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EFFECTS OF INCLINATION HOUSES INDUCED BY LIQUEFACTION ON HEALTH PROBLEM IN RECENT EARTHQUAKES IN JAPAN

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Abstract

Many serious damages such as liquefaction of houses occurred by the 2016 Kumamoto Earthquake and the 2018 Hokkaido Iburi-tobu Earthquake, Japan. Field investigation and inspection were conducted to study an effect of inclination of the house due to liquefaction on health problems of the residents. The outer wall inclination angle of 125 houses in liquefied sites of Kumamoto and Sapporo Cities was measured.

The inclination of 68 houses at Chikami and Karikusa, Kumamoto City, Japan was measured after the 2016 Kumamoto Earthquake, and the maximum value and direction of inclination are shown on the map. The degree of inclination is seemed to be related to the type of the houses and buildings. The inclination of the houses has a tendency associated with direction of old river.

The inclination of 57 houses at Utsukushigaoka, Sapporo City, Japan was measured, which were damaged by the 2018 Hokkaido Iburi-tobu Earthquake. The houses located at the reclaimed land of the former river and former valley plain were inclined. Therefore, the old terrain greatly affected to the inclination of houses. These liquefaction-induced damage occurred in the same area where liquefaction occurred during the 2003 Tokachi-oki Earthquake. It is found that the inclination direction of the houses and buildings is related to the old terrain as well.

A questionnaire survey was conducted about one month after the earthquakes. As a result of the questionnaire survey, about 75% of respondents suffered from health problems. The most common symptom was a fluffy feeling. Fatigue feeling, tow feeling, headache, dizziness also occurred a lot. All these symptoms occurred after the earthquake. As the angle of incline increases, the sufferers from health problems tend to increase and the fluffy feeling and dizziness increases. Even if the angle of inclination was less than 0.6°, health problems have occurred. The results of this survey revealed the actual situation of inhabitant's health problems due to inclined houses induced by liquefaction.

Keywords: earthquake, liquefaction, residential house, inclination angle, health problem

1. Introduction

In the 2016 Kumamoto Earthquake and in the 2018 Hokkaido Iburi-tobu Earthquake, liquefaction occurred, and the uneven settlement in detached houses became a serious problem. As a result, a health problem appears in residents, resulting in loss of usability and functionality of a residence.

Since the 1964 Niigata Earthquake in Japan, many researchers have studied liquefaction damage so far. Among them, there are ones investigating health problems of residents lived in buildings tilted due to liquefaction. The past researches clarified when the tilt angle exceeds 0.6 ° (10/1000), dizziness etc. occurs gradually and obstacles appear in life [1, 2]. In the 2011 Great East Japan Earthquake, many houses were inclined due to liquefaction, so health problems occurred in the residents.

It is important to investigate the inclination of houses by liquefaction and clarify the relationship with the health condition of the residents, because the inclination of houses has a great influence on health of residents. A field surveys such as measurement of inclination of houses, interview to residents and so on for Kumamoto City on May 2016 and Sapporo City on September 2018 in this study. We showed the direction and angle of 125 inclined houses in total on a map and considered damage due to liquefaction.

In addition, we conducted the second field investigation at the same area to measure the inclination of inside the house, that is, floor, pillar and inner wall under permission of residents. Finally, we discussed the influence of the inclination inside houses on health disorders.

2. Outline of recent earthquakes in Japan

2.1 2016 Kumamoto Earthquake

The earthquake of magnitude 6.5 occurred at the depth of 11 km in the Kumamoto City of Kumamoto Prefecture at 21:26 on April 14, 2016. At 1:25 on April 16, an earthquake of magnitude 7.3 also occurred at the depth of 12 km in the same region. The earthquake of magnitude 7.3 on April 16 is called the main shock in this paper [3]. These earthquakes caused many damages of houses, buildings and infrastructures in Kumamoto City and around areas. The human damage of this earthquake were 273 deaths, 1,203 seriously injured and 1,606 minor injuries. The damage to houses and buildings were completely destroyed in 8,667, 34,719 partially destroyed and 163,500 slightly damaged. 13,385 non-residential buildings were also damaged [4]. Fig.1 shows ground crack, subsidence of buildings and utility poles due to liquefaction.

Fig. 1 – Damage caused by liquefaction at Kumato City

2.2 2018 Hokkaido Iburi-tobu Earthquake

An earthquake of about 35 km in depth and 6.7 in magnitude occurred at middle east of Hokkaido-iburi region at 3:07 local time on September 6th, 2018. The human damage of this earthquake were 42 deaths, 31 seriously injured and 731 minor injuries [5]. The damage to houses and buildings were completely destroyed in 462, 1,570 partially destroyed and 12,600 slightly damaged. 2,456 non-residential buildings were also damaged. The main cause of these damages was landslides at Atsuma town near the epicenter. One of causes of the landslides seems to be a large amount of water contained in soil because heavy rain fallen in the previous day by a strong typhoon.

Uplift and settlement of road and inclination of houses were caused by liquefaction in the southeastern part of Sapporo city. The location of Satozuka and Ustukushigaoka towns and some photographs of the damage at each site are shown in Fig.2. Enormous liquefaction-induced damage occurred in a wide area of Satozuka and Utsukushigaoka towns, Kiyota ward, Sapporo city.

The green portion in Fig.2 indicates Utsukushigaoka 1 jo. There were many inclined houses due to liquefaction. The houses shown in photo. Seem to suffer no damage at first glance, but inclination of houses occurred. Although the inclination of houses can be seen by visual inspection at Satozuka 1 jo, there were few houses where the inclination can be judged visually at Utsukushigaoka. However, many houses at Utsukushigaoka also suffered inclination by liquefaction. Such residents have continued to live at the inclined houses just after the earthquake, but many residents moved without being able to withstand the inclination of houses after around one month.

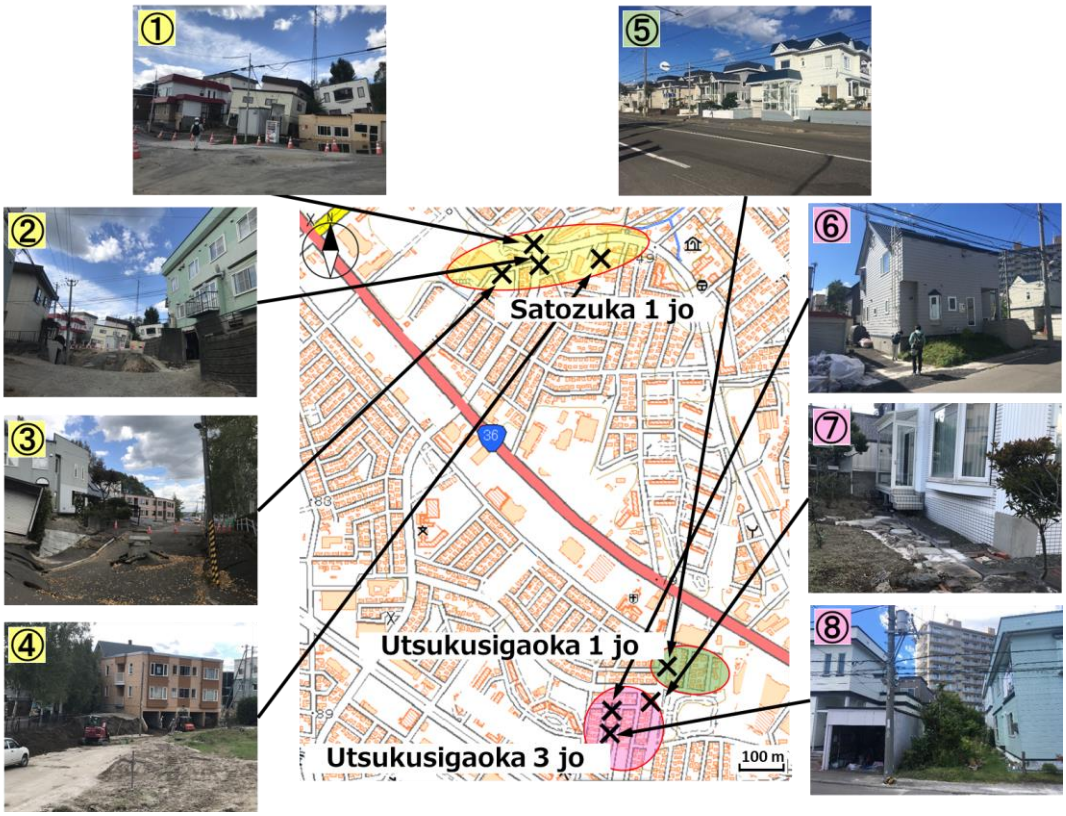

Fig. 2 – Liquefaction damage at each point

3. Outline of field investigation

3.1 Purpose of field investigation

The survey was conducted at Chikami and Karikusa, Kumamoto City on May, 2016 and Utsukusigaoka Kiyota, Sapporo City on September, 2018. We investigated the inclination of 125 houses of remarkable damage caused by liquefaction. The purpose of this field survey is as follows.

・Measurement of inclination of outer wall of houses

・Observation of the structural type of the houses and damage situation

・Hearing to the situation of ground condition during the earthquake

The influence of the ground condition and the structural type of the house on the inclination of the house was investigated based on the results of the survey. We found that health problems occurred in many residents through the field survey. Therefore, we conducted second field survey focused on health problem at same area. Survey items of the questionnaire are as follows.

I. Liquefaction damage to residence

II. Health disorders of family after the earthquake

III. Structure type and age of the house

IV. Earthquake resistance of the house

V. Attribute of the answerers

3.2 Method of inclination measurement

The inclination of 8 points of outer walls of a house as shown in Fig.3 was measured by using an inclined surface measurement function of a laser distance meter (Leica DISTO D510). We recorded the inclination and direction of the house. The measurement of the inclination inside a house was done at the floor and inner wall where the resident feels the most inclination if the residents permit the measurement. In case of absence of residents, we posted the questionnaire survey sheet and asked the residents to measure inclination of the floor and inner wall.

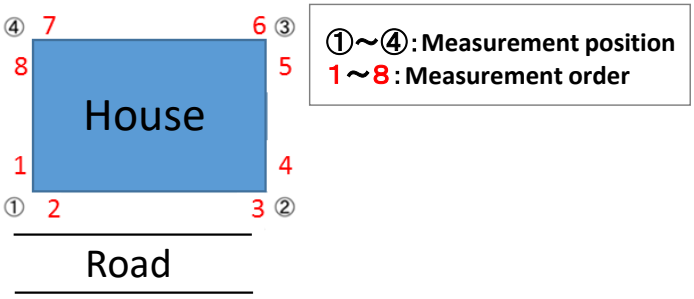

Fig. 3 – Measuring points of house

4. Inclination of outer wall

4.1 Measurement results at Kumamoto City

Fig.4 shows the measurement results of the inclination of the houses at Chikami. The inclination angle is indicated on the map in color-coded of every 0.5° (8.7/1000). Vector synthesis was performed in two orthogonal directions and the direction of inclination with larger inclination is indicated by an arrow in this figure. If the both larger inclinations are less than 0.5° (8.7/1000), vector synthesis is not performed and only

the direction of the maximum inclination is shown. There was a tendency that houses with large inclination are adjacent. And the inclination direction is roughly southeast.

Fig.5 shows the measurement results of the inclination of the house at Karikusa. The building which was the most greatly inclined was a one-story flat house and there was no noticeable damage to walls and other members, but a lot of ejected sand remained around the building.

Fig.6 shows the number of houses in relation to the inclination angle. Approximately 30% of the surveyed houses inclined to 0.6° (10/1000) or less, while the remaining inclined more than 0.6° (10/1000) and this inclination may cause health problems of the residents according to the past studies [2].

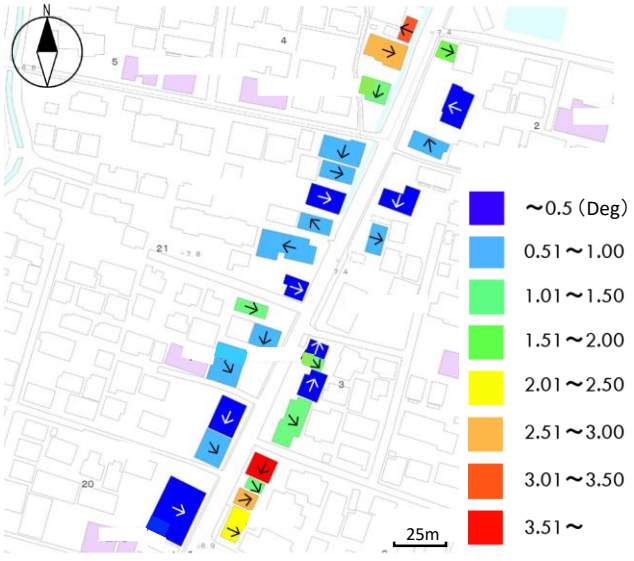

Fig. 4 – Inclination and its direction at Chikami

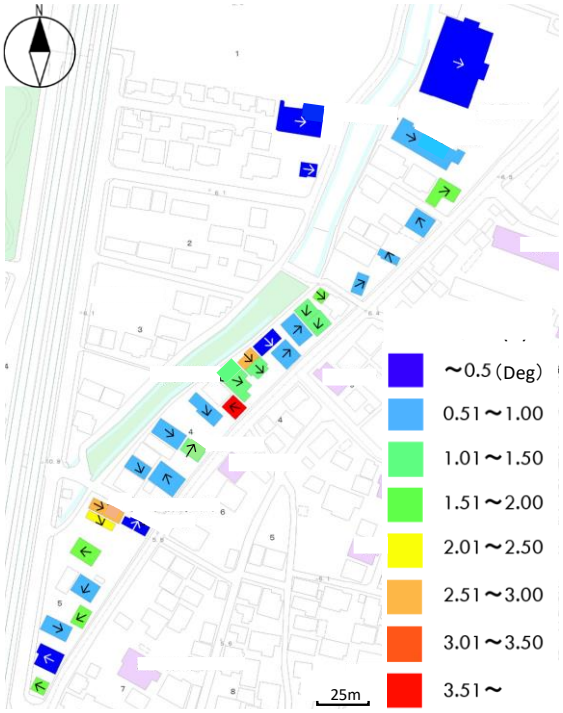

Fig. 5 – Inclination and its direction at Karikusa

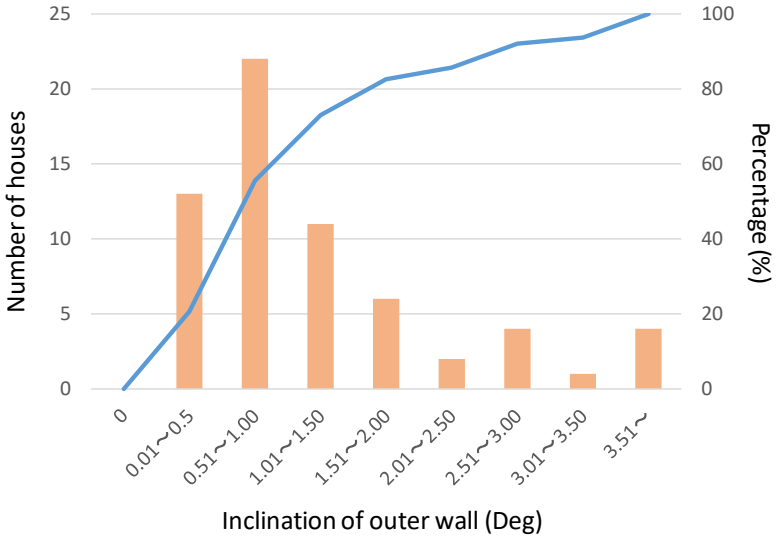

Fig. 6 – Percentage of the inclination angle

4.2 Measurement results at Sapporo City

Fig.7 shows inclination of the outer wall of the houses at Utsukushigaoka 1jo and 3 jo. The inclination was shown in color-coded of every 0.25° (4.4/1000) on the map. Vector synthesis was performed in two orthogonal directions and the direction of inclination with larger inclination is indicated by an arrow in this figure. If the maximum inclination and the synthesized inclination are less than 0.25° (4.4/1000), vector synthesis is not performed and only the direction of the maximum inclination is shown. Also, the location of largest subsidence of road is indicated by red cross in this figure.

It is found that the houses that were greatly inclined were adjacent and that such houses are inclined in the same direction according to Fig.7. Also, the houses were inclined in the direction of the largest subsided road. The houses in the vicinity of the subsided road, houses A to C are located near the Utsukushigaoka Sumire park where many sand volcanos appeared by liquefaction. The houses B and C were greatly inclined in the direction of the subsided road. The houses D and E were inclined in the north direction, the houses F and G were inclined in the west direction. These houses have almost the same structural type and the years after construction is the same as 29 years.

The inclination of the outer wall of the house J was 2.58° (45/1000), which was the largest inclination among the surveyed houses. The second largest inclination house H was inclined in 2.40° (42/1000). The houses H and J were inclined in the southeast direction, and the house I was inclined in the southwest direction. The houses J and I were inclined to the front road. These results revealed that most of the large inclined houses inclined in the same direction.

The number of houses in each inclination angle is shown in Fig.8. Health problems may occur at the houses with an inclination of 0.6° (10/1000) or more [2], and about 53% of the surveyed houses exceeded it. Survey of inclination of houses was conducted again in one month after the earthquake. Inclination of houses increased more than 1.8° (31/1000) in some cases by the aftershocks. The residents were difficult to live there and most of residents decided to move.

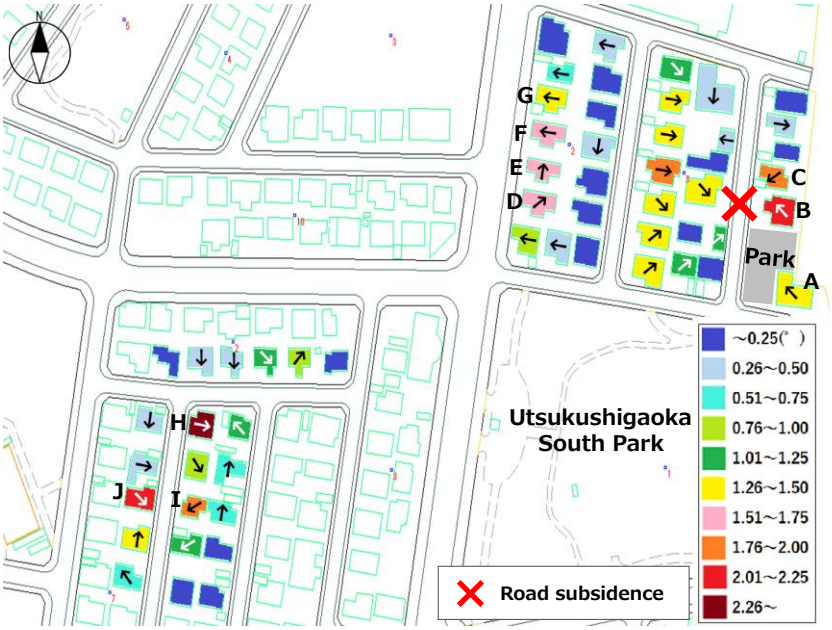

Fig. 7 – Inclination and its direction at Utsukushigaoka

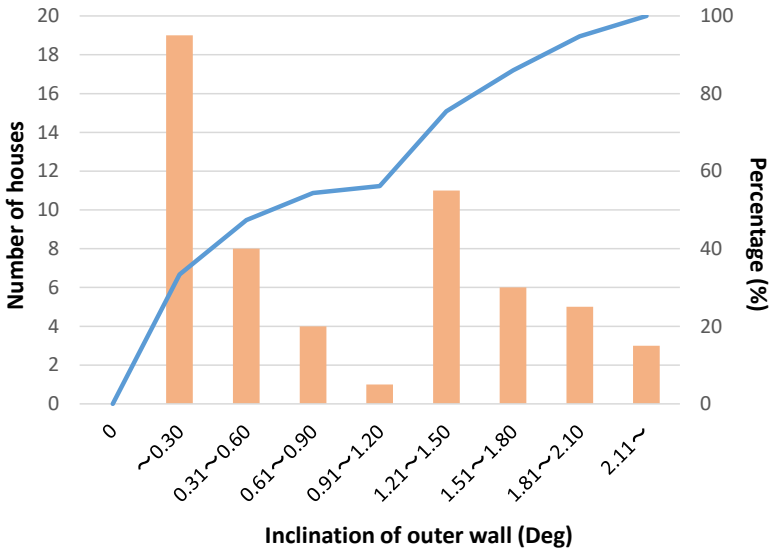

Fig. 8 – Percentage of the inclination angle

5. Influence of inclination on health disorder of residents

5.1 Questionnaire survey results at Kumamoto City

21 households experienced health disorders after the 2016 Kumamoto Earthquake, 6 households were in no health disorder, and three were unanswered among 30 answered households. In case of six households of no health disorder, two houses were under renovation work, the inclination of the floor was less than 0.5° (8.7/1000) and the inclination of the wall / pillar was 1.0° (17/1000) in other two houses, and the rest two houses suffered no inclination. Excluding the two houses that repair work was done immediately after the earthquake, 32 persons suffered health disorder after the earthquake, so approximately 74% of respondents had health problems.

Fig.9 shows the percentage of residents in health disorder in relation to the inclination of outer wall. The percentage of health disorder increases in increase of the inclination of outer wall, but one person answered that health disorder did not occur even if inclination exceeded 1.2° (21/1000). Fig.10 shows the number of residents of symptom-based health disorders in relation to the inclination of outer wall. The symptoms such as dizziness and fluffy feeling increases as the inclination increases. It was found that the types of symptoms were varied at even with a slope of 0.6° (10/1000) or less.

Fig.11 shows the percentage of residents in health disorder in relation to the inclination of floor. It is found that the inclination of the floor of house where health disorder appeared for the resident is smaller than that of the outer wall. Although the inclination of the floor is small, the incidence of health disorders is high. The health disorder appeared for all respondents in the case of the inclination exceeding 0.6° (10/1000). Fig.12 shows the number of residents of symptom-based health disorders in relation to the inclination of floor. In the case of inclination up to 0.9° (16/1000), health disorders are four symptoms, that is, tow feeling, fluffy feeling, fatigue feeling and insomnia. However, the symptoms are greatly related to physical function such as nausea, anorexia, headache, etc. in the case of the inclination exceeding 1.0° (17/1000). As a result, it is thought that the impact of inclination of floor on health disorders is large even if the inclination is not large.

In addition, a questionnaire survey was conducted for residents who lived in houses without inclination damage in the same areas. Only three of 30 residents answered that they had occured health problems after the earthquakes. The incidence of health problems was much lower than those who lived in a incling house.Therefore, the inclination of the housese due to liquefaction is considered to be a major factor causing health problems.

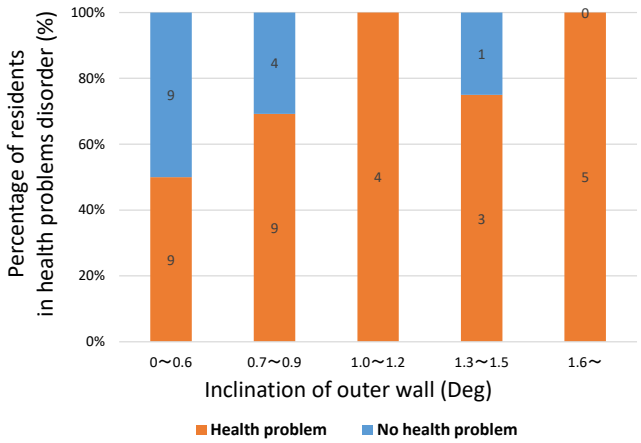

Fig. 9 – Incidence of health disorder (Outer wall)

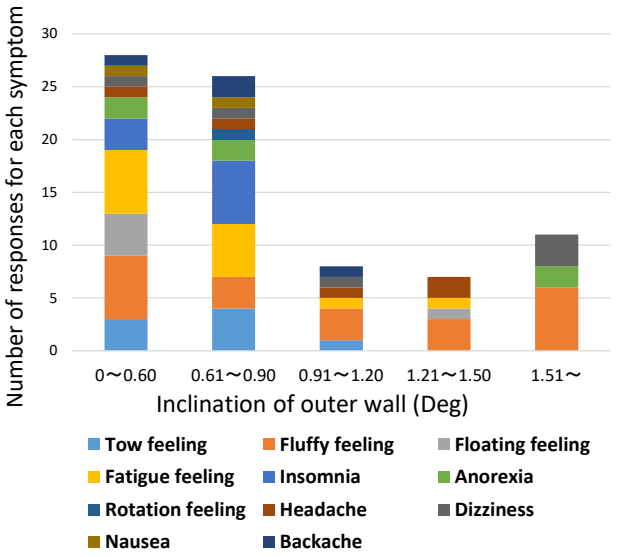

Fig. 10 – Symptoms in each inclination(Outer wall)

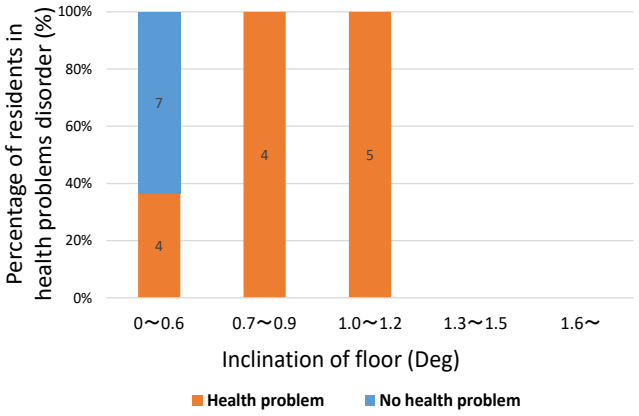

Fig. 11– Incidence of health disorder (Floor)

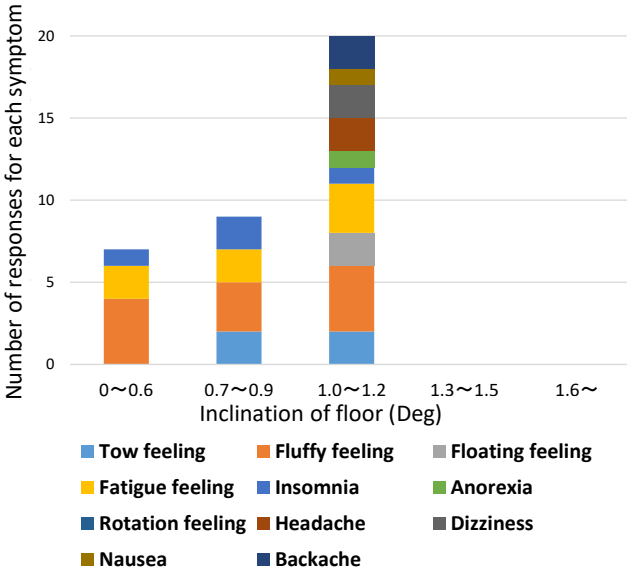

Fig. 12– Symptoms in each inclination(Floor)

5.2 Questionnaire survey results at Sapporo City

20 households experienced health disorders after the earthquake, 18 households were in no health disorder. Fig.13 shows the percentage of residents in health disorder in relation to the inclination of outer wall. The percentage of health disorder increases in increase of the inclination, but two person answered that health disorder did not occur even if inclination exceeded 1.83° (32/1000). These two are men and women living in the same house. Fig.14 shows the number of residents of symptom-based health disorders in relation to the inclination of outer wall. As the amount of inclination increases, the types of symptoms that occur also increase. Above 1.51° (26/1000), the incidence of insomnia and anorexia increased, making it difficult to maintain normal health.

Fig.15 shows the percentage of residents in health disorder in relation to the inclination of floor. It is found that the inclination of the floor of house is larger than that of the outer wall. The health disorder occurs at the inclination of 0.4° (7/1000) and it appeared for all respondents in the case of the inclination exceeding 1.41° (25/1000). This suggests that the floor inclination has a greater effect on the health problems of residents than the outer wall inclination. Fig.16 shows the number of residents of symptom-based health disorders in relation to the inclination of floor. When the floor inclination was 0.6° (10/1000) or less, there were five health problems: lightheadedness, fatigue, insomnia, headache, and dizziness, and the inclination exceeded 1.81° (32/1000), symptoms related to physical function such as nausea and anorexia appeared. These results suggest that the floor has a greater inclination than the outer wall and has a greater effect on health problems.

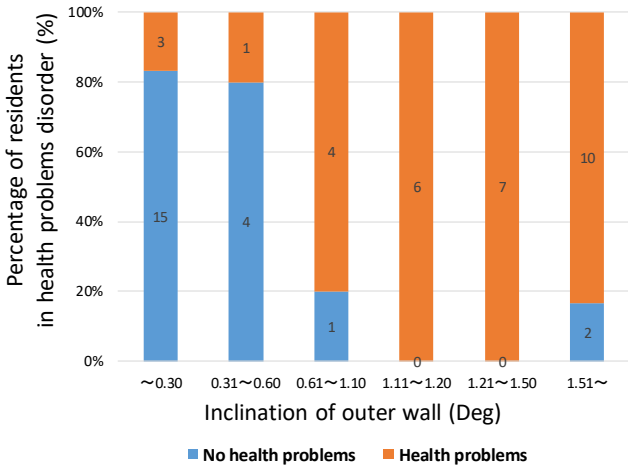

Fig. 13– Incidence of health disorder (Outer wall)

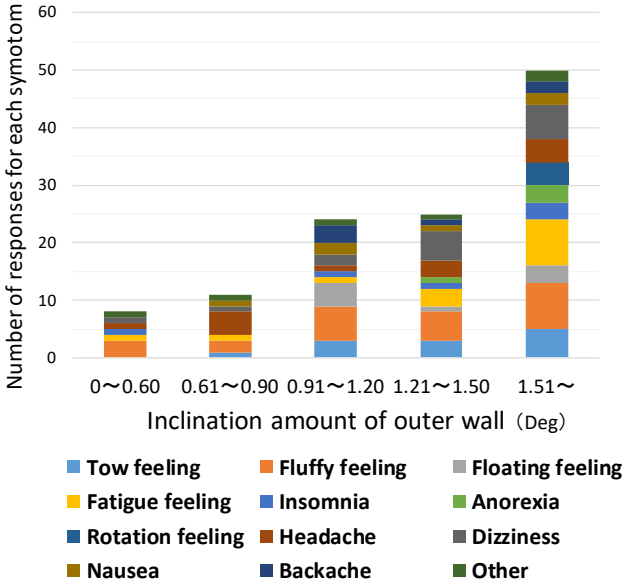

Fig. 14– Symptoms in each inclination(Outer wall)

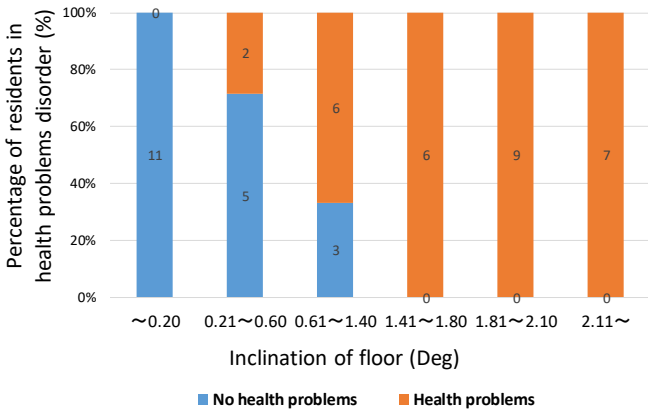

Fig. 15– Incidence of health disorder (Floor)

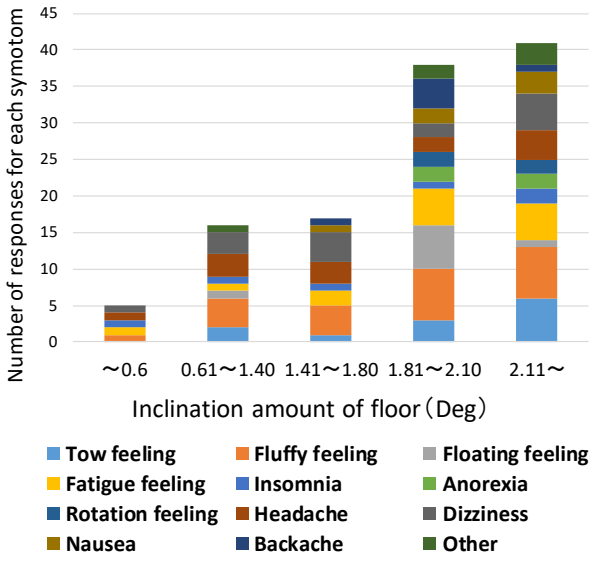

Fig.16– Symptoms in each inclination(Floor)

5.3 Dicussion

Fig.17 shows the number of persons with health problems in each symptom in the 2016 Kumamoto Earthquake and the 2018 Hokkaido Iburi-tobu Earthquake. The most common symptom was a feeling of fluffiness, then a feeling of fatigue. Regarding other symptoms, various items ranging from mental disorders to disorders of physical function were cited. The tendency of the occurrence of symptoms is the same in the both earthauakes. When living in a house with an outer wall inclination of more than 0.30° (5/1000), the occurrence of health problems was about 79% in the Kumamoto Earthquakes and about 73% in the 2018 Hokkaido Iburi-tobu Earthquake.

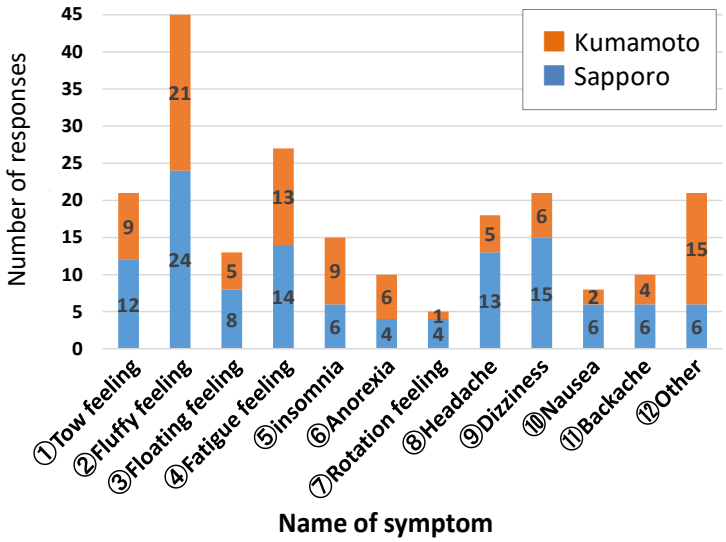

Fig. 17– Number of persons with health problems per symptom

6. Conclusions

Influence of inclination of houses induced by liquefaction on health disorder is studied in this paper. Firstly, field survey was done to clarify an inclination of outer wall of houses after the 2016 Kumamoto Earthquake and 2018 Hakkaido Iburi-tobu Earthquake. Then a questionnaire survey and hearing for residents were conducted to investigate the relation between inclination of outer wall and floor, and to study an effect of the inclination on health disorders. The results of this study are summarized as follows.

1) We investigated the inclination of outer wall of 125 houses in total in Kumamoto City and Sapporo City where the liquefaction occurred and remarkable damage was caused by liquefaction. Approximately 62% of the surveyed houses inclined to 0.6° or more at the outer wall.

2) As a result of the questionnaire survey, about 75% of respondents suffered from health problems.

3) A most common symptom of health disorders induced by inclination of houses was a feeling of fluffiness, then a feeling of fatigue. Regarding other symptoms, various items ranging from mental disorders to disorders of physical function were cited.

7. Acknowledgments

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