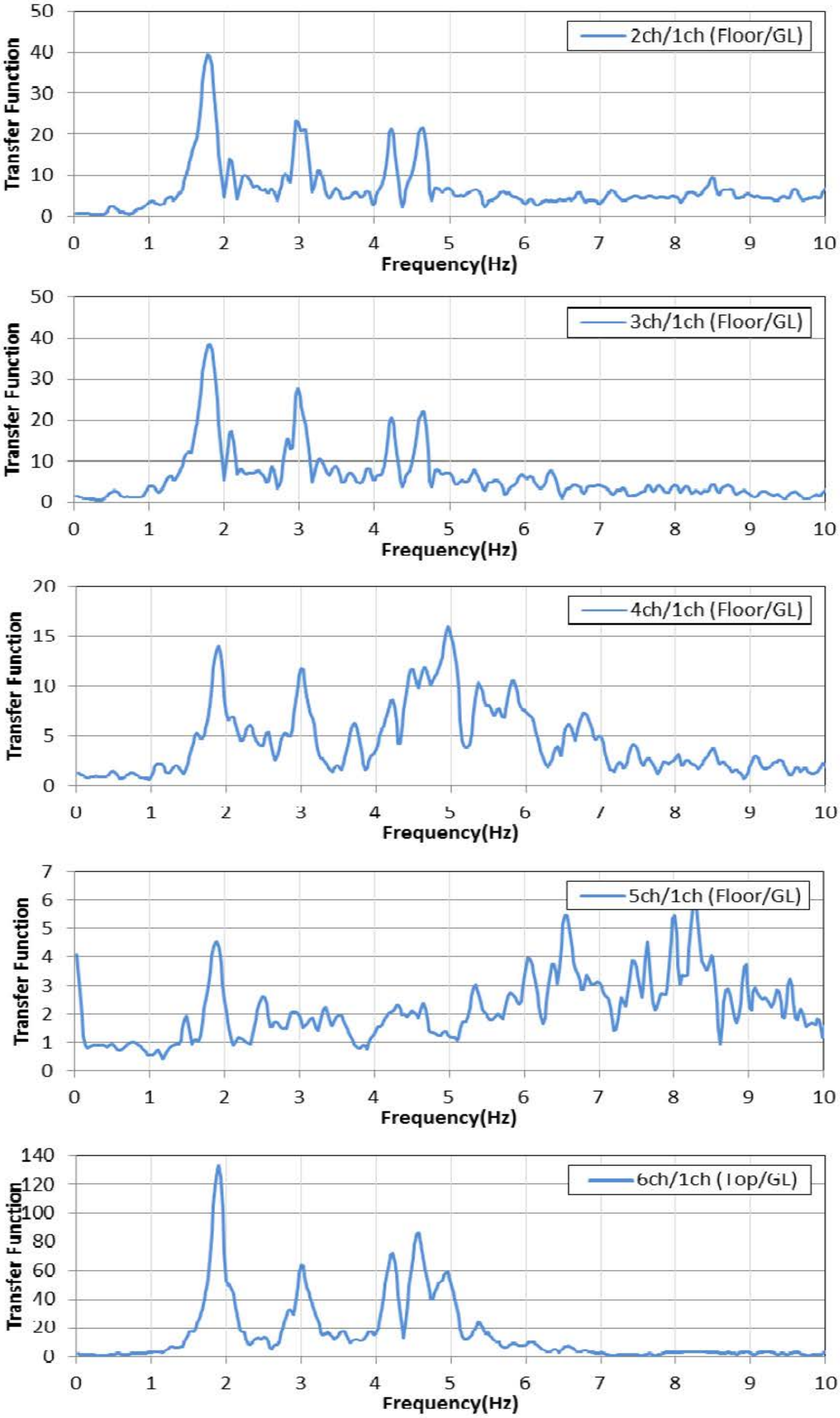


Fig.2-17 Transfer Function measured in case 1-1' (span direction)

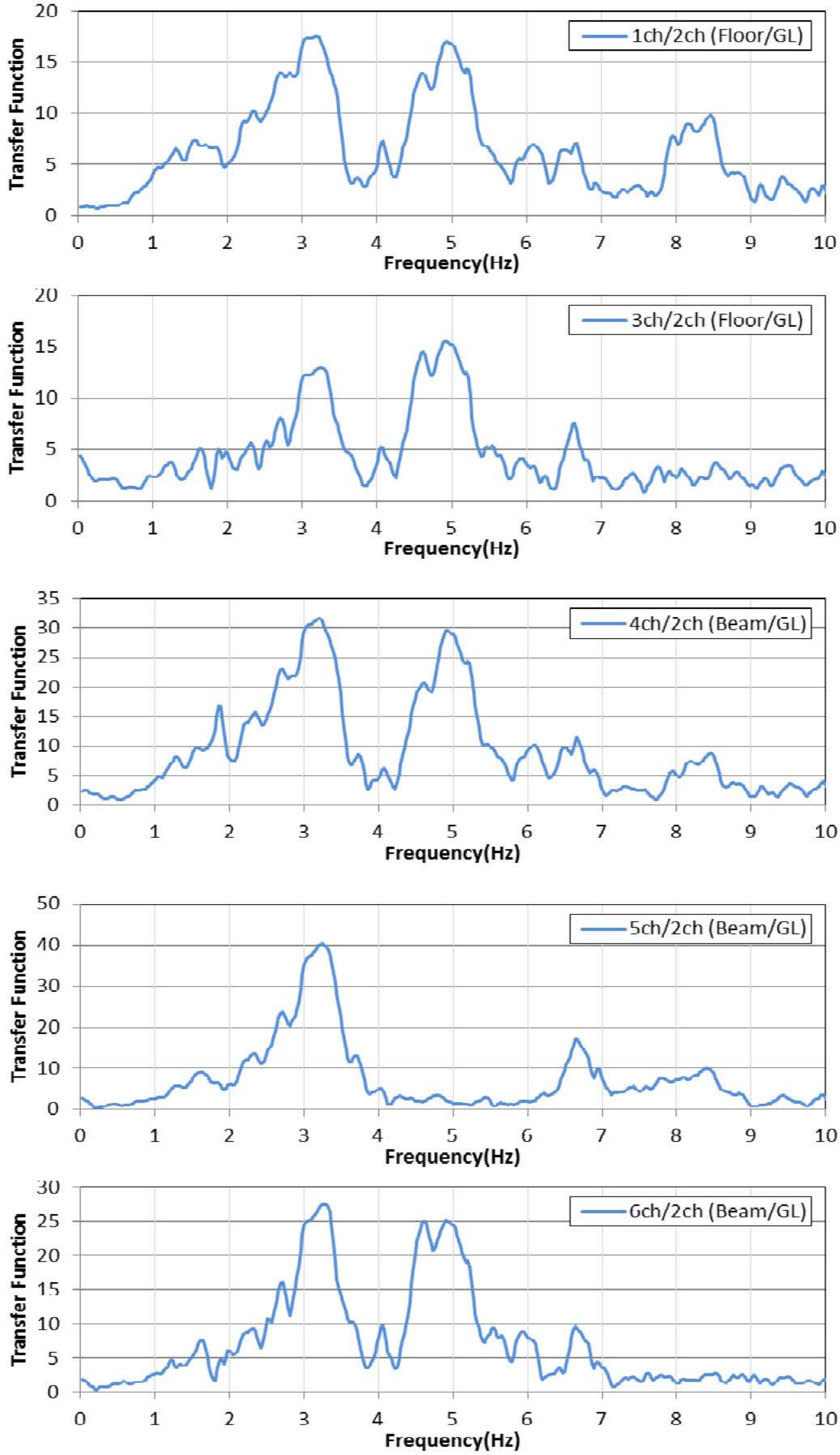


Fig.2-18 Transfer Function measured in case 1-2’ (ridge direction)

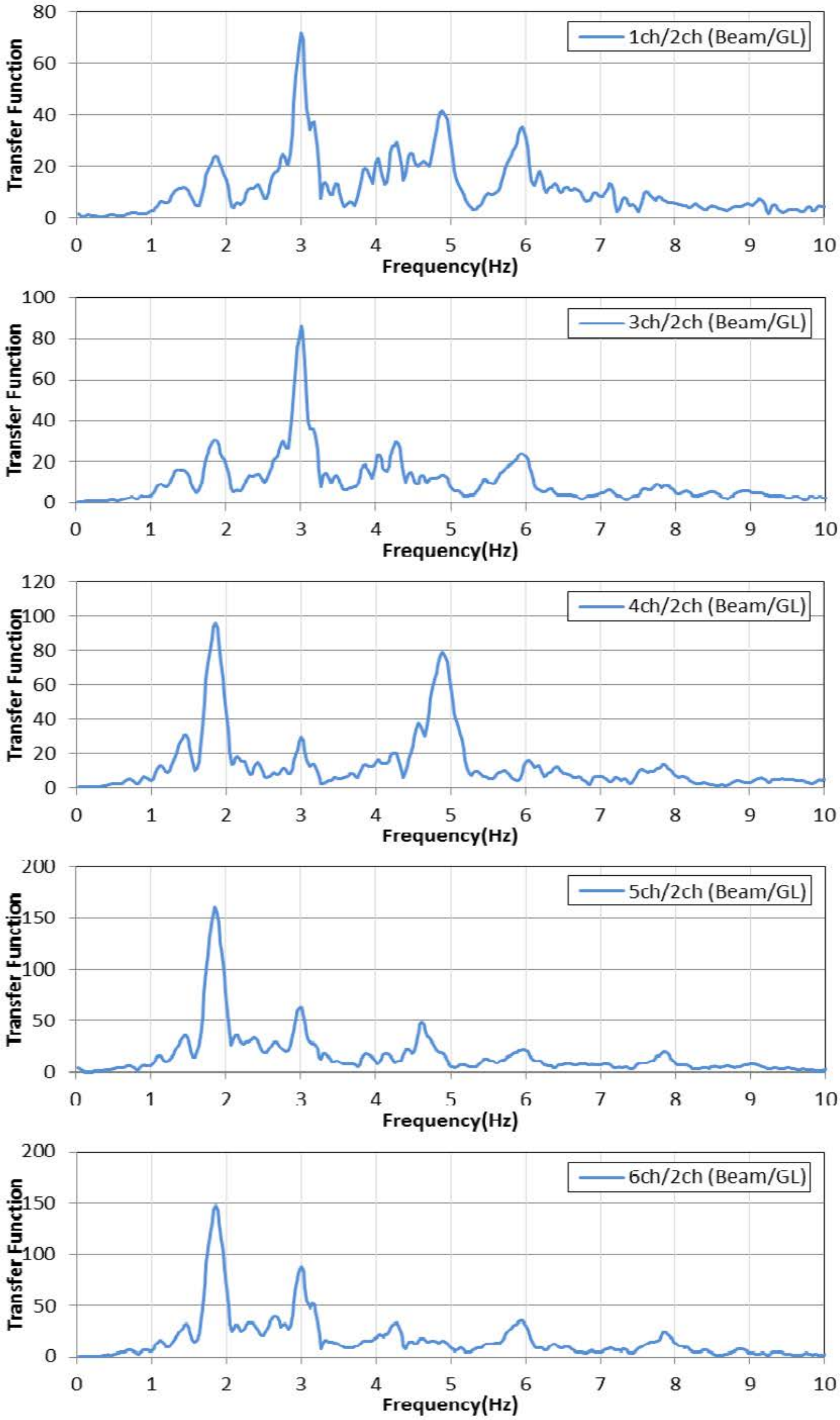


Fig.2-19 Transfer Function measured in case 1-7 (span direction)

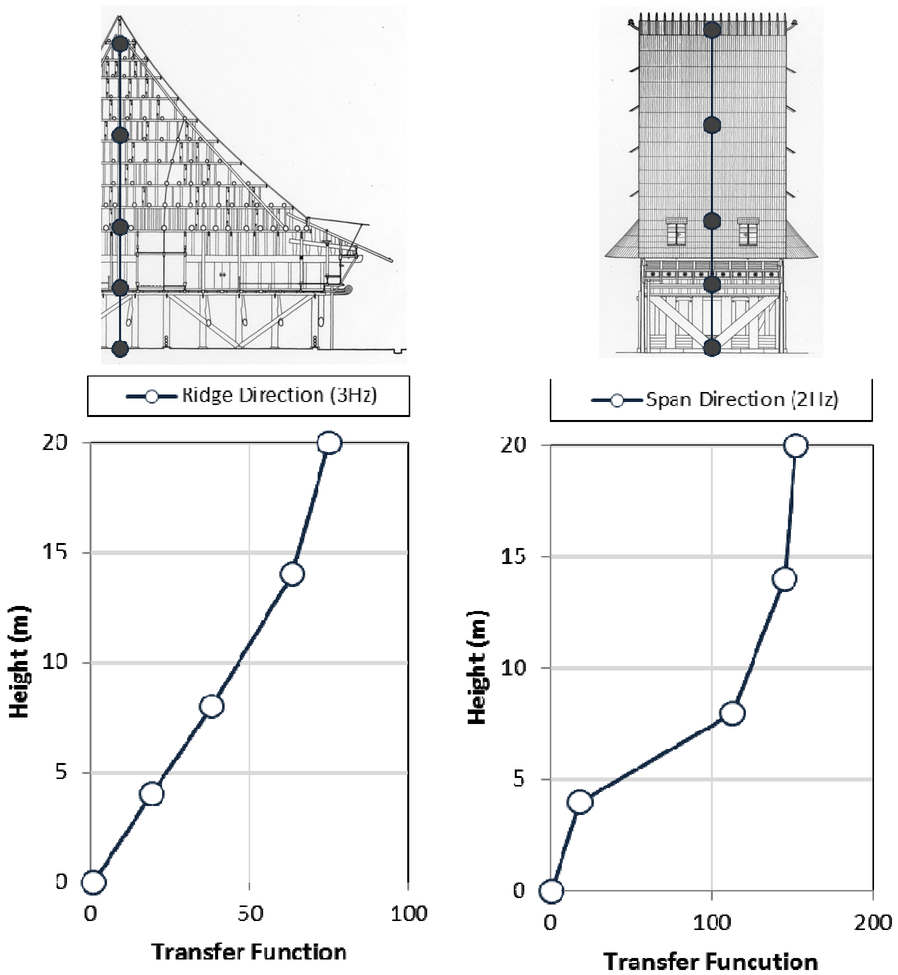


Fig.2-20 Vibration mode of Ridge Direction

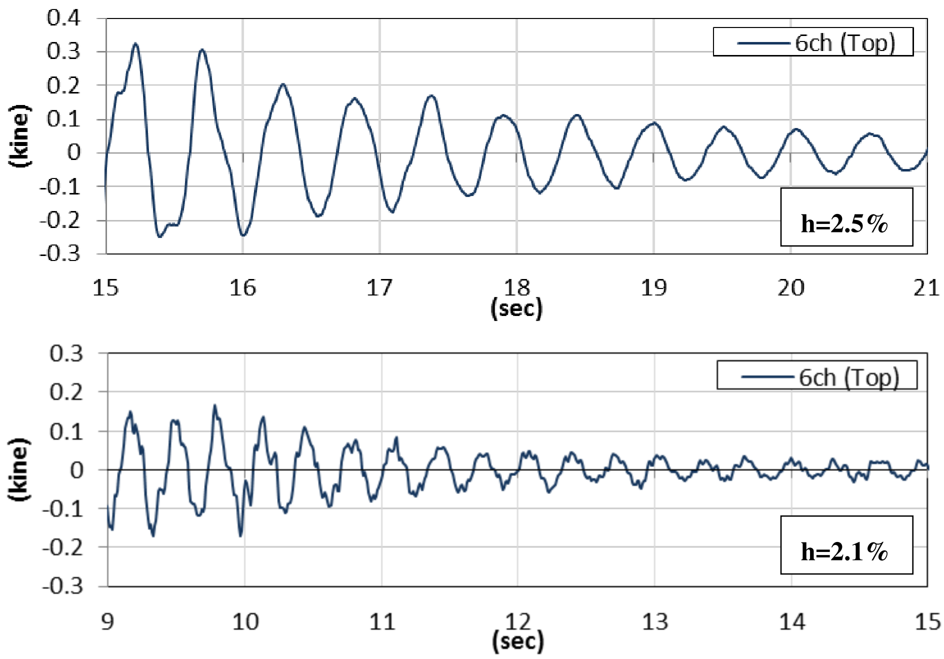


Fig.2-21 free vibration wave (upper: span direction / lower: ridge direction)

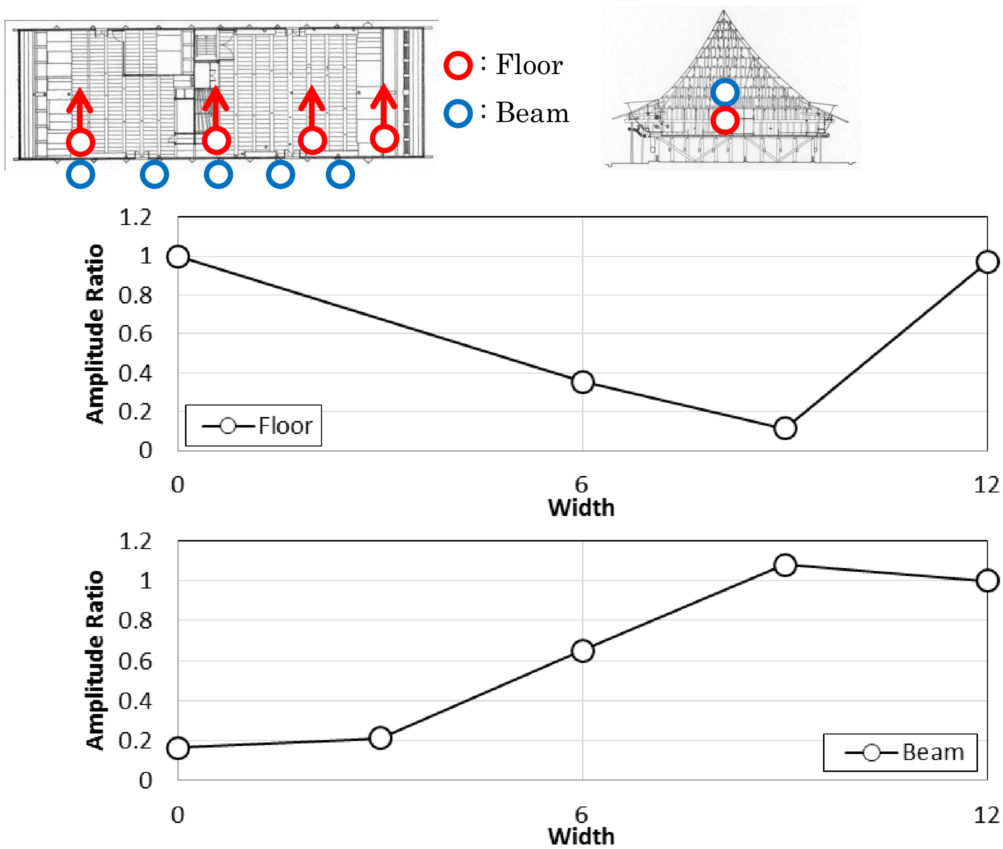


Fig.2-22 Vibration mode of Span direction (2 Hz)

(Upper: Floor level, Lower: Beam level)

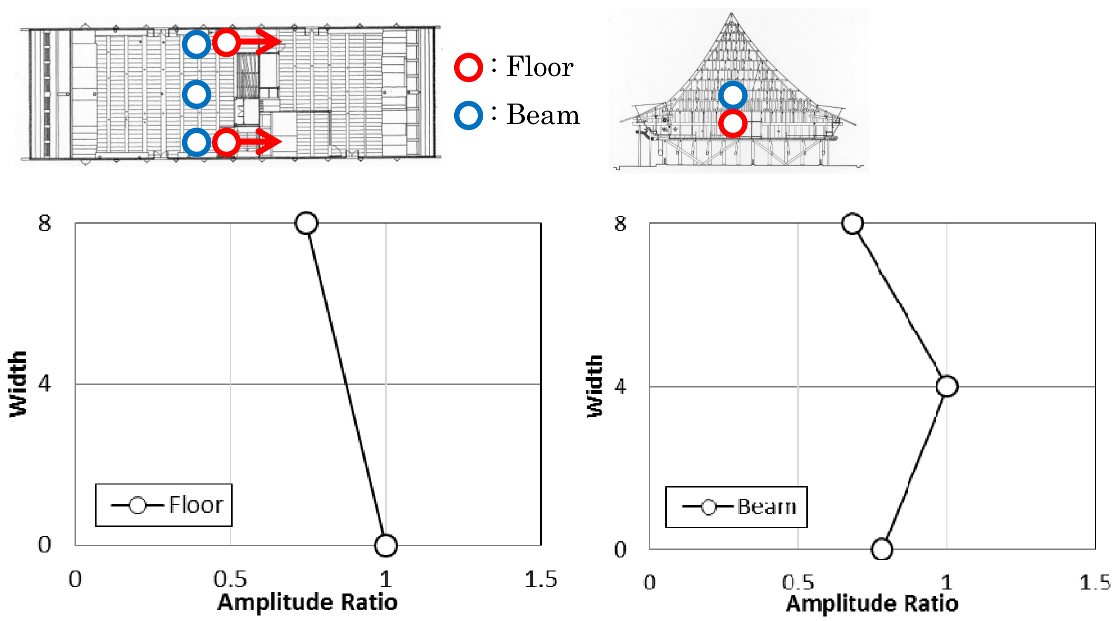


Fig.2-23 Vibration mode of Ridge direction (3 Hz)

(Left: Floor level, right: Beam level)

2.3 Omo hada

Transfer function calculated from the micro tremor records showed that the natural frequency was 3.4 Hz in X direction (=span direction) at *Omohada,* shown in Figs.2-24, 2-25, and 2-28. On the other hand, the natural frequency in Y direction (=ridge direction) was not observed clearly, which could be considered 5～5.5Hz, shown in Figs.2-26, 2-27, and 2-29. The significant difference could not be found in the natural frequency between the house roofed with GI sheet and the house roofed with Sago leaves.

The vibration mode for the first mode determined from the amplitude of the transfer function which measured at case 2-5 from the foundation to the measures points are presented in Fig.2-30. It should be noticed that the story drift at middle structure (living space) in span direction is larger than that in ridge direction, caused by stiffness of walls in ridge direction. Additional sensors should be put on the roof frame to calculate vibration mode in more details for further study.

The damping factor was calculated from the free vibration test as 5～6% and 7% for X direction and for Y direction, respectively. This record showed that the damping factor of omohada was high in comparison with that of omosebua. Fig.2-31 shows the free vibration waveforms produced by man power. The recorded waveform did not show the features of free vibration with damping particularly in ridge direction, therefore, it would need more survey to exactly evaluate the damping factor.

The groups of Omohada stand side by side, connected with one passage. It could be considered that such connecting condition caused coupling effect that would be effective in reduction of the structural response. The man power excitation tests were performed to verify this effect on the dynamic performance. When the house No.① was excited by manpower, the house No.④ started to vibrate with its natural frequency, shown in Fig.2-32.

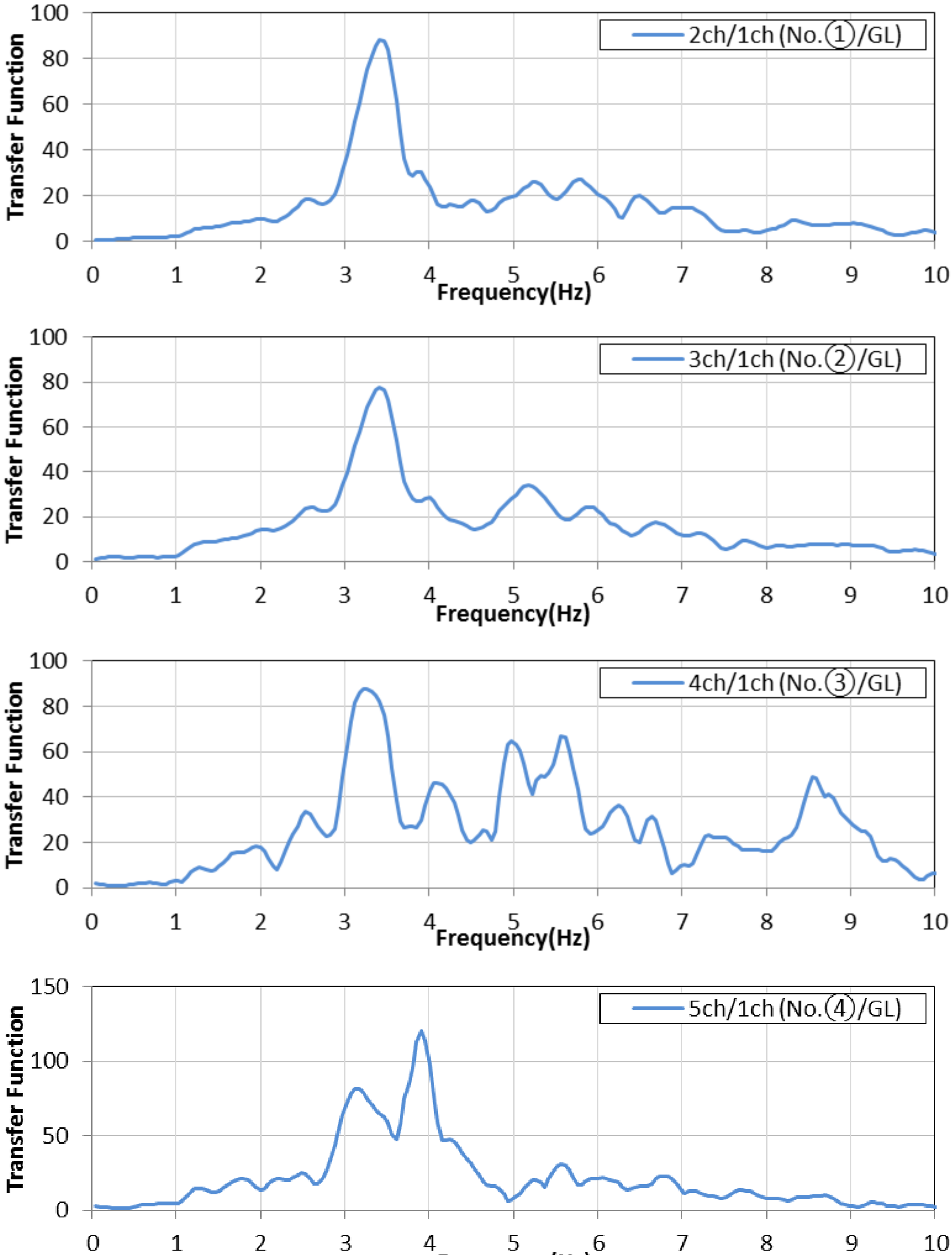


Fig.2-24 Transfer Function measured in case 2-3 (span direction)

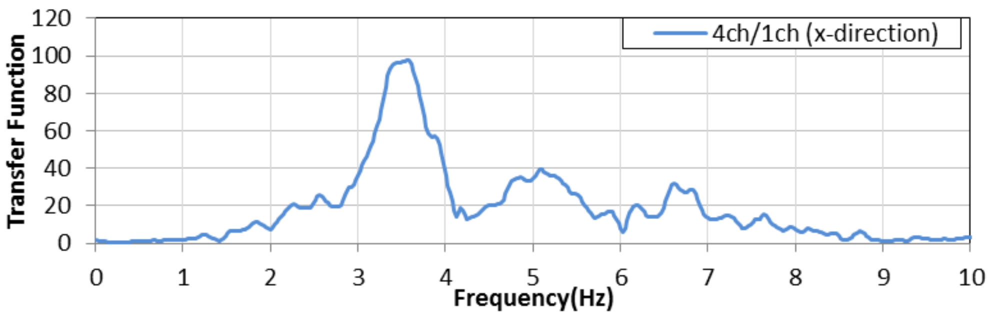


Fig.2-25 Transfer Function measured in case 2-5 (span direction)

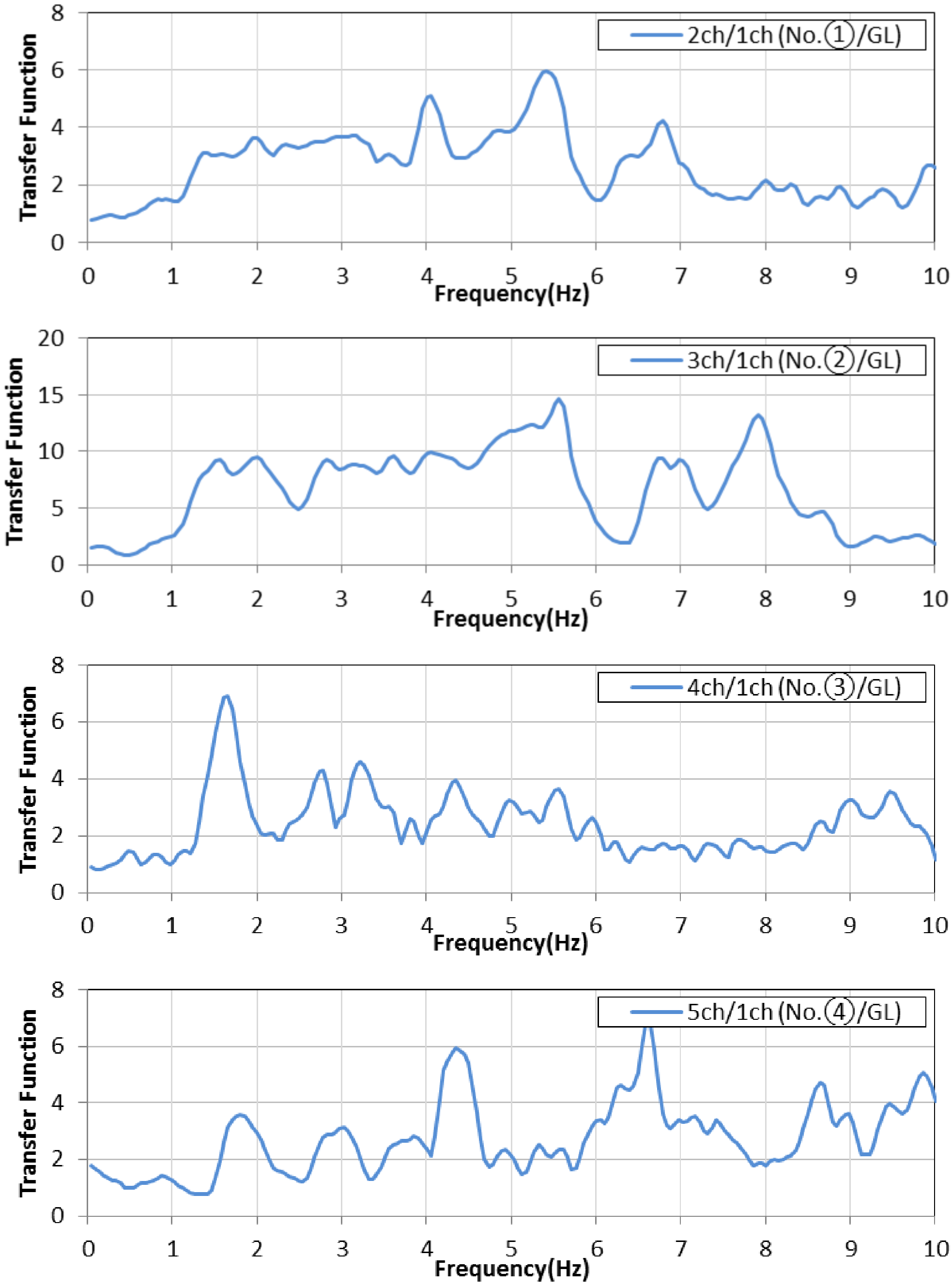


Fig.2-26 Transfer Function measured in case 2-4 (Ridge direction)

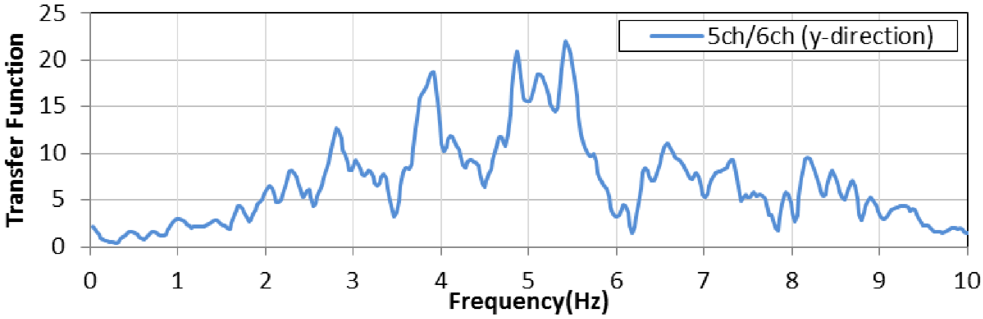


Fig.2-27 Transfer Function measured in case 2-5 (Ridge direction)

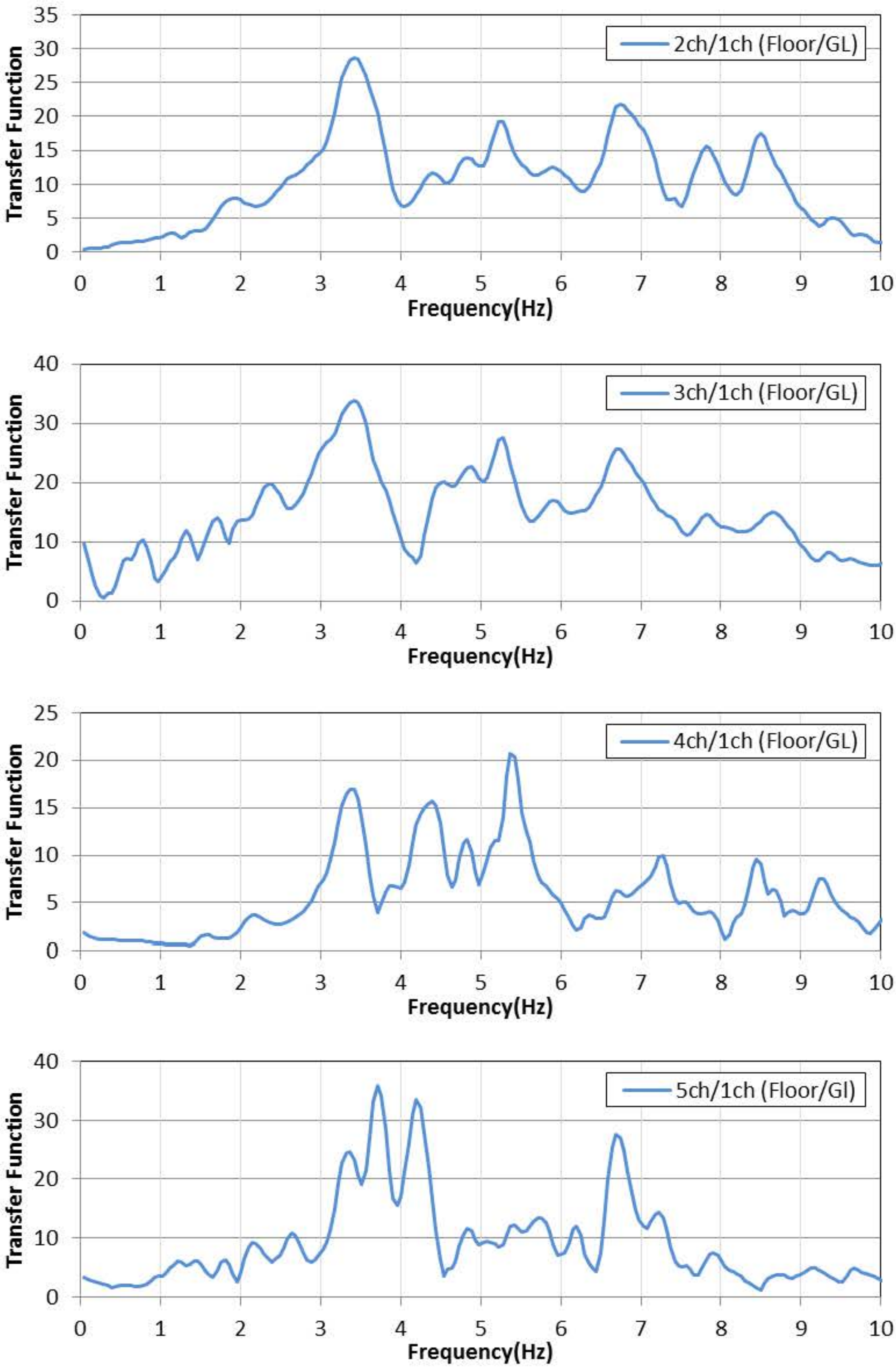


Fig.2-28 Transfer Function measured in case 2-1 (Span direction)

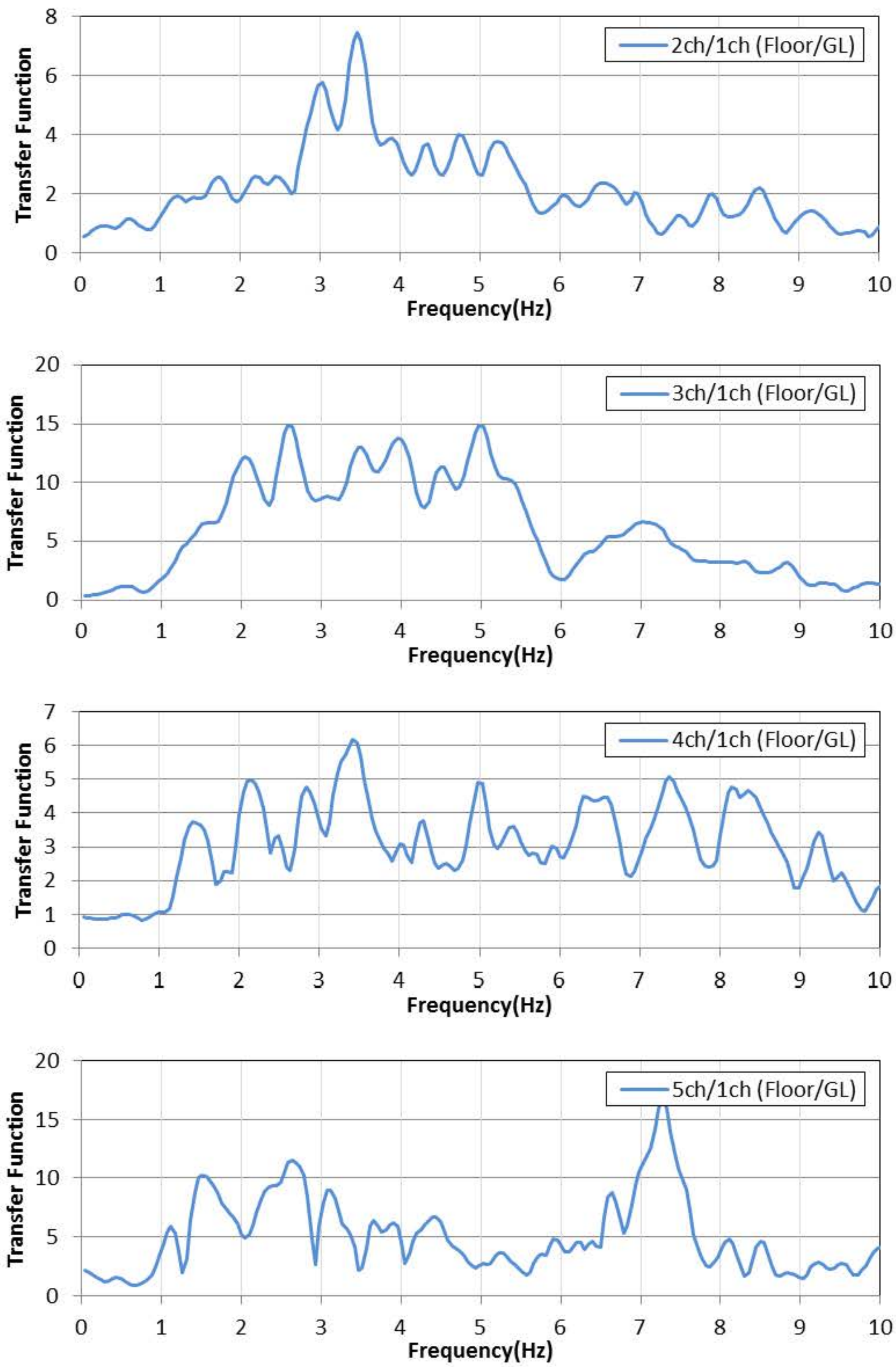


Fig.2-29 Transfer Function measured in case 2-2 (Ridge direction)

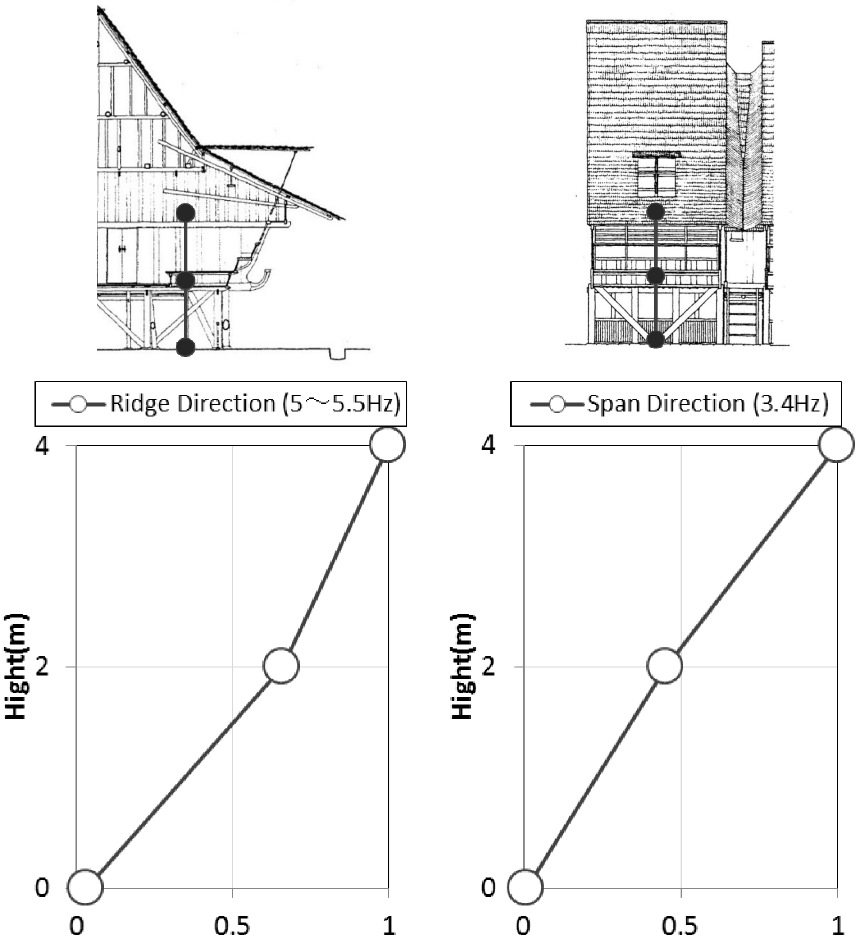


Fig.2-30 Vibration mode of *Omohada*

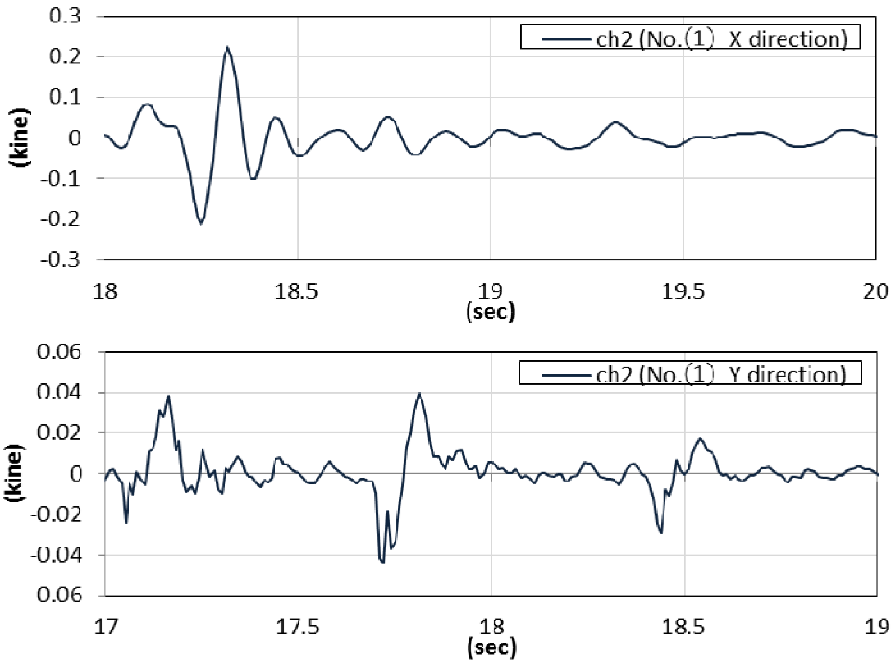


Fig.2-31 Free vibration waveform (upper: span direction / lower: ridge direction)

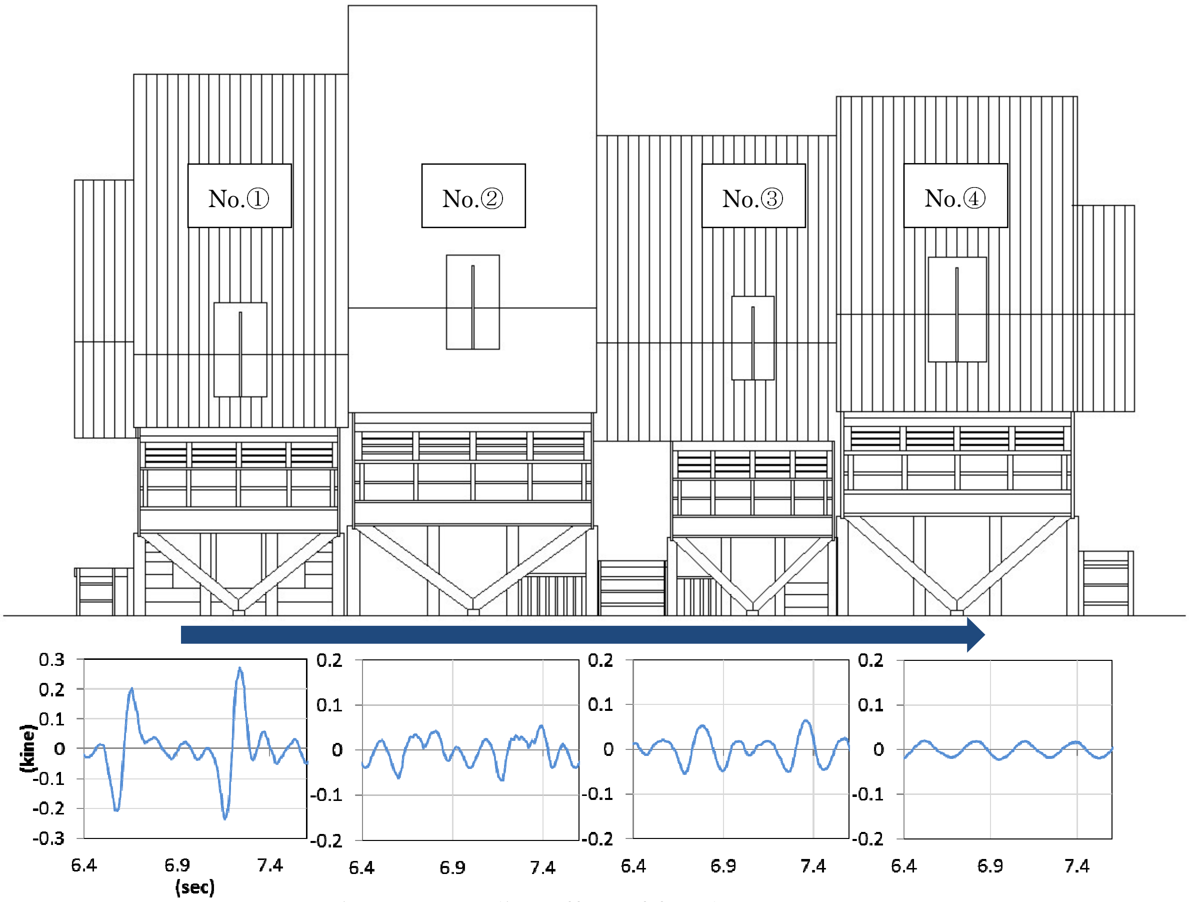


Fig.2-32 Coupling effect of four houses

2.4 Concluding Remarks

The natural frequency in span direction was lower than that in ridge direction at both of *omosebua* and *omohada*, indicating the structural stiffness in span direction is more flexible than that in ridge direction. It was considered that there is a difference in dynamic behaviors between two directions caused by braces at understructure, and roof structure, and walls at middle structure.

Although the fundamental characteristics peculiarity of *omosebua* were made clear from the micro tremor measurement, it would need more study to evaluate the seismic safety.

Chapter 3 Survey of Structure and Deterioration

3.1 Introduction

Nails were not used for construction of the traditional houses in Nias, therefore, the detail of joints are important for the structural analysis. We surveyed *omosebua* and *omohada* especially of joints to understand the detail. This survey was performed by using tape measure and laser range finder (see Photo.3-2).

In addition, deterioration and deformation of the timbers were inspected in *Omosebua* in order to discuss the restoration methods by NITTO (Tokyo Univ. of the Arts). The survey was performed as the followings; 1. Visual inspection, 2. Percussion tests using wooden hammer. 3. Using Laser Marking Equipment to investigate a lean of frame or differential settlement

3.2 Results of Survey

3.2.1 Survey of Deterioration of *Omosebua*

1) Foundation/ Under the floor

It was very humid under the elevated floor, in particular, at the corner of northeast where was close to the next house. It was unclean condition because of scattered garbage. The foundation stones did not have cracks so that the stone cut out from natural stone, however, conspicuous differential settlement were obviously found.

Both columns and braces were seriously damaged by attack of termite. (see Photo.3-3) It seems that the timbers in the living space were already damaged by termite which came from the columns at under-floor. From this survey, 29 columns and 10 braces should be replaced because of serious damage by termite. Most of those timbers seem to be new members or second-used members, which made it difficult to identify the members originally used.

The maximum inclination of columns was 10/100, of while most of columns were inclined 4/100. The maximum differential settlement of columns was 13 cm. As the members under floor are easy to be damaged by termite and decay, those timbers have been replaced with new members quite frequently using conventional method (; dig around the target column cornerstone, replace the column, and put the cornerstone back to the original position.). The conventional method might cause remarkable differences in inclination and differential settlement of each column.

Photo.3-1 Laser Marking Equipment

Photo.3-2 Laser range finder
(Source: Leica Geosystems-Japan)

Photo.3-4 Distortion of living space floor

Photo.3-3 Bite mark of termite and
laser light of Laser Marking Equipment

2) Space of living

Some of the side columns tilted toward inside, of which maximum inclination was 6/100. Irregular settlement of floor line was also found as deterioration. The floor was not horizontally flat, but it was curved as the center was higher than the side end of the room in span direction. There was 16 cm difference in height between the center and the end. This deformed floor was originally designed as the present traditional wooden houses were originated from ships. Harms by termite were found in the living space particularly at the back room.

3) Roof structure

The Nias offshore earthquake of 2005 caused damages to the roof frame and roofing material (cf. chapter1). The roof frames decayed in several places because of rain leaking from roof apertures caused by the earthquake. Harms by termite were also found at the roof frame. (see Photo.3-5) It could be considered that the roof frames of traditional house were damaged by earthquake because of those deteriorations.

Photo.3-5 Harms by termite and roof frame

3.2.2 Survey of Structure

We observed the structure of both *omosebua* and *omohada* (In particular, the house which is roofed with Sago). Detail of joints and dimensions were recorded by this structural survey. Although there are some differences in numbers or in dimensions of structural members between *omosebua* and *omohada*, the construction method of both structures is basically the same.

1) Connection between houses

Photo.3-6 shows the entrance which connects neighboring houses. The detail of these connections is important to assess interaction and coupling effect between houses (cf. chapter2). The passage is supported by both sides of columns using wooden pegs (see Fig.3-1). Some traditional wooden houses have timbers connecting walls of neighboring houses above the passage (see Photo.3-7). On the other hand, there are only a few timbers to connect at the other side, which has only about 10 cm gap between houses, shown in Photo.3-8. Roofing materials are overlapped each other above the passage.

Photo.3-7 Above the passage

Photo.3-6 Connection between houses

Photo.3-8 Opposite opening

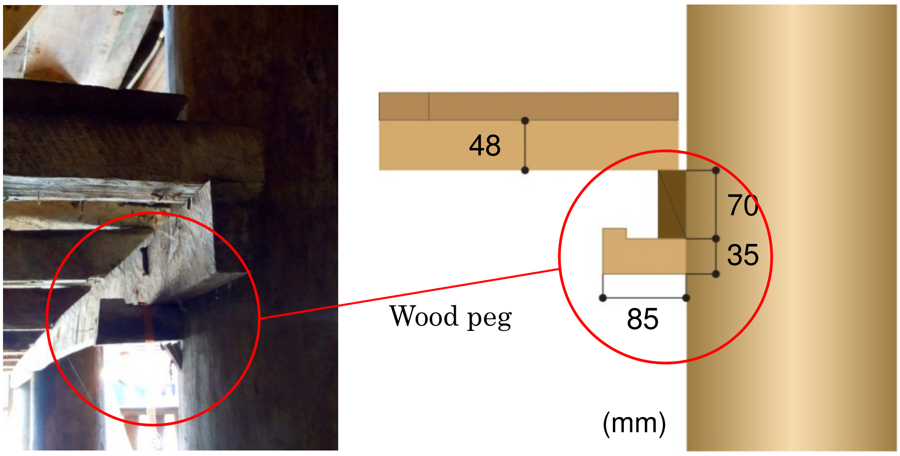


Fig.3-1 Joint of passage using wooden peg

2) Under the floor

Fig.3-2 shows the joint between a column and a horizontal member under the floor. The traditional houses have 4-row columns for span direction regardless of width of the house. Each column is connected with penetrating beam in span direction, of which ends are connected by "*kashiranuki*" in ridge direction.

They have braces for both of span and ridge direction. The braces for span direction are penetrated by horizontal members, while the braces for ridge direction are only put on the horizontal members shown in Photo.3-10 and Photo.3-12. Front façade is characterized by thick braces which are connected each other at the base (see Photo.3-11). Photo.3-13 shows the understructure and column with penetrating beam, respectively.

Harms by termite were also found particularly at the lower part of the columns, shown in Photo.3-14.

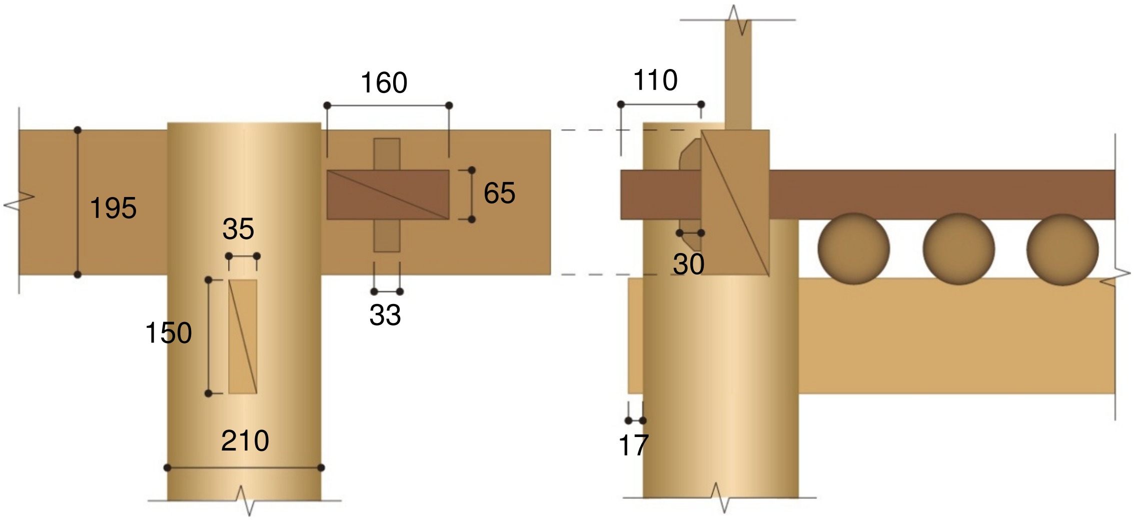


Fig.3-2 The joint around the column

Photo.3-9 Front façade

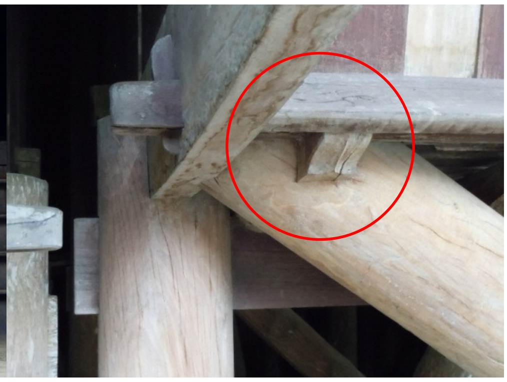


Photo.3-10 Brace with penetrating member

Photo.3-11 Base of front brace

Photo.3-12 Brace for ridge direction

Photo.3-13 Understructure

Photo.3-14 Harms by termite

3) Living space

People who live in *Bawomataruo* often spend their time at the stage facing to the main street shown in Photo.3-15, which serving both for bench and storage space (see Photo.3-17). Flesh air can blow through the house because of the main lattice opening at the stage and other two opening at the roof, shown in Photo.3-15.

The living space is surrounded by thick walls shown in Fig.3-3. The wall consisted of wooden panels inserted into mortise at the crossbeam (see Fig.3-4). Those tenon are complicated configuration to make surface area larger, which would improve strength of embedment and friction force.

Two posts which directly support the ridge of a roof stand on the floor, being separated from the columns under the floor (see Photo.3-16).

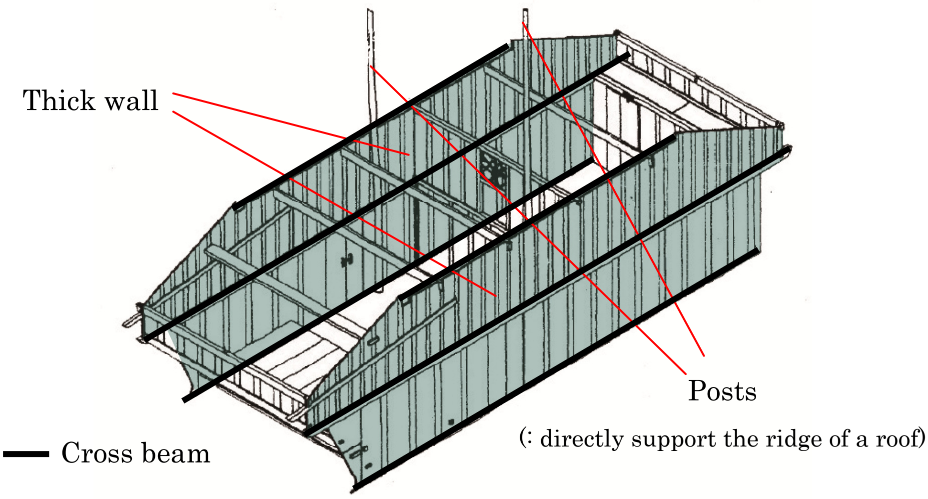


Fig.3-3 Living space (source: M. Inoue,"Housing construction method in Nias")

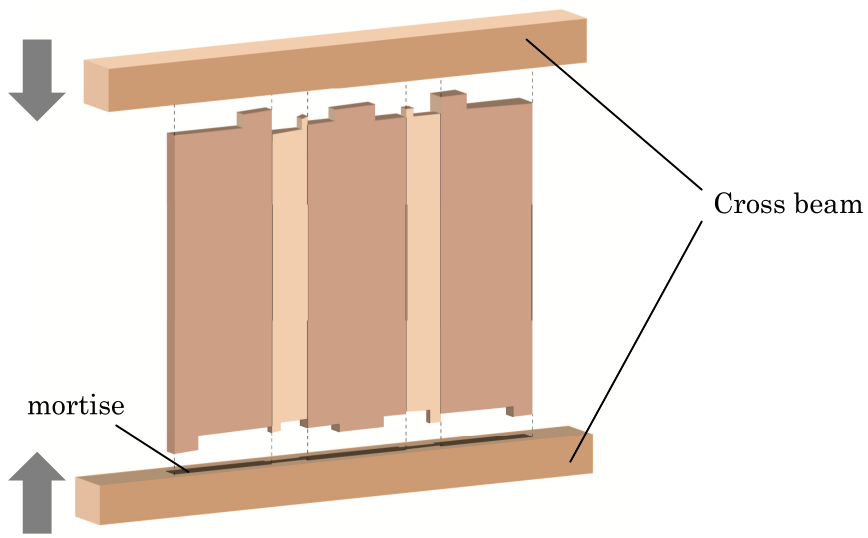


Fig.3-4 Detail of thick wall

Photo.3-15 The stage at living space

Photo.3-16 Post stand on the floor

Photo.3-17 Serving both for bench and storage

4) Roof frame

Omohada have various heights because of different number of timbers and different dimensions. According to the past studies, some of the houses were damaged by the Sumatra earthquake in 2004 and Nias earthquake in 2005. However, those damages concentrated at roof structure.

Triangular frame consisted of struts with tenon in regular interval (see in Fig.3-5) were connected with beams. There were 20 braces only for span direction, shown in Photo.3-18 and Fig.3-6. The posts which directly support the ridge of a roof were connected with triangular frame using pin, shown in Photo.3-20.

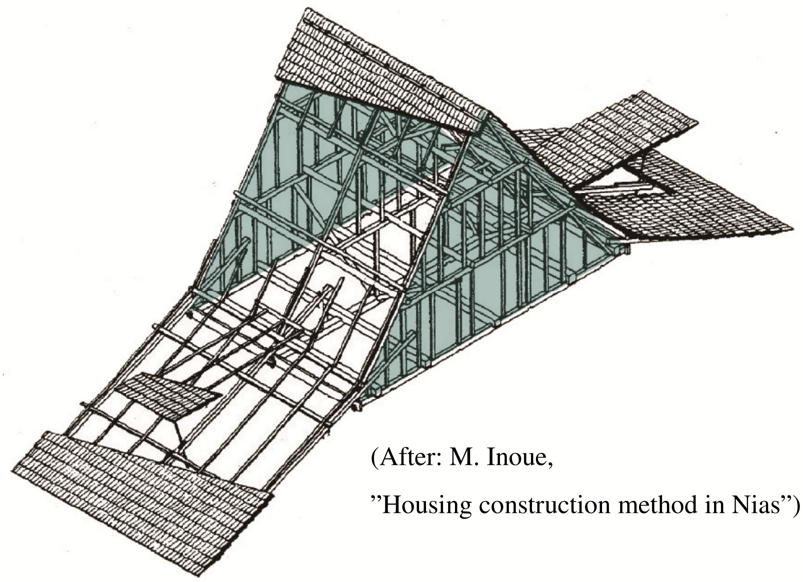


Fig.3-5 Roof structure and triangular frame

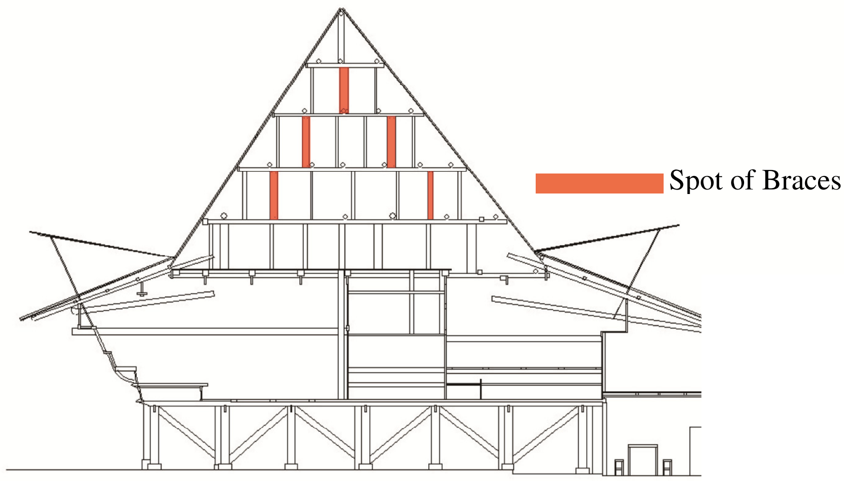


Fig.3-6 Spot of braces at roof structure

Photo.3-18 Detail of braces at roof structure

Photo.3-19 Inside roof frame

Photo.3-20 Joint of post and triangular frame

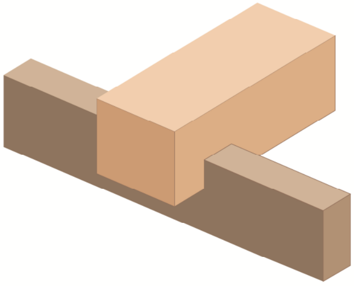
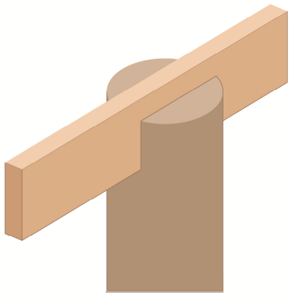
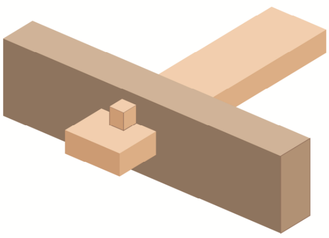
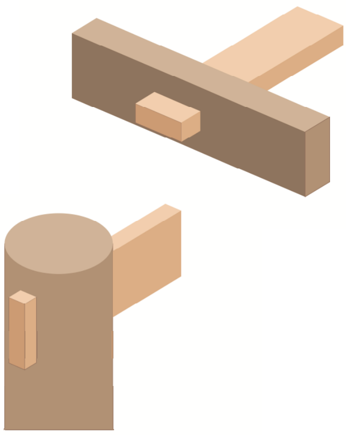
3.3 Concluding Remarks

In conclusion, joints used in the traditional wooden houses in South Nias can be categorized into 4 types from the present survey, shown in Table3-1.

Most joints can be categorized into joint No.1. There exist high rigid joints at lower part of the house, for example joint No.3 or No.4. It indicates the stability of the house.

On the other hand, we found tilting of the structures caused by the earthquakes or aging deterioration with differential settlement and harms by termite. It could be considered that those damages would reduce structural stability of the traditional houses.

Table3-1 Categories of joints

①Joint connected with notch 	■Under floor Braces for ridge direction. ■Living space Joint between beams and crossbeams. Upper part of the stage. ■Roof frame All beams connected with both side.
② *Kashira-nuki* 	■Under floor Joint between columns and cross beams.
③ Penetrating beam with pin 	■Under floor Joint between cross beams and under floor beams. ■Living space Lower part of the stage. At the middle crossbeams.
④ Penetrating beam without pin 	■Under floor Joint between columns and beams. Some of the joint between cross beams and under floor beams.

Chapter 4 Monitoring of Temperature and Humidity

4.1 Introduction

There are many houses roofed not only with Sago leaves but also with GI sheets in *Bawomataruo*. To discuss how the roof materials affected the climate condition in the roof structure, temperature and humidity monitoring was conducted. We installed hygrothermographs at two of the house of Sago leaves roof and of GI sheets roof to record temperature and humidity for half a year from Dec.12, 2011 to Jul.12, 2012

The monitoring had been carried out by using 2 sensors (LR5001, Hioki Co.). Both sensors were installed in the roof structure of houses roofed with Sago leaves and GI sheet (see Photo.4-1). Photo.4-3 shows the arrangement of the sensors.

Another monitoring to measure temperature and humidity of living space and under floor space was started on Dec.27, 2012. The data for three days were collected and analyzed. Two sensors were installed at living space and under floor space of the house roofed with Sago, shown in Photo.4-4.

4.2 Result of Monitoring

The monitoring records showed that the temperature and humidity of the house roofed with GI sheets varied more largely in a day (in 24 hours) than the house roofed with Sago leaves. The temperature inside GI sheets roof reached nearly 40℃, being higher than that inside Sago roof, shown in Fig.4-1. On the other hand, there are no clear differences between rainy season and dry season.

Fig.4-3 and 4-4 show the result of monitoring for 2 days when other sensors were installed. In comparison between the results of roof frame from Jan.1 to Jan.7, 2011 and results of living space and understructure from Jan.1 to Jan.7, 2012, the highest temperature was shown inside the roof frame. On the other hand, the humidity inside the roof frame was lowest among them. The humidity of the space under the floor is relatively higher than that of living space, indicating that humidity promote the deterioration of timbers.

Photo.4-2 Hygrothermograph

Photo.4-1 Traditional houses in which sensors were installed

Photo.4-3 Arrangement of the sensors inside roof frame

Photo.4-4 Arrangement of the sensors (left: understructure, right: living space)

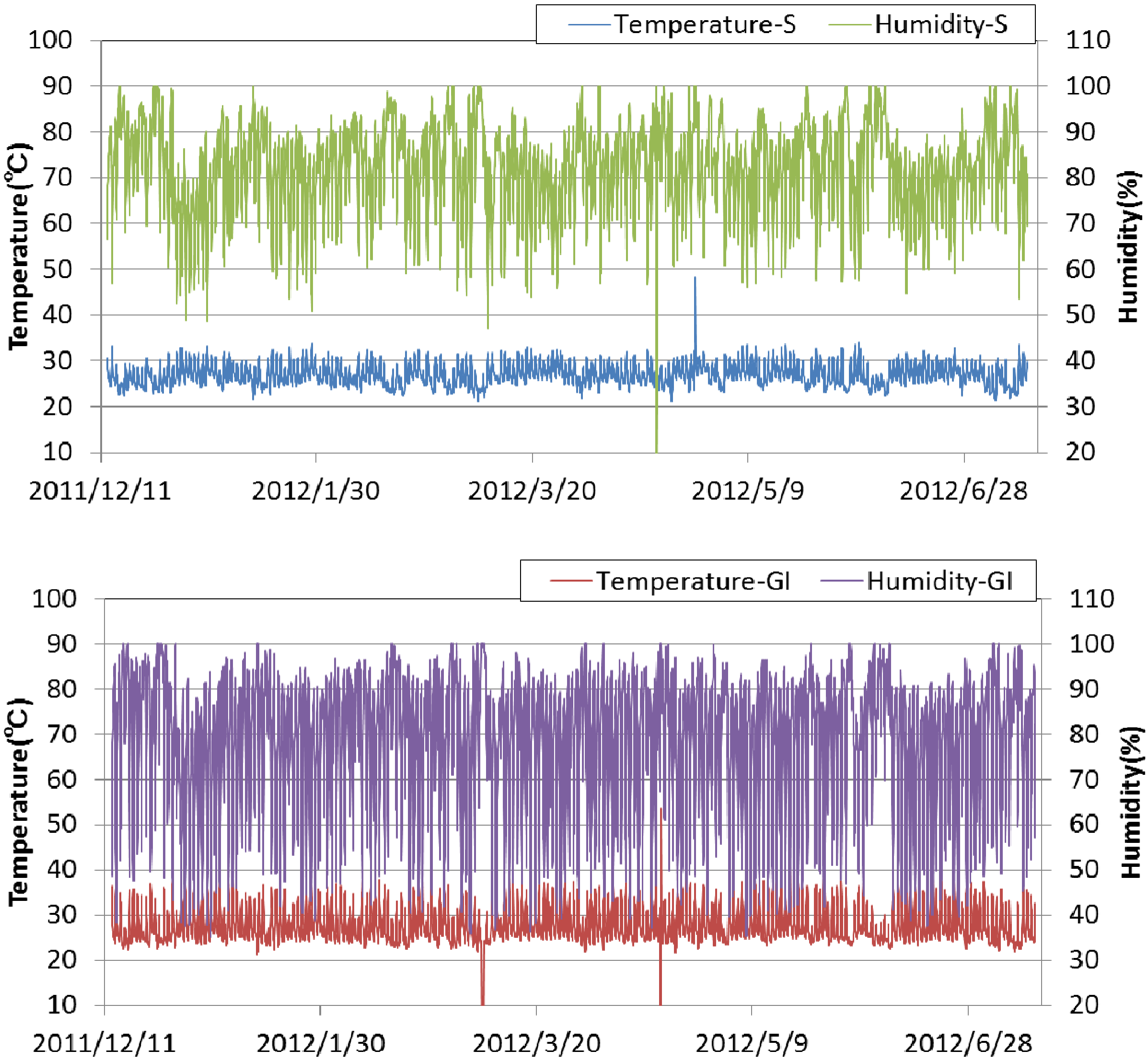


Fig.4-1 Result of monitoring inside the roof frame (S: Sago leaves, GI: GI sheet)

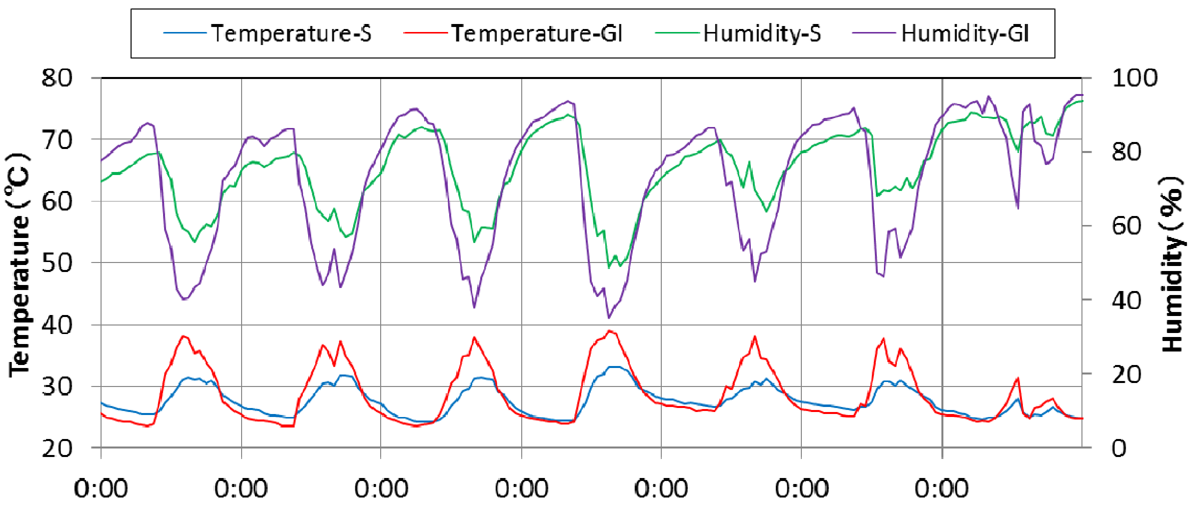


Fig.4-2 Result of monitoring for 1 week (Jan.1 ~ Jan.7, 2012)

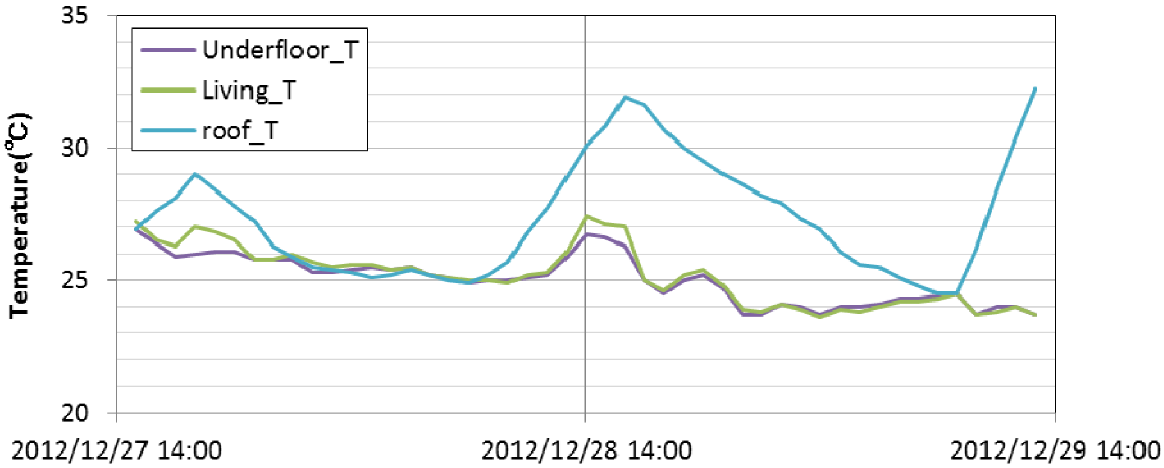


Fig.4-3 Comparison of three monitoring points for 2 days (Temperature)

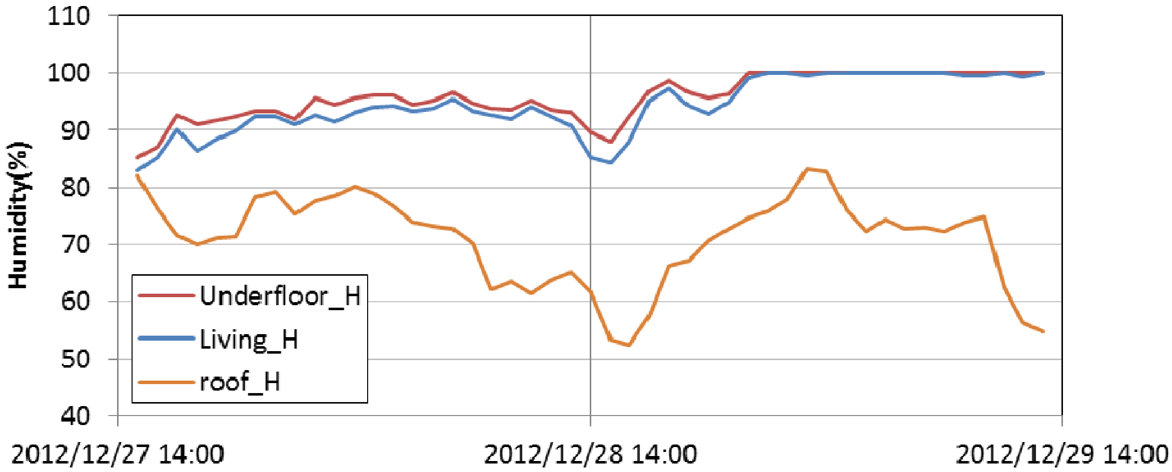


Fig.4-4 Comparison of three monitoring points for 2 days (Humidity)

4.3 Concluding Remarks

The monitoring of temperature and humidity indicated that the deterioration of timbers was caused by high humidity recorded in both Sago roof and GI sheets roof. Furthermore, timbers under floor part are prone to deteriorate as the humidity was so high there.

Further study would be needed to understand the effect of large difference between high and low humidity, observed in the GI sheet roof, on the deterioration of the wooden materials.

Chapter 5 Material Tests of Timber members

5.1 Introduction

The traditional wooden houses in Nias are constructed with local woods such as *Afoa, Berua, Manawadano, Siholi*, and so on. However there have been no reports regarding to characteristics of local timber in Nias. Therefore, material mechanical tests of those woods were conducted to obtain fundamental mechanical properties of those wooden members used for the traditional wooden house in South Nias.

5.2 Compression Test of Wood

5.2.1 Introduction

We conducted compression test of wood materials (*Berua, Manawadano, Afoa*) actually used for structure of traditional houses in South Nias. The compressive strength and rigidity of these woods were evaluated by the tests.

In the present test, the test pieces are cut down in rectangular ones (25mm×25mm×75mm). Three test specimens were made from the wooden members. Those specimens were compressed in the grain direction, shown in Table 5-1 and Fig.5-1.

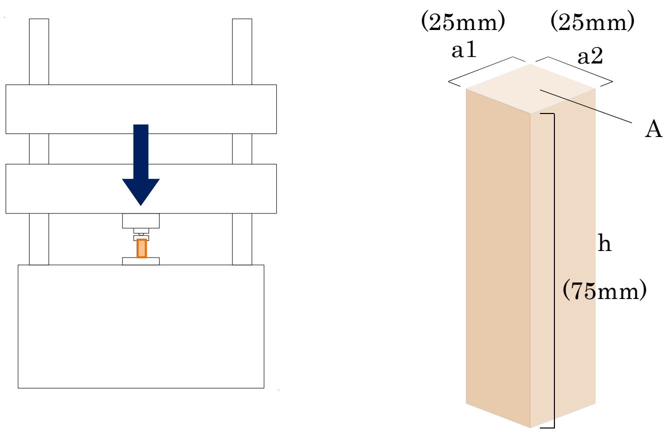


Fig.5-1 Test specimen and the way of loading

Photo.5-1 Test pieces (A:Afoa, M:Manawadano, B:Berua)

Table 5-1 Test specimen

	a1	a2	A	h	V	m	ρ
	mm	mm	mm^2	mm	cm^3	g	g/cm^3
A-1	24	24.5	588	75.5	44.4	25	0.56
A-2	25	24.5	612.5	75	45.9	23.6	0.51
A-3	25	25	625	75	46.9	22.2	0.47
M-1	25	24.5	612.5	75.5	46.2	37.6	0.81
M-2	25	24	600	76	45.6	39	0.86
M-3	23	25	575	73	42.0	39.3	0.94
B-1	25	24	600	75	45	38.1	0.85
B-2	25	25	625	76	47.5	41.7	0.88
B-3	24	25	600	76	45.6	43.7	0.96

5.2.2 Test results

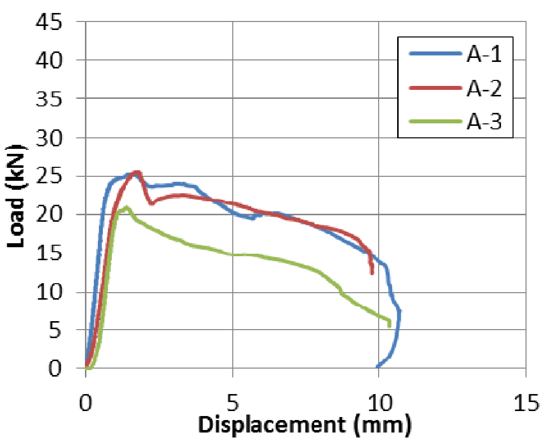
Compressive strength and displacement at the maximum strength of three kinds of woods were obtained (see Table5-2). The compressive strength of Nias timber is relatively higher than that of Japanese woods (see Table5-3). In particular, *Berua* and *Manawadano* have large compressive strength as 2 or 3 times strong as the Japanese one. Fig.5-2 describes Stress-strain relation. The rigidity of *Manawadano* and *Berua* was close to that of the Japanese woods. (see Table5-3)

Table 5-2 Result of test

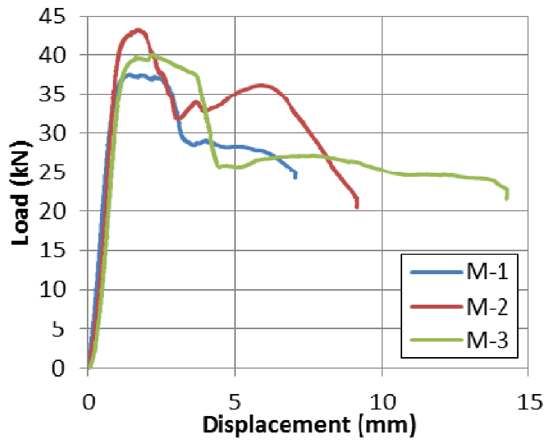
	compressive strength	displacement (max strength)	initial stiffness	stiffness
	N/mm^2	mm	N/mm^2	N/mm^2
A-1	42.9	1.7	642.0	1605.0
A-2	41.6	1.8	775.5	2571.4
A-3	33.4	1.4	572.3	2840.0
Ave(Afoa)	39.3	1.6	663.3	2338.8
M-1	61.3	1.4	1540.8	5053.9
M-2	72.0	1.7	1931.7	10893.3
M-3	69.7	2.2	465.5	7363.5
Ave(Manawadano)	67.7	1.8	1312.7	7770.2
B-1	66.8	2.7	458.3	7250.0
B-2	70.3	1.4	1641.6	13619.2
B-3	52.8	1.8	1604.4	4222.2
Ave(Berua)	68.6	2.1	1050.0	10434.6

Table 5-3 The material strength standard of timber structural design criteria (AIJ)[14]

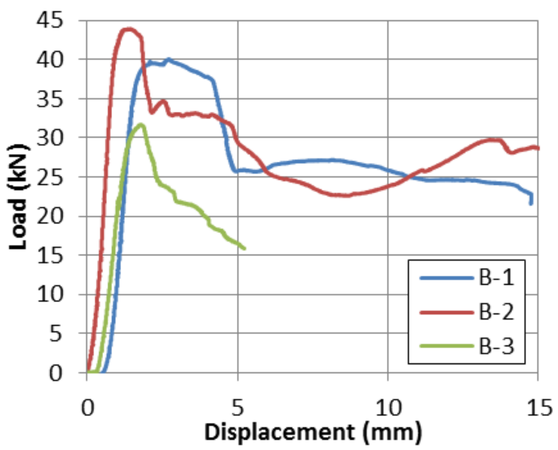
Standard strength of material			Fc	E_0
Coniferous Tree	Ⅰ class	*Beimatsu*	22.2	10000
	Ⅱ class	*Hinoki*	20.7	9000
	Ⅲ class	*Karamatu*	19.2	8000
	Ⅳ class	*Sugi*	17.7	7000
Broadleaf Tree	Ⅰ class	*Kashi*	27.0	10000
	Ⅱ class	*Keyaki, Nara*	21.0	8000
	Ⅲ class	Lauan	21.0	7000
			(N/mm^2)	(N/mm^2)



(*Afoa*)



(*Manawadano*)



(*Berua*)

Fig.5-2 Stress-strain relation

The upper part of A-1, M-2 and B-1 were smashed, on the other hand, the lower part of A-3 was compressed and splitted lengthwise. A-2 and M-3 showed shear failure behavior. The upper part of B-2 and M-1 embedded in the bottom. B-3 indicated the maximum load in a short time and cracked lengthwise because of knot the test specimen has. The condition of test pieces affected the failure mechanism.

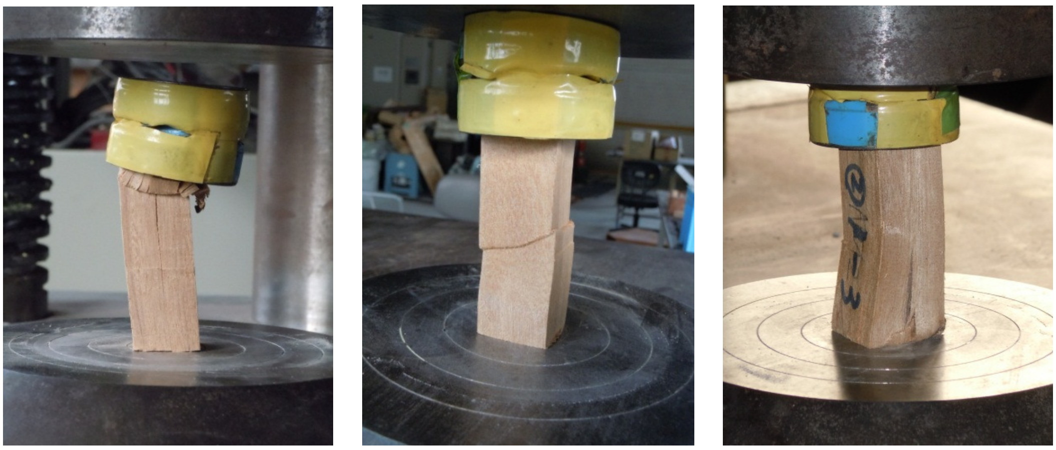


Photo.5-2 Failure mode of Afoa (from the left: A-1, A-2, A-3))

Photo.5-3 Failure mode of Manawadano (from the left: M-1, M-2, M-3)

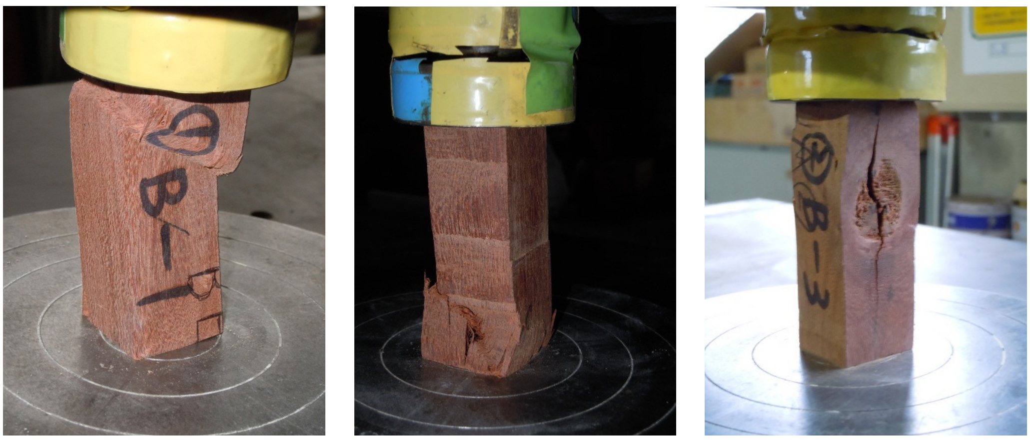


Photo.5-4 Failure mode of Berua (from the left: B-1, B-2, B-3)

5.3 Partial Compression Test of Wood

5.3.1 Introduction

We conducted partial compression test of wood materials (*Berua, Manawadano, Afoa*) used for structure of traditional houses in South Nias The partial compressive strength and embedding stiffness were measured by the test in accordance with the Manual of structural timber (published by Japan Housing and Wood Technology Center[15]).

The test specimens were cut down in rectangular ones (approximately 60mm×60mm×600mm). A total of three specimens were made from each wood, compressed partially in the direction perpendicular to the grain. The vertical load was applied through a plate of steel (10mm×100mm×300mm) . That was put in the center of the test piece, shown in Table5-4 and Fig.5-3.

The displacement of the steel plate was also measured at two points by displacement transducer (see Fig.5-4). Embedding displacement was evaluated from the average of the two transducers.

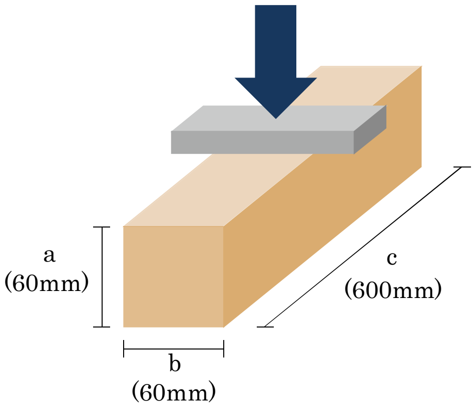


Fig.5-3 Method of loading

Table 5-4 Test specimen

	a	b	c	Density	Loading area face	Loading area back
	mm	mm	mm	g/cm^3	mm^2	mm^2
A-1	61.5	63.5	398	1.20	6600	7200
A-2	66.5	68.5	630	0.79	7400	7400
A-3	65.5	64.5	588	0.78	6500	7100
M-1	65.5	74.5	558	0.85	7600	7600
M-2	59.5	80.5	595	0.74	8300	8500
M-3	67	73.5	515	0.87	7300	7700
B-1	79.5	70	590	0.93	7200	6300
B-2	92.5	54.5	588	0.96	5600	5600
B-3	77.5	61	592	0.92	6300	6000

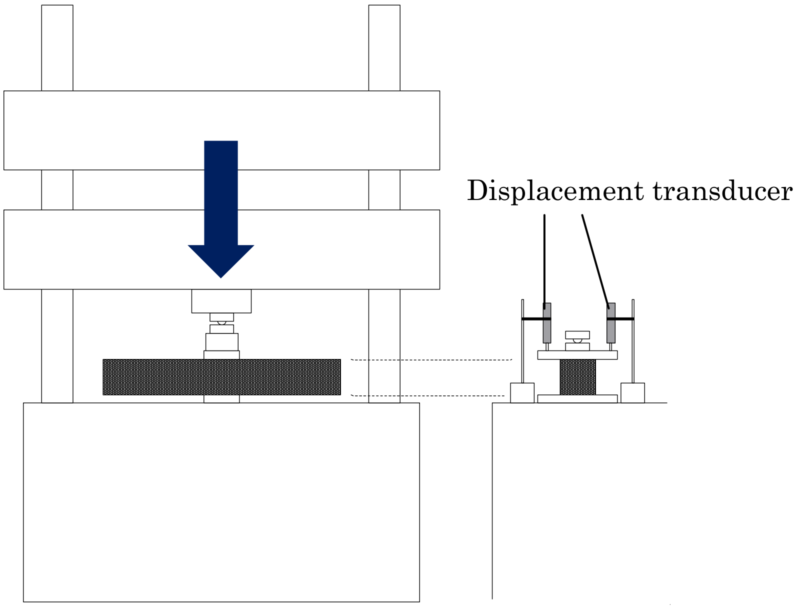


Fig.5-4 Loading instrument

Photo.5-5 Test pieces of *Afoa* (left: A-1, middle: A-2, right: A-3)

Photo.5-6 Test pieces of *Berua* (left: B-1, middle:B-2, right:B-3)

Photo.5-7 Test pieces of *Manawadano* (left: M-1, middle: M-2, right: M-3)

5.3.2 Test results

Partial compressive strength and embedding stiffness were measured (see Table5-5). The yielding strength of embedment of *Afoa* is relatively close to that of Japanese woods (see Table5-6). On the other hand, *Berua* and *Manawadano* have larger yielding strength of embedment as 3 times strong as the Japanese one. Fig.5-6 describes Load-displacement relation. The partial compression stiffness of *Manawadano* and *Berua* was higher than that of Japanese woods.

Table 5-5 Result of test

	loading area	yielding strength of embedment	strength of embedment	stiffness of embedment
	A	f_y	f	K
	mm^2	N/mm^2	N/mm^2	N/mm^3
A-1	6600	12.42	33.86	11.41
A-2	7400	10.61	20.88	11.65
A-3	6500	11.15	19.0	12.31
Afoa(ave)		11.40	24.58	11.79
B-1	7200	29.44	50.42	44.44
B-2	5600	31.43	37.23	52.38
B-3	6300	28.81	29.84	40.21
Berua(ave)		29.89	39.16	45.68
M-1	7600	22.37	47.96	39.47
M-2	8300	17.11	60.30	25.06
M-3	7300	25.75	41.10	36.53
Manawadano(ave)		21.74	49.79	33.69

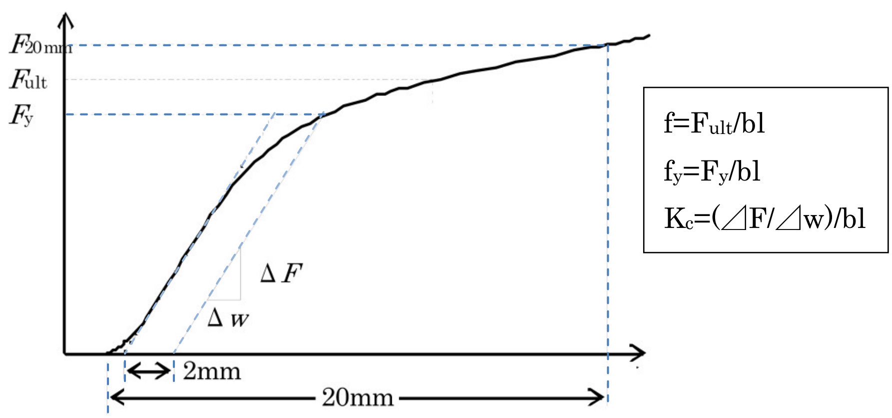


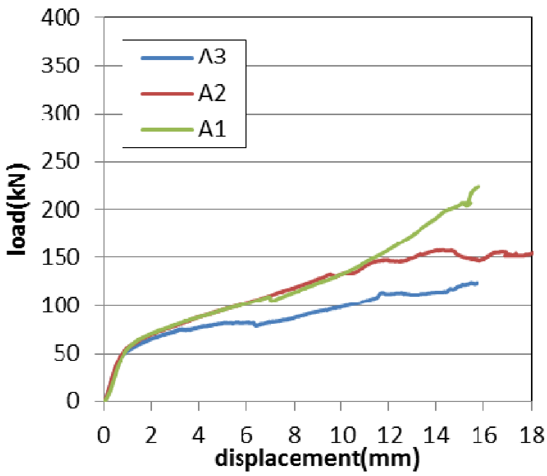
Fig.5-5 Parameter for nonlinear mode (After Japan Housing and Wood Technology Center[15])

Table 5-6 The material strength standard of timber structural design criteria (AIJ)[14]

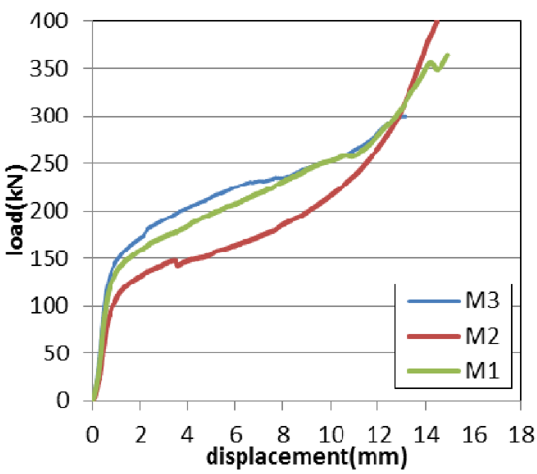
Standard strength of material			f_1	f_2
Coniferous Tree	Ⅰ class	*Beimatsu*	9.0	2.8
	Ⅱ class	*Hinoki*	7.8	2.6
	Ⅲ class	*Karamatu*	7.8	2.4
	Ⅳ class	*Sugi*	6.0	2.2
Broadleaf Tree	Ⅰ class	*Kashi*	12.0	5.4
	Ⅱ class	*Keyaki, Nara*	10.8	4.2
	Ⅲ class	Lauan	9.0	4.2
			(N/mm^2)	(N/mm^2)

f_1: partial compressive strength of perpendicular to the grain

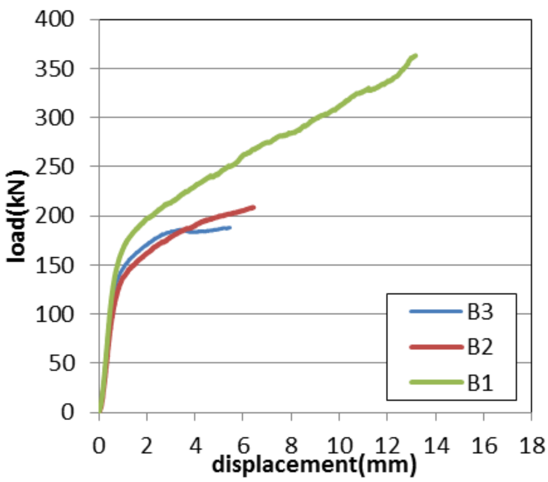
f_2: lateral compression strength



(*Afoa*)



(*Manawadano*)



(*Berua*)

Fig.5-6 Load-Displacement relations

The wooden members for the test were collected from Nias Island. Those members were used as a part of the house before, therefore, some defects could be found. Because A-1 was not loaded at the center of the member to avoid a defect, it was split for grain direction at one side. Though B-1 which affected by a knot indicated exceptionally large maximum load, no differences could be found in rigidity. B-3 happened to split before the displacement became 20mm. The shape condition or grain condition of test pieces affected the failure mechanism.

Photo.5-8 Failure mode of *Afoa* (from the left: A-1, A-2, A-3)

Photo.5-9 Failure mode of *Manawadono* (from the left: M-1, M-2, M-3)

Photo.5-10 Failure mode of *Berua* (from the left: B-1, B-2, B-3)

5.4 Lateral Compression Test of Wood

5.4.1 Introduction

We conducted lateral compression test of wood materials (*Berua, Manawadano, Afoa*) used for structure of traditional houses in South Nias. The lateral compressive strength and rigidity of each wood were measured in the test.

The test specimens were cut down in rectangular ones (approximately 30mm×30mm×70mm) from the test specimen used for Partial compression test. 3 or 4 test specimens of each wood were compressed in the direction perpendicular to the grain, shown in Table5-7 and Fig.5-7.

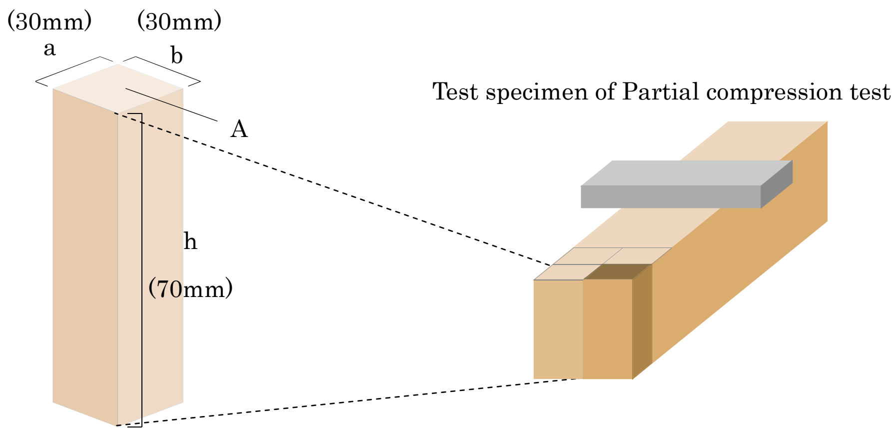


Fig.5-7 Test specimen

Table 5-7 Test specimen

	Test piece No. of Partial compression test	a (mm)	b (mm)	h (mm)	ρ (g/cm³)
A1	A-2	30	33	66	2.00
A2		35	32	67	2.09
A3	A-3	35	34	70	2.06
A4		33	38	69	1.82
B1	B-1	33	33	77	2.33
B2		33	34	76	2.24
B3		33	33	80	2.42
M1	M-1	36	37	65	1.76
M2		36	37	65	1.76
M3		35	37	68	1.84

Photo.5-11 Test specimens and test instrument (A:Afoa, M:Manawadano, B:Berua)

5.4.2 Test Results

Lateral compressive strength and rigidity were measured (See Table 5-8). The lateral compressive strength is nearly 1/4 times lower than compressive strength for grain direction. In comparison with Japanese timber, the lateral compressive strength was significantly larger than that of Japanese timbers (See Table 5-6).

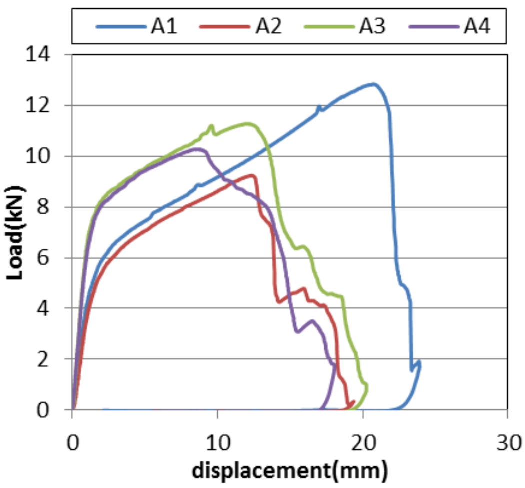
Fig.5-8 shows Load-displacement relation. Test piece No.M1, M2 and B1 suddenly split open, so that the load was reduced suddenly. Each test piece failed in various modes depends on the grain type or the size of test piece.

Most of all test pieces were crushed in grain direction (See Photos.5-12～5-14). However B-1 and M-2 suddenly split open, there were no large differences among others in the compressive strength and stiffness.

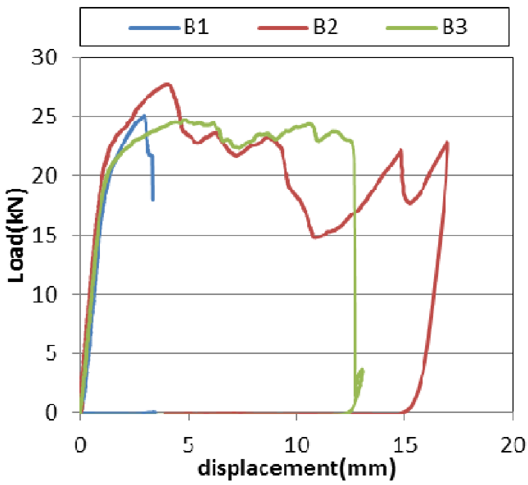
It seemed that almost all test specimens were heartwood considering from the direction of grain.

Table 5-8 Test Results

	displacement (max strength)	Lateral compressive strength	stiffness
	mm	N/mm²	N/mm²
A1	20.65	12.97	226.67
A2	12.38	8.25	239.29
A3	12.13	9.48	529.41
A4	8.63	8.20	374.16
Ave(Afoa)	13.44	9.72	342.38
B1	2.93	23.05	1343.43
B2	4.10	24.69	1467.62
B3	4.85	22.73	1212.12
Ave(Berua)	3.96	23.49	1341.06
M1	6.53	20.01	780.78
M2	11.75	21.19	618.12
M3	9.10	16.49	787.64
Ave(Manawadano)	9.13	19.23	728.85

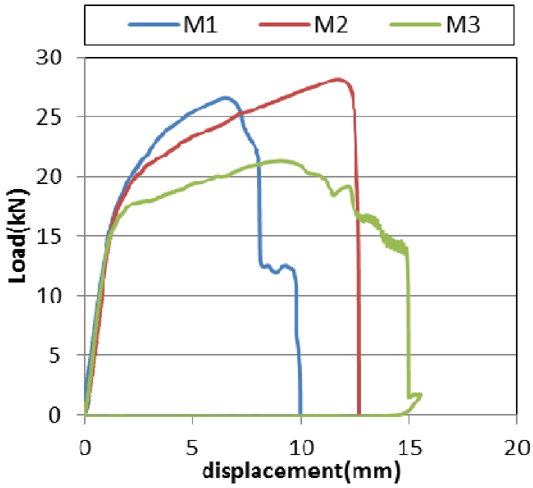


(Afoa)



(Berua)

Fig.5-8 Load-displacement relations



(Manawadano)

Fig.5-8 Load-displacement relations

Photo.5-12 Failure mode of Afoa (from the left: A1, A2, A3)

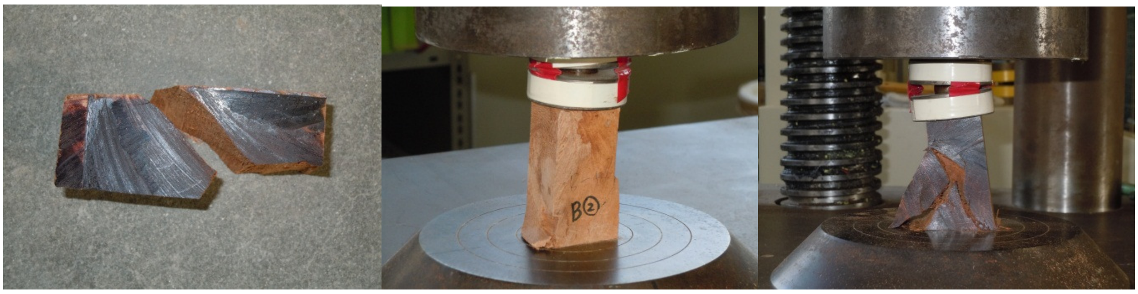


Photo.5-13 Failure mode of Berua (from the left: B1, B2, B3)

Photo.5-14 Failure mode of Manawadano (from the left: M1, M2, M3)

5.5 Concluding Remarks

The strength of compression, partial compression and lateral compression were evaluated from the present experiments. However there showed various failure mechanism affected by grain direction or the shape of test specimen.

Test pieces shaped symmetric should be used for material test. Furthermore, to compare with Japanese timber more correctly, another compression test should be conducted with Japanese timber in the same condition.

Chapter 6 Structural Analysis

6.1 Introduction

The traditional wooden houses in South Nias have survived against large earthquakes. This fact indicates that they have inherent anti-seismic potentialities. As an engineering approach, dynamic response analyses were conducted to evaluate the seismic safety in the present chapter.

6.2 Coupling effect

As mentioned in chapter2, the microtremor measurement demonstrated the coupling effect on the dynamic performance of *Omohada*. Coupling effect means the interaction effect of the structures connected each other. To evaluate this coupling effect to reduce earthquake response, a simple analysis model was employed. For the case of *Omohada*, each house has different characteristics such as: height, weight, width of the house, roofing material, natural frequency, etc. It should be noticed that such discrepancy would reduce the structural response.

6.2.1 Analysis Model

Earthquake response analysis was conducted by employing the lumped masses system, shown in Fig.6-1. To analyze seismic response, the earthquake data of JMAKobe NS and EW (recorded in Japan Meteological Agency in Kobe at Hanshin-Awaji Great Earthquake) was used for input motion.

Each house was idealized by the simple mass model. Table 6-1 presents the parameters used for the single mass model and lumped masses system. The spring constant was calculated from the mass and the natural period measured by the micro tremor measurement. Damping ratio was also calculated from free vibration test (See chapter2).

$$T = 2\pi\sqrt{\frac{m}{k}}$$

T: natural period, k: spring constant, m: mass

The earthquake response of the model connecting each single mass system (which called “Model A” below) was compared with 2 models. Model 1 was the single mass system of each house which independently responded to the grand motion (See Fig.6-2). On the other hand, Model 2 was the lumped mass model connecting four same single mass systems (See Fig.6-3). Parameter analysis was performed to examine the spring constant (k_b) between the house’s models, shown in Table 6-2 and 6-3.

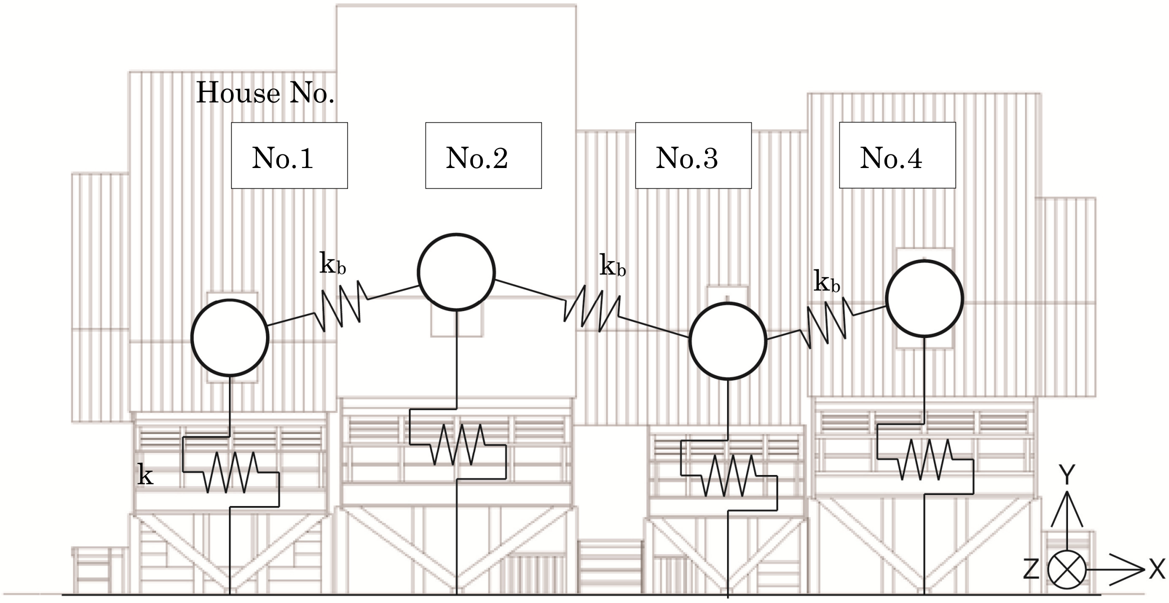


Fig.6-1 Lumped mass system (Model A)

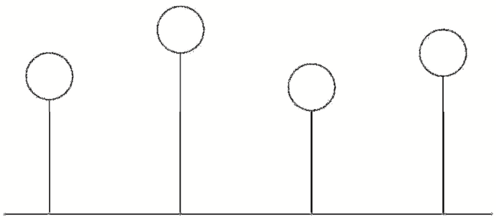


Fig.6-2 Model 1

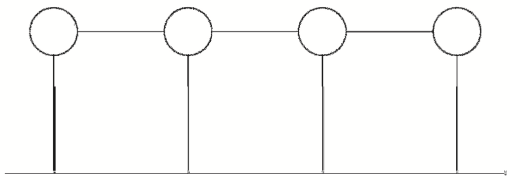


Fig.6-3 Model 2

Table 6-1 Parameters used for Lumped masses model

		①	②	③	④	Model 2
Height	(m)	10.26	11.57	9.11	9.84	-
Model height	(m)	3.15	4.11	2.93	3.09	3.32
Mass	(kg)	7333	10384	6669	7398	8000
Natural frequency	X (Hz)	3.4	3.4	3.2	3.2	3.2
	Y (Hz)	5	5.5	5	6.5	5.6
Spring stiffness	X (kN/m)	3343.5	4734.1	2693.6	2987.8	3200
	Y (kN/m)	7230.8	12388.2	6576.2	12330.4	9500
Damping ratio	X			0.05		
	Y			0.07		

6.2.2 Results of Analysis

Tables.6-2 and 6-3 show the response displacement and acceleration when the stiffness of connecting spring between houses was (1/1000)*k, (1/100)*k, (1/10)*k, k, respectably. Hence, "k" denotes the average of spring constant of house's model.

The analysis results showed that the connection between houses could reduce earthquake response in comparison with Model A and Model 1. Figs.6-4 and 6-5 show the differences of response displacement and acceleration between Model A and Model 1, indicating the reduction of response. The earthquake response of each house was greatly reduced when the spring constant between houses (=k_b) was (1/100)k or (1/10)k in X direction. On the other hand, the earthquake response was reduced in Y direction when the spring constant (k_b) was (1/1000)k or (1/100).

It could be found that the difference in structural characteristics could also reduce the response displacement and acceleration in comparison with Model A and Model 2. There can be found significant difference in displacement and acceleration, affected by the house location and the spring constant between houses (=k_b). The response displacement of house No.4 in Y direction slightly increased in comparison with Model A and Model 1. However, it can be considered that the lower spring constant between houses (k_b) the more reduce the earthquake response, shown in Fig.6-6 and 6-7. The response was reduced when the spring constant between houses (k_b) was (1/1000)k or (1/100) in any cases.

Table 6-2 Maximum response displacement and acceleration in X direction

JMAKobe(NS)×1.0				
k_b	①	②	③	④
Displacement in X direction (m)				
Model 2	0.0265			
k(1/1000)	0.0247	0.0249	0.0290	0.0287
k(1/100)	0.0247	0.0249	0.0291	0.0288
k(1/10)	0.0250	0.0252	0.0296	0.0295
k	0.0261	0.0264	0.0280	0.0283
Model 1	0.0328	0.0333	0.0411	0.0409
Accelelation in X direction (m/sec^2)				
Model 2	11.9			
k(1/1000)	11.6	11.6	11.9	11.9
k(1/100)	11.6	11.6	12.0	11.9
k(1/10)	11.7	11.7	12.5	12.2
k	12.1	11.9	12.1	12.2
Model 1	15.1	15.3	16.7	16.7

Table 6-3 Maximum response displacement and acceleration in Y direction

JMAKobe(EW)×1.0				
k_b	①	②	③	④
Displacement in Y direction (m)				
Model 2	0.0112			
k(1/1000)	0.0125	0.0108	0.0125	0.00626
k(1/100)	0.0126	0.0107	0.0128	0.00621
k(1/10)	0.0134	0.0105	0.0135	0.00630
k	0.0131	0.0118	0.0109	0.00829
Model 1	0.0184	0.0156	0.0184	0.00734
Accelelation in Y direction (m/sec^2)				
Model 2	13.7			
k(1/1000)	12.8	13.4	12.7	10.9
k(1/100)	12.1	13.2	13.1	10.8
k(1/10)	14.0	12.6	15.3	10.3
k	15.3	13.9	13.4	11.2
Model 1	18.5	18.8	18.3	12.4

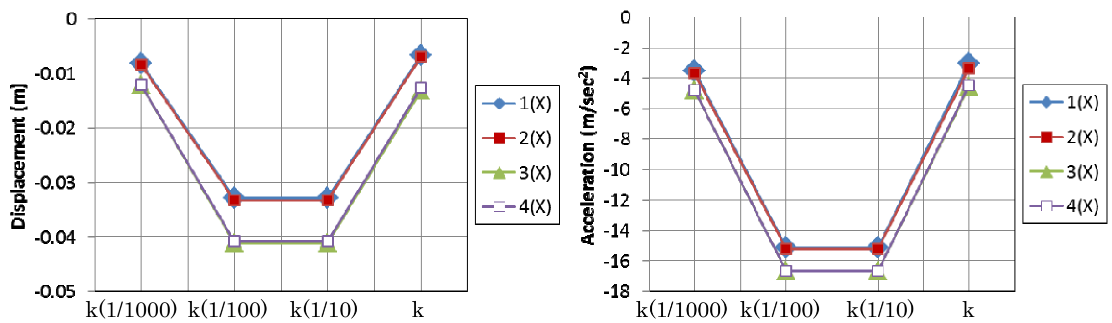


Fig.6-4 Difference in response disp. and acc. between Model A and Model 1 in X direction

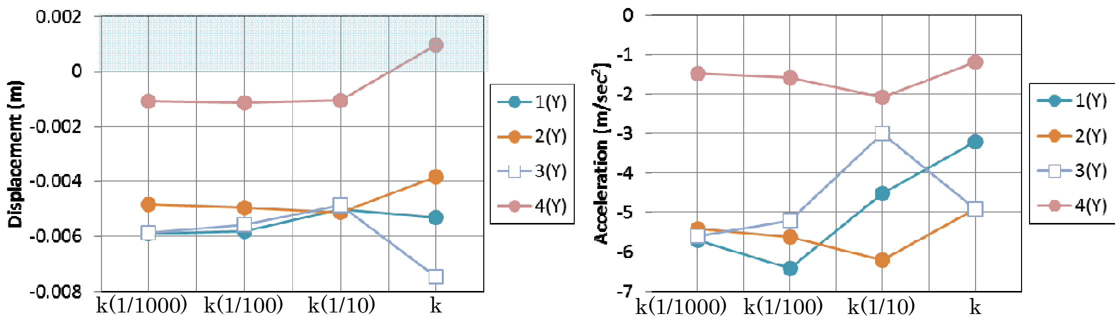


Fig.6-5 Difference in response disp. and acc. between Model A and Model 1 in Y direction

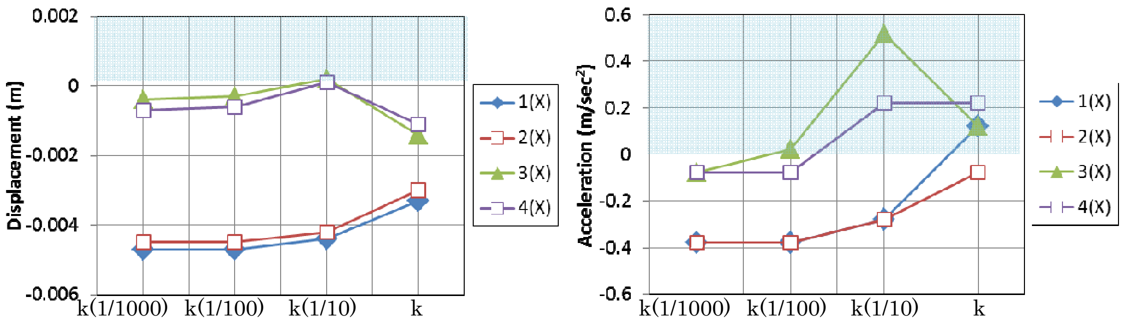


Fig.6-6 Difference in response disp. and acc. between Model A and Model 2 in X direction

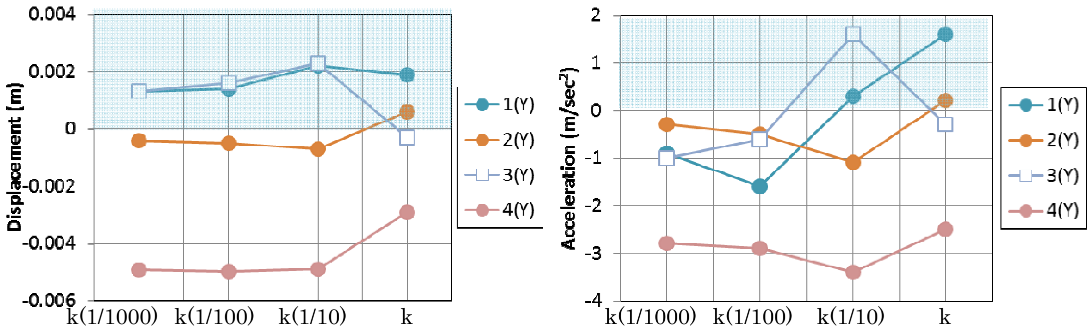


Fig.6-7 Difference in response disp. and acc. between Model A and Model 2 in Y direction

6.3 Collapsing Process Simulation

Structural analysis should be employed to study the dynamic behaviors of the traditional wooden house under the strong motions. Seismic performance of traditional wooden houses in South Nias was examined by using the software "wallstat ver.*.*" (developed by Dr. T.Nakagawa, Building Research Institute, using Extended Distinct Element Method [16]). To understand the limit state, collapsing process was simulated by this software.

The numerical analyses were carried out. 6 earthquake motions were employed to analyze the collapsing process in numerical analysis, shown in Table 6-4.

6.3.1 Analysis Model

Fig.6-8 shows the analysis model employed in the present study. For such structural model, rigidity of the joints would be the main factors to affect the seismic behaviors. The mechanical models of the joints were introduced as follows.

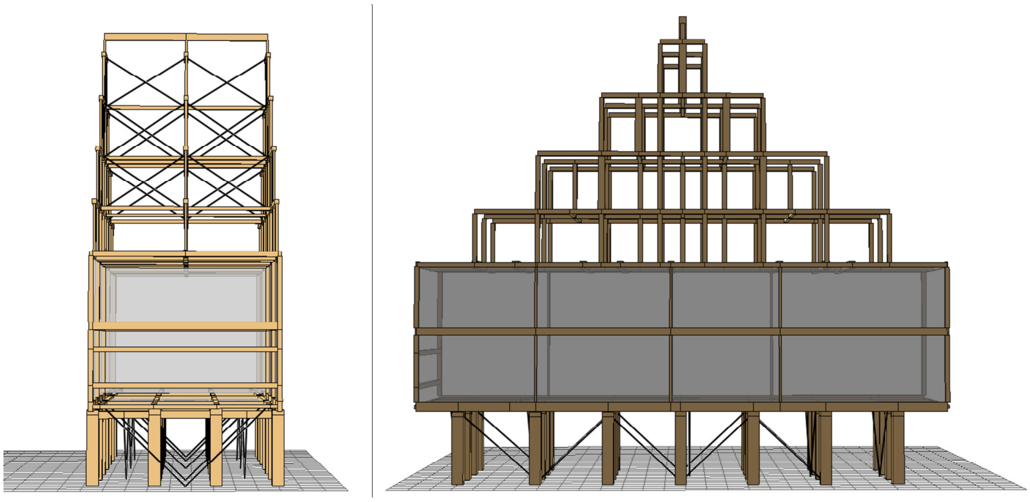
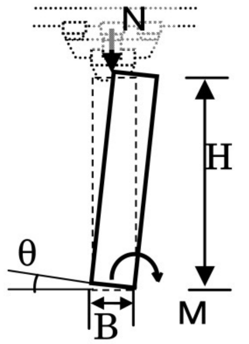


Fig.6-8 Numerical model (made by using wallstat. ver**)

1) Column rocking resistance

The experimental study of column rocking resistance was first made by S.Ban [8]. The traditional wooden houses in South Nias have thick columns (approximately 20～30cm in diameter) supporting the floor. Such large-diameter columns would contribute to rocking resistance against horizontal earthquake motions. Fig.6-9 shows non-liner rotational spring model.



H=1.7(m)
B=0.2(m)

$A_0=B/H$
$M_0=NB$
$N=W=mg$
(W=2695 N /per one column)

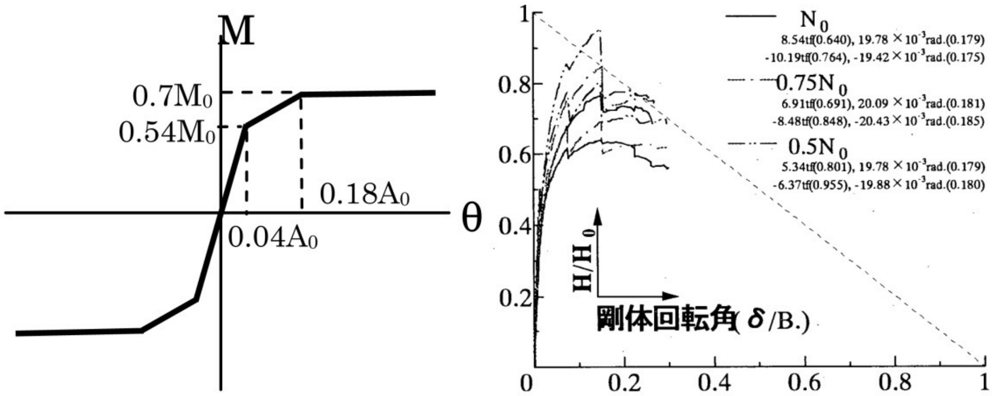
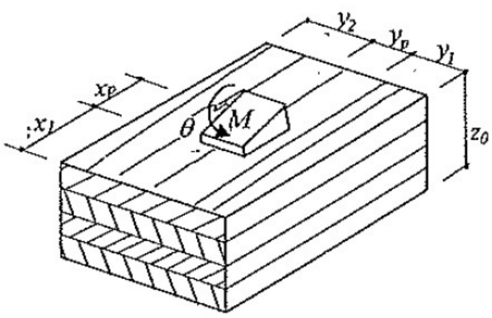


Fig.6-9 Non-liner rotational spring model
(After: M.Karube, Y.Ooka[10,11])

2) Effect of embedment

No nails are used to construct the traditional wooden houses in Nias, therefore, it is important to take into account the effect of embedment. The equations of embedment effect (See Fig.6-10) were applied to the joint models such as: beams, tenon jointing, or penetrating beams.



Elastic Limit Deformation angle

$$\theta_y = \frac{z_0 f_m}{x_p E \sqrt{C_x C_y C_{xm} C_{ym}}}$$

Yielding moment

$$M = \frac{x_p{}^3 y_p C_y E \theta}{z_0}\left\{C_{xd} + \frac{1}{3}\right\}$$

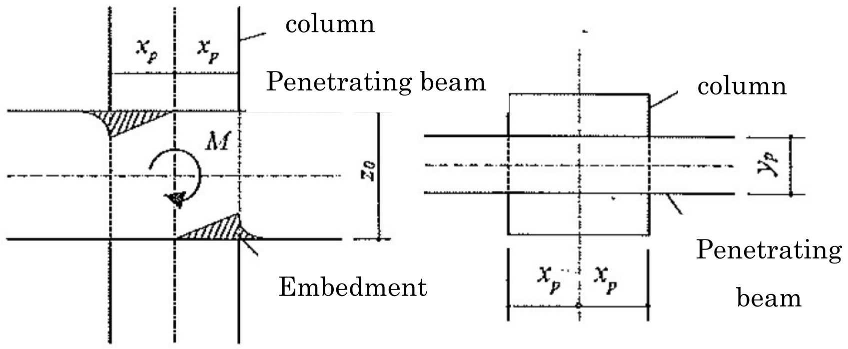
$$C_{xm} = 1 + \frac{z_0}{0.8x_p} \qquad C_{ym} = 1 + \frac{z_0}{0.8ny_p}$$

(E: Stiffness of Lateral Compression)

Fig.6-10 Embedment condition (After: M.Inayama[9])

▼Joint of column and *Nuki*

Understructure of the traditional house is connected tightly with large-diameter columns and penetrating beams. The rotational stiffness can be calculated by employing the following equations.



X_p=10 (cm)
Z_0=15 (cm)
y_p=3 (cm)
E=13410.6 (kN/cm^2)
F_m=299 (kN/cm^2)

$$K_\theta = x_p{}^2 y_p E \left\{ \frac{x_p}{z_0} \left(C_{xm} - \frac{1}{3} \right) + 0.5 C_{xm} \right\}$$

$$M_y = \frac{K_\theta Z_0 F_m}{x_p E C_{xm} \sqrt{C_{ym}}}$$

Fig.6-11

(Japan Housing and Wood Technology Center[12])

6.3.2 Results of Analysis

Numerical analyses were carried out using the inputs listed in Table6-4. The model fell down in direction toward the rear at understructure first, and then roof frame collapsed in ridge direction when the earthquake wave of JMAKobe (No.1) was inputted. The collapsing process in the analysis showed the same tendency with the damage by the Earthquake, being inclined forward and collapsed at the part of the roof frame. While braces are at roof part in span direction, the roof frame collapsed in span direction.

The understructure of model didn’t completely collapsed when the earthquake motions listed in Table 6-4 were inputted with the exception of JMAKobe. The waves from No.2 to No.6 were inputted only in one direction. The upper side of the house swayed particularly with No.5 and No.6 motions. On the other hand, the model didn’t response so much with the earthquake waves of long period such as No.2.

Table6-4 Input wave

Number	Input wave
No.1	JMAKobe 1995 NS/EW/UD
No.2	Hachinohe 1952 NS
No.3	Elcentro 1940 NS
No.4	Taft 1952 EW
No.5	KHL2-1
No.6	Rinkai NS2

6.4 Concluding Remarks

The reduction of earthquake response of *omohada* was shown in simple structural analysis. The analysis results indicated that they have an effect such as Coupled vibration control system between houses. It is important to connect each other which standing in a row especially with different dynamic properties.

Although the numerical model of traditional house collapsed in great earthquakes, the living space (middle structure) remained as box-shaped. The understructure which has high stiffness should be discussed in their seismic resistance for further study.

It would be desirable to conduct shaking table test for comparison with the result of numerical analysis for further study,

Chapter 7 Conclusions

7.1 Summary of the Study

Some unique cultural things remain in Nias Island, located to the west of Sumatra Island. They have traditional wooden houses which worth preserving. Furthermore, the traditional wooden houses have survived against past large earthquakes. The structural characteristics of traditional houses were investigated to study the seismic safety in present research.

The traditional house can be divided into three parts; understructure, living space, and roof frame. *Nuki* and *Kashira-nuki* supported understructure rigidly with braces. At the living space, beams and walls of front and back connected two parts of thick walls in ridge direction as a BOX. The roof frame structure is relatively light, consisting of braces in span direction.

Fundamental characteristics of traditional wooden house of South Nias were evaluated by micro tremor measurement in the present study. In addition, deterioration and deformation of the timbers were inspected in *Omosebua* in order to discuss the restoration methods. To discuss how the roof materials affected the climate condition in the roof structure, temperature and humidity monitoring was conducted. Furthermore, the earthquake response analysis was performed to verify the coupling effect of *omohada*.

The microtremor measurement showed that the traditional houses in Nias have the natural frequency close to that of the Japanese traditional wooden houses. In particular, the structure in span direction was more flexible than that of ridge direction. However, we found tilting of columns caused by the recent devastating earthquake. Furthermore, aging deterioration with differential settlement and harms by termite was found in every part of the house. Such damages might reduce earthquake resistant capacity of the traditional houses. In addition, the weak point from earthquake engineering point of view was also found in span direction (See.chapter2). On the other hand, the natural frequency was not figured out clearly for ridge direction at *omohada*, which would need more study in detail.

The monitoring of temperature and humidity was carried out at *omohada* roofed with Sago leaves and with GI sheets. The temperature inside the roof with sago leaves reached nearly 40℃, being higher than that inside roof with GI sheets. It could be considered that changing roofing material from Sago leaves to GI sheets would make the climate condition under the roof hot and discomfort, indicating that people should remain traditional style as roofing with Sago leaves. Among the measuring points, it was the highest in humidity nearly 100% in the part under the floor, which might cause deterioration of timbers. It would be needed to continue monitoring of temperature and humidity.

The traditional house is characterized by three structural parts; the under-floor frame with large-diameter columns and braces, the wall structure used for living space and the roof structure. The understructure supports the living space surrounded by wooden panels. Some structural elements would make the house possible to survive against earthquakes; such as braces for both direction at understructure, thick walls with beams, and braces for span direction at the roof frame. People construct traditional house in traditional way mostly used tenon jointing with no nail, indicating that the deteriorated timbers could be replaced with new one easily. However, it might cause irregular settlement when people replaced the timbers regardless of making level or verticality.

To discuss the structure of traditional houses in detail, it should be needed to simulate the seismic performance. The simple structural analysis showed that discrepancy in dynamic properties of the houses “omo hada” connecting each other would be effective in improvement of the seismic performance. In particular, this effect was better shown in span direction.

The numerical model of traditional house collapsed by earthquake motion of JMAKobe. However, the living space (middle structure) remained as box-shaped in Extended distinct element method. It is needed to discuss the relationship between the result of microtremor measurement and the result of numerical analysis. It is considered that the understructure of model collapsed in ridge direction first when the earthquake waves of short period were inputted. Therefore, the understructure which contributes to high stiffness should be considered about seismic resistant capacity for further study. On the other hand, the model didn’t response so much with the earthquake waves of long period.

It is to be desired to conduct shaking table test to evaluate the dynamic behavior, being compared with the result of numerical analysis for further study,

7.2 Future Studies

In this research, fundamental characteristics of traditional wooden house were studied. However, the characteristic of *omohada* for ridge direction was not evaluated exactly. It would be needed to study seismic resistant capacity of *omohada* in detail.

In addition, deterioration and deformation of timbers could be found in every part of the traditional house, which must reduce seismic safety. Further structural analysis considering the effect of deterioration and deformation should be conducted in the future.

The monitoring of temperature and humidity is useful to evaluate the living environment and to maintain the house structure. It should be necessary to continue monitoring of temperature and humidity at the site.

Furthermore, how to retrofit the structure of traditional houses against earthquake should be discussed in the present international project.

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