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HEALTH DISTURBANCE OF RESIDENTS IN A HOUSE WITH LIQUEFACTION DAMAGE IN MIHAMA WARD, CHIBA CITY

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ABSTRACT: The 2011 earthquake off the Pacific coast of Tohoku triggered liquefaction of soil in wide areas, particularly at the landfill in Kanto area. There were many residents who complained about health disorders caused by a tilted house due to liquefaction. We carried out a questionnaire survey to residents in Mihama Ward, Chiba City on earthquake damage to their house, health disturbance, etc., and constructed models of health disturbance in terms of tilt angle. It is clarified that the number of residents who suffer insomnia significantly increases when the tilt angle exceeds 1/100 rad.

Key Words: Great East Japan earthquake, Liquefaction, Floor tilt, Health disturbances, Detached house

INTRODUCTION

Triggered by the Great Alaskan earthquake and Niigata earthquake in 1964, the liquefaction study concerns many researchers so far. Particularly, there are several studies about health disturbances and the tilt feeling of residents and users who live or work in a building tilted by liquefaction. Kitahara and Uno (1965) carried out investigation concerning the residents and workers of buildings tilted by the Niigata earthquake of June 16, 1964 by interviewing them in November 1964 and discussing about causes of vertigo for example. Uno and Endo (1996) conducted investigation about 42 female residents who lived at accommodation unit tilted by the Niigata earthquake, by interviewing them in 1981 and performed experiments using tilt simulating equipment; i.e. they led examinees into a sloped room and carried out an analysis about perception of examinees through the tilted window frame (Endo, Uno 1982). Similarly they made a study on examinee’s felling about their posture and the tilt direction (Endo, Uno 1981). Fujii et al. (1998) surveyed about 100 liquefaction-damaged houses due to the 1995 Hyogo-ken Nanbu Earthquake in Ashiya City, and as a consequence they established a relation between the tilt angle and the functional failure of a building. Yasuda and Hashimoto (2002) and Yasuda (2004) also surveyed liquefaction-damaged housing estate in Abe-Hikona, Yonago City, which was struck by the Western Tottori Prefecture earthquake in 2000. Accordingly they discussed that 1/100 rad was the bearable limit of tilt angle of a house and, leveling repair was needed and made on houses with lager slope because of health disturbances.

During the 2011 Great East Japan earthquake, soil was liquefied in wide areas. In particularly, there were many liquefaction-damaged detached houses at reclaimed land in Kanto region. There were numbers of residents who complained of health disturbances due to the large tilt of their houses. This paper reports on survey results collected through questionnaire with interview during consultation meetings aiming at repairing detached houses damaged by liquefaction, which were held at Mihama Ward Office, Chiba City. Meeting participants were asked about characteristics of their residence, seismic damage, health disturbances, disaster awareness, and their communications with housing suppliers when purchasing house. A probability model of heath disturbance occurrence in terms of the maximum tilt angle of a house due to liquefaction is presented based on the survey data.

OUTLINE AND RESULTS OF QUESTIONNAIRE SURVEY

Outline of questionnaire survey

This investigation was carried out through questionnaire survey interview in four sessions at previously cited meeting place. At the dates of August 20, 21, 27 and 28, 2011, we interviewed 26, 12, 17 and 13 households, respectively. In total, 68 households responded to us, but one household did not suffer liquefaction damage. Thus, the target of the analysis is 67 households composed of 80 persons (42 men and 38 women). Note that all the households were owner-occupiers.

Specification of houses

Fig. 1 shows the distribution of structural types of their houses; 41 (61%) houses were built of timber framework and 8 (19%) houses light-gauge steel. Next, Fig. 2 shows the distribution of construction year. There were not a small number of relatively newly built houses, which had been replaced old houses due to deterioration with age or change of an owner. Then, 22% of houses, which were constructed from 1971 to 1980, conformed to old standards of earthquake resistance; in 1981, the Building Standard Law of Japan had major amendment with respect to earthquake resistance. It should be noted that 24 out of the 67 houses (36%) were made alteration or enlargement after construction by their owner.

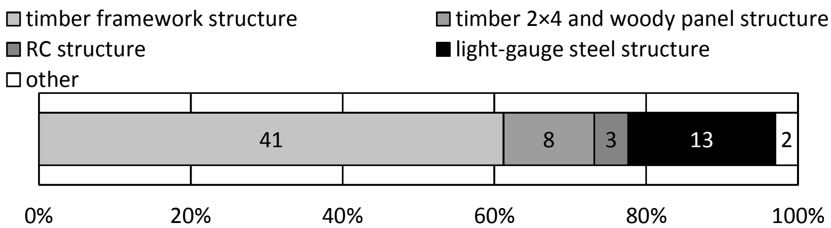

Fig. 1 Distribution of structural types of houses (N = 67)

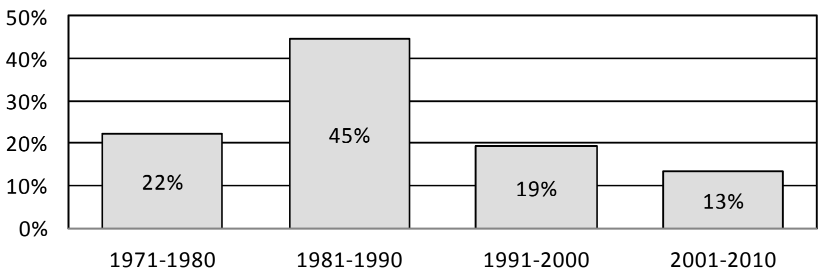

Fig. 2 Distribution of construction years (N = 67)

In terms of a number of stories, 66 houses had two stories, and there was one three-storied house. Regarding a type of use, 66 out of the 67 houses were exclusively residential dwelling houses, and the other one house was used as both a dwelling and an office.

Among the 67 houses, 36 (54%) were ready-built and 31 (46%) were custom-built. Fig. 3 shows the distribution of foundation types. A large number, 47 (70%) of houses were built on footing foundations, and 12 (18%) had mat foundations. Fig. 4 shows the distribution of existence of soil reinforcement and subsurface exploration; three households (4%) conducted the soil reinforcement and 23 (34%) conducted subsurface exploration. Fig. 5 shows the number of households who conducted subsurface exploration according to the construction years of their houses; the percentage of conducting subsurface exploration is high for the houses built after 2001.

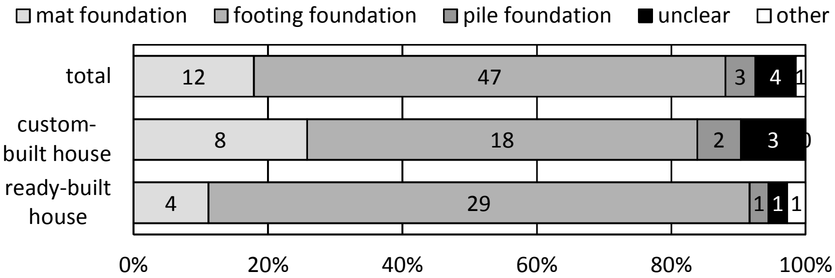

Fig. 3 Distribution of constructional years (N = 67)

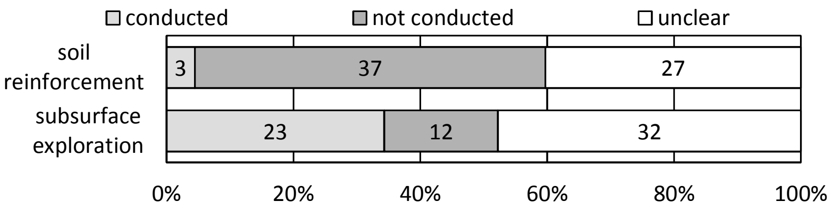

Fig. 4 Distribution of existence of soil reinforcement and subsurface exploration (N = 67)

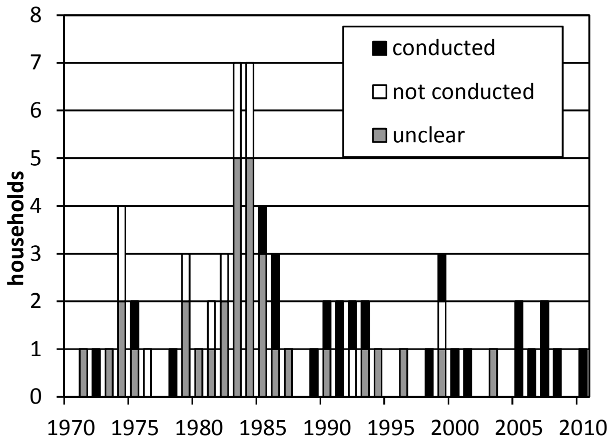

Fig.5 Number of households who conducted subsurface exploration according to the construction years of their houses (N = 67)

Fig. 6 shows the number of households who received explanations about liquefaction and those about earthquake resistance; 65 (97%) and 46 (69%) of households did not receive explanations about liquefaction and earthquake resistance, respectively. Fig. 7 shows the number of households who were explained about earthquake resistance according to the construction year of their houses; the respondent households living in newly built houses tend to have received explanations about earthquake resistance.

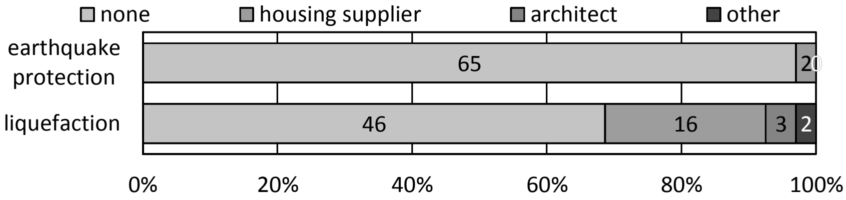

Fig.6 Distribution of existence of explanations about liquefaction and earthquake resistance (N = 67)

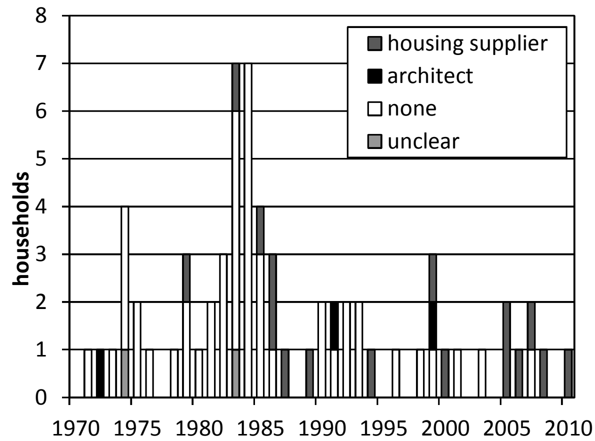

Fig.7 Number of households who were explained about earthquake resistance according to the construction years of their houses (N = 67)

Seismic damage

Here the situation of seismic damage to their detached houses is discussed. Fig. 8 shows the distribution of damage certificates issued by the local government, Chiba City; 37 (55%) houses were judged as partially destroyed, and there was no completely destroyed house. Fig. 9 shows the distribution of damage ranks evaluated by insurance companies; 37 (55%) households were subscribers of earthquake insurance, and 22 were judged as half loss and 10 as the complete loss.

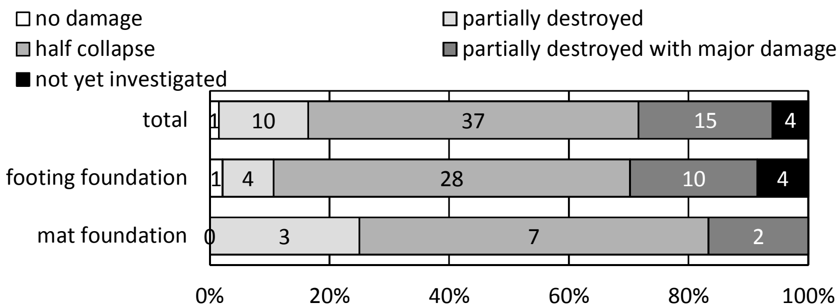

Fig. 8 Distribution of damage certificates issued by the local government (N = 67)

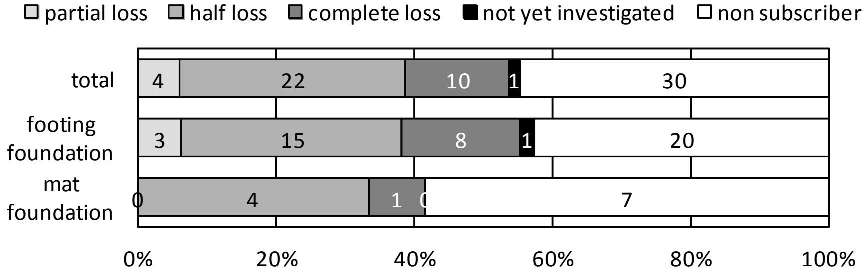

Fig. 9 Distribution of damage level according to earthquake insurance (N = 67)

Next the damage situation is described. Fig. 10 shows the situation of damage to the ground at the sites of their house. Sand boiling occurred at 64% of the housing lots. Fig. 11 shows the distribution of existence of cracks in foundations and outer walls of their houses. There were comparatively more cracks in foundations than cracks in outer walls.

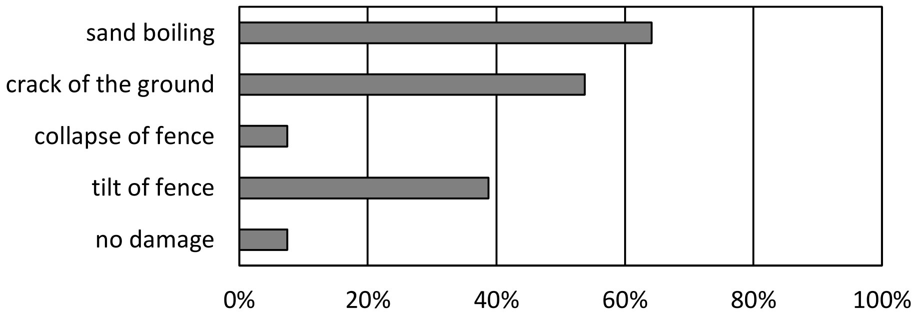

Fig. 10 Damage to housing lots (N = 67)

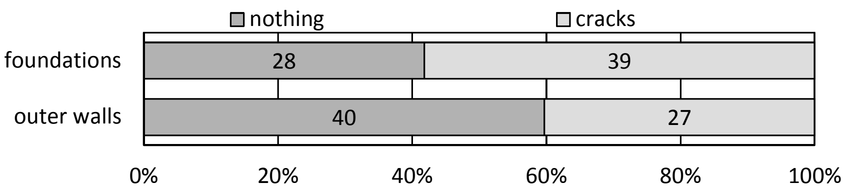

Fig. 11 Existence of cracks in foundations or outer walls (N = 67)

Fig. 12 shows the relation between the maximum tilt angles of houses and construction years; these tilt angles were surveyed by the local government, insurance companies, or home builders. The categories of damage certificates are indicated in the right side of the graph. Note that, considering the wide-spread liquefaction damage to houses in the Great East Japan Earthquake Disaster, the tilt of a house was additionally considered for the following two categories of damage certificates:

- Partially destroyed with major damage: equal to or more than 1/60 rad and less than 1/20 rad
- Partially destroyed: equal to or more than 1/100 rad and less than 1/60 rad

The criterion for ‘completely destroyed’ (tilt angle equal to or more than 1/20 rad) had been already considered before the disaster. According to the figure, mat foundations were often employed in the newly built houses; the houses with tilt angle exceeding 1/60 (≒0.017) rad tended to have footing foundations, but there was no houses with the mat foundations of which tilt angle exceeded 1/60 rad.

Fig. 13 shows the distribution of damages to door fit; 85% of households claimed that they had inconvenience that a door moved automatically due to tilt of their houses.

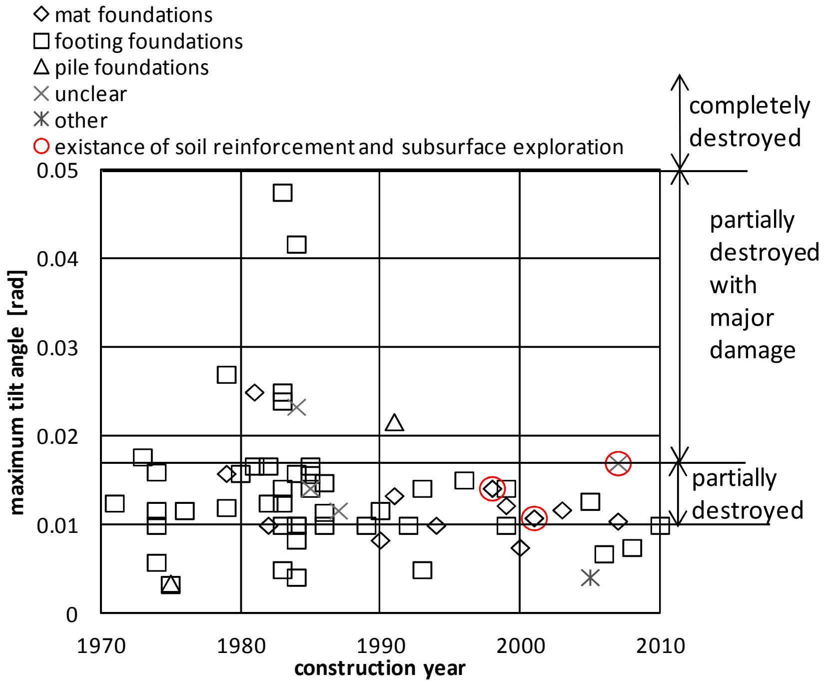

Fig. 12 Relation between the maximum tilt angles of houses and construction years (N = 64; the number of houses of which tilt angle is clarified)

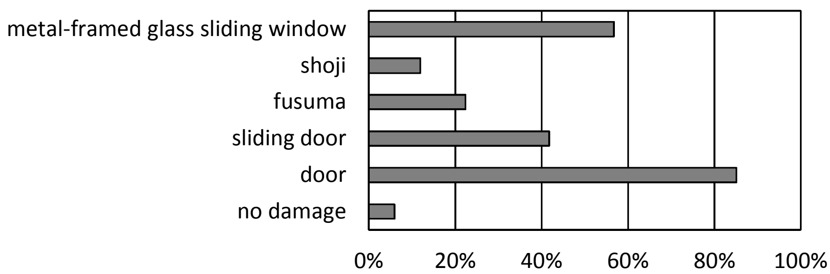

Fig. 13 Distribution to damages of door fit (N = 67)

Health disturbances

In this section, health disturbances of the respondents are discussed. First, Fig. 14 shows the distribution of age and gender of the respondents. It had a high percentage of senior people in age 60s and especially women.

Fig. 15 shows the distribution of sensitivity to tilt; among the 80 respondents, 55 (men: 27, women: 28) were clearly aware of the tilt of their houses. The ratio of the women who felt the tilt strongly is larger than that of the men; possible explanations were that people who spent long time at house and practice housework might feel tilt strongly.

Fig. 16 shows the relation between tilt adjustment time and the maximum tilt angle of a house. The correlation between them is not clear, and the adjustment time seems to differ from one to another.

Fig. 17 shows certain symptoms of health disturbances caused by tilt, which the examinees experienced between the occurrence of the Great East Japan earthquake and the present survey. There were some examinees who complained about shoulder stiffness, foot pain, and other health disturbances, and some examinee stated that their sick became worse after the earthquake. It should be noted that the causes of health disturbances could be not only related to the slope of the floor, but also to the vibration of aftershocks.

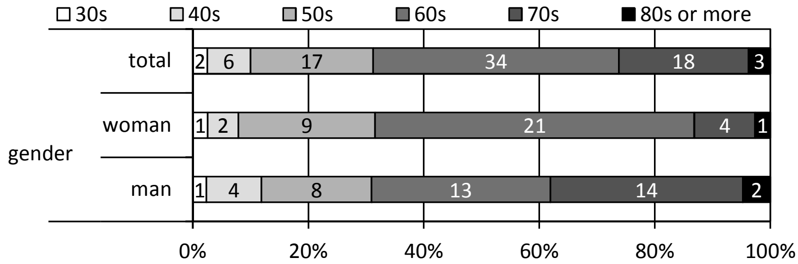

Fig.14 Distribution of age and gender of the respondents (N = 80)

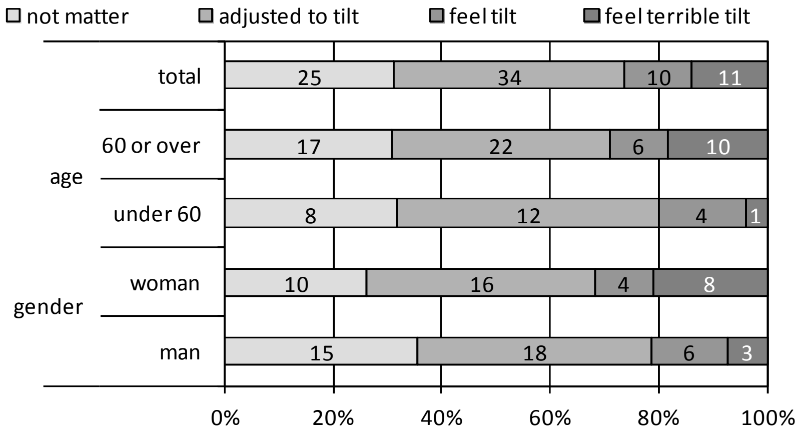

Fig. 15 Sensitivity to tilt at the time of the survey (N = 80)

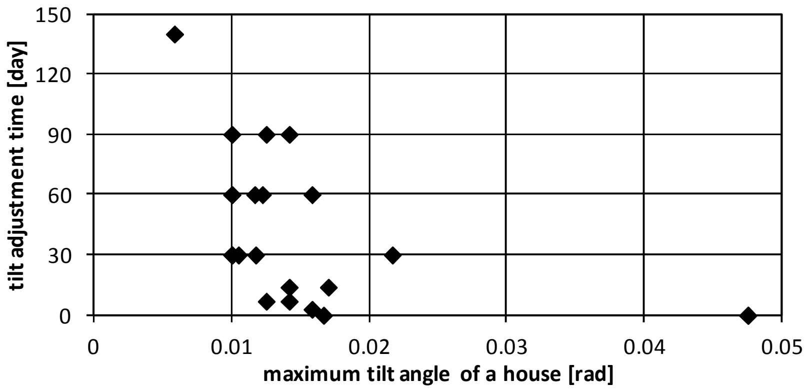

Fig.16 Relation between tilt adjustment time and the maximum tilt angle of a house (N = 25; the number of examinees who answered both the maximum tilt angle and the time to adjust to tilt)

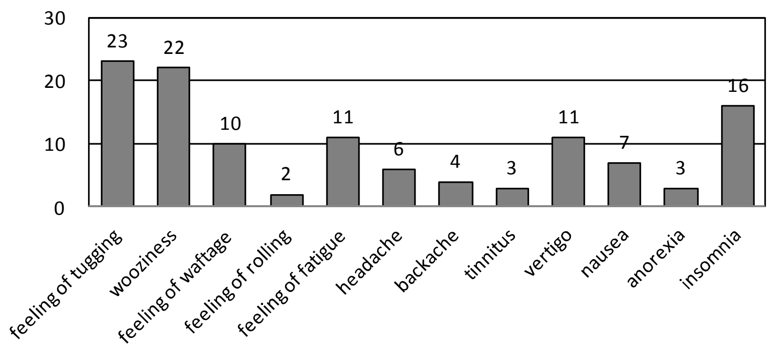

Fig.17 Health disturbance symptoms related to tilt between the occurrence of the earthquake and the present survey (N = 77; the number of examinees who answered the maximum tilt angle)

As for the 55 examinees who were aware of the tilt, Fig. 18 shows the changes in health condition between the earthquake occurrence and the present survey. Here also, it seems not possible to establish a relation between those state changes and age or gender of the examinees.

Fig. 19 shows the existence of the examinees concerned with vertigo when going out of their house; in particular, the women examinees who were in age 60 or over were concerned. There were some examinees whose symptoms were worsened when they saw tilted power poles or tilted buildings. Some examinees who got used to the tilt of their house felt that the outside world was leaning.

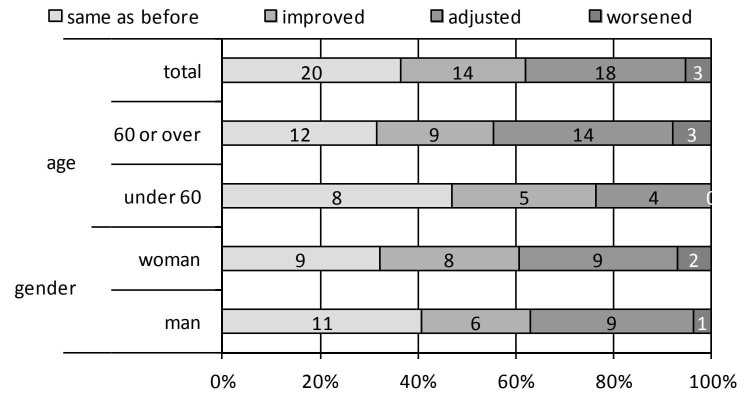

Fig. 18 Evolution of health state between the occurrence of the earthquake and the present survey (N = 55; the number of examinees who were aware of the tilt)

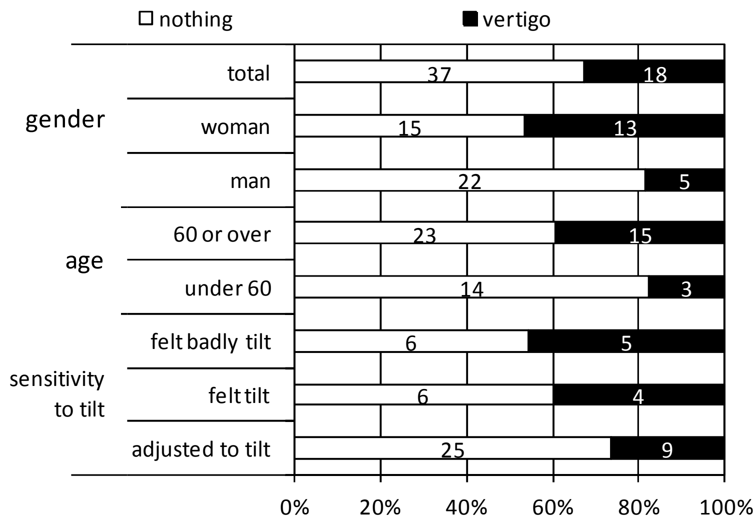

Fig. 19 Vertigo feeling when going out (N = 55; the number of examinees who were aware of the tilt)

HEALTH DISTURBANCE MODEL

The logarithmic probit models of health disturbances are constructed, in terms of the maximum tilt angle of a house due to liquefaction. In the present survey, the data of the 77 examinees who replied about the tilt angle are available. In order to complement this data, the data of past literature are also considered. Figs. 20 and 21 show the survey results in Kitahara and Uno (1965) and Uno and Endo (1996), respectively; Kitahara and Uno (1965) surveyed 66 persons and Uno and Endo (1996) surveyed 42 persons.

Since the vertigo, headache, and insomnia symptoms were included in the data of all the above three surveys, we focus on these three symptoms. The symptoms: feeling of rolling, feeling of waftage, wooziness, and vertigo in the data of the present survey and the survey in Uno and Endo (1996) are categorized into “vertigo”, and they are aggregated with the survey data in Kitahara and Uno (1965). To use the survey data of the past studies, the range of the tilt angles in degrees has been transformed into median values of the intervals to obtain tilt angles in radians.

The maximum likelihood method is employed to construct the models, and models based only on the present survey are compared with those based on all the three surveys. The parameters of the resulting models are presented in Table 1. Figs. 22-24 represent the models for vertigo, headache, and insomnia, respectively. In the figures, points on 0% and 100% lines show data about respectively the absence or the presence of the symptom in the above three survey data.

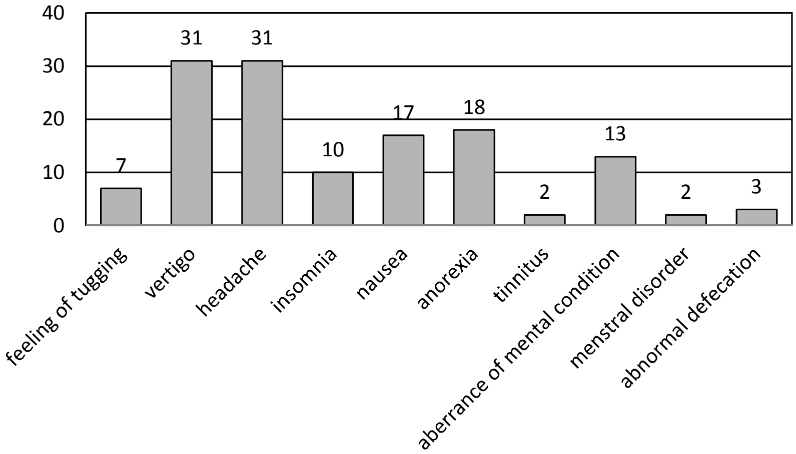

Fig. 20 Symptoms of health disturbances in Kitahara and Uno (1965) survey (N = 66)

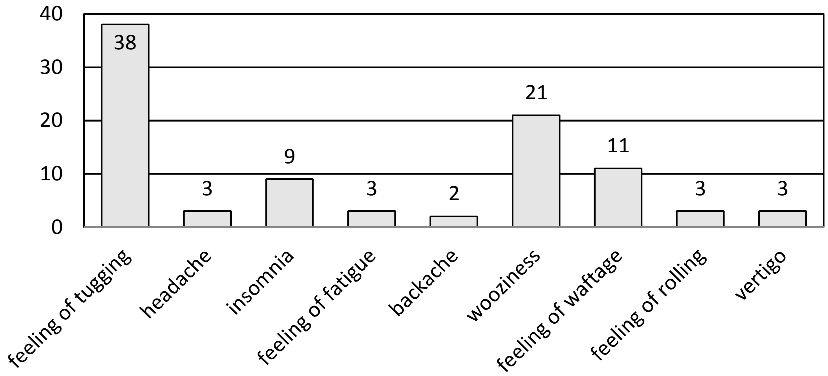

Fig. 21 Symptoms of health disturbances in Uno and Endo (1996) survey (N = 42)

Table 1 Parameters of health disturbance models

Data	Symptoms	Logarithmic mean	Median [rad]	Logarithmic standard deviation
The present survey	Vertigo	–4.05	0.0175	0.845
	Headache	–3.26	0.0385	0.638
	Insomnia	–3.45	0.0316	1.08
All the three surveys	Vertigo	–3.23	0.0395	1.57
	Headache	–2.76	0.0635	1.00
	Insomnia	–1.58	0.207	2.38

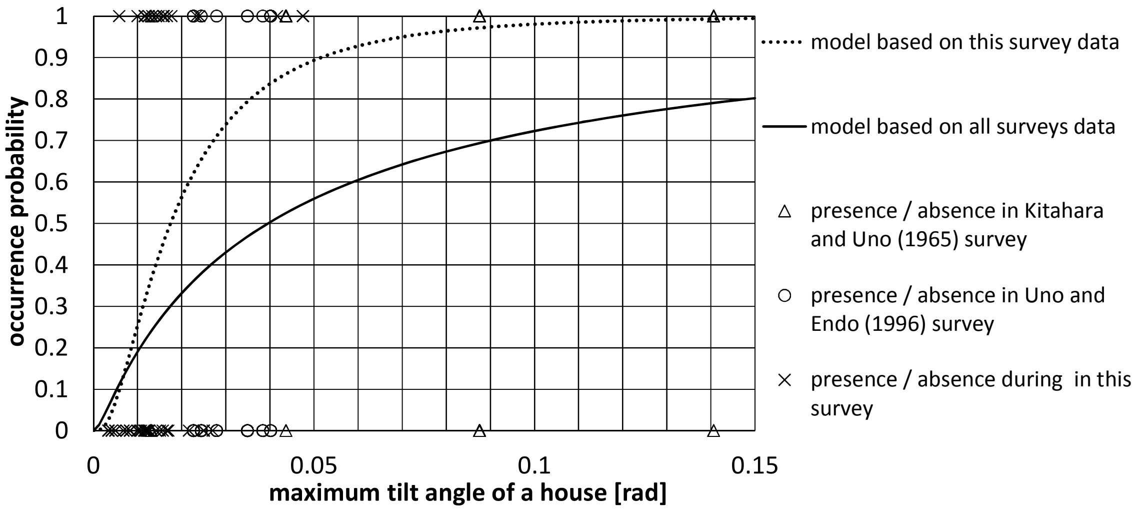

Fig. 22 Occurrence probability model of vertigo in terms of the maximum tilt angle of a house

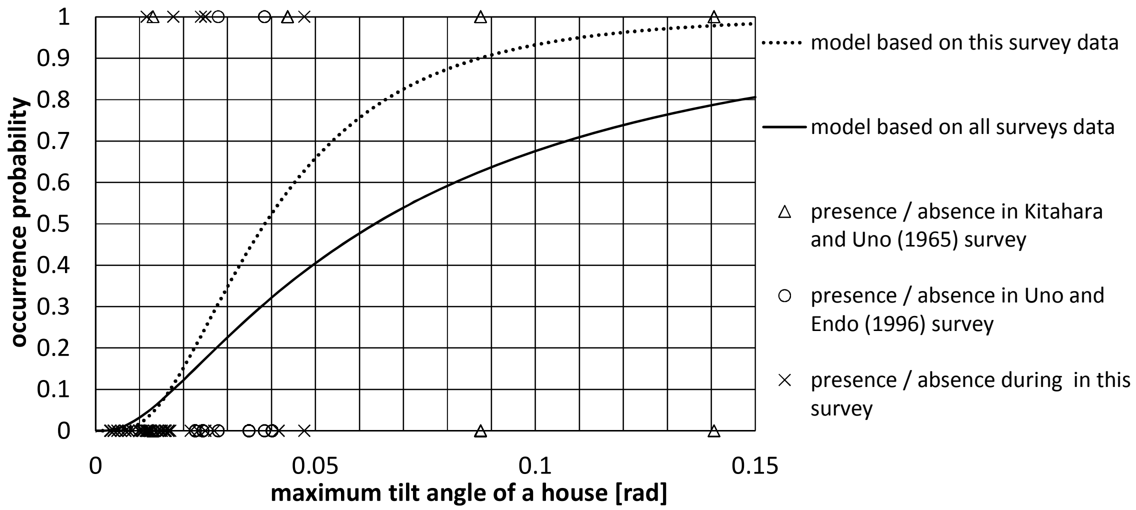

Fig. 23 Occurrence probability model of headache in terms of the maximum tilt angle of a house

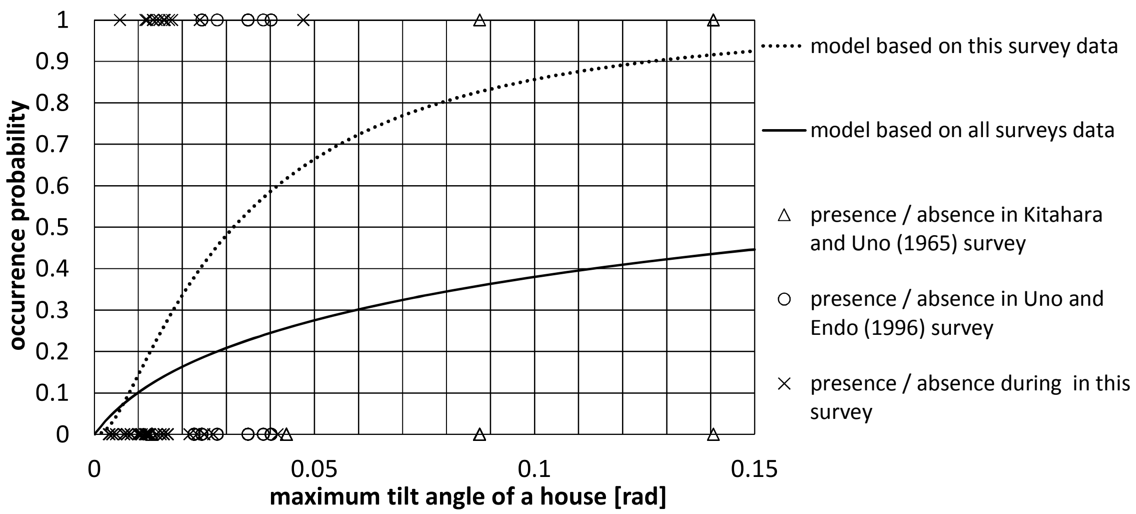

Fig. 24 Occurrence probability model of insomnia in terms of the maximum tilt angle of a house

It is observed that, in the models constructed from the data of the present survey, the number of people who complain about health disturbances increases rapidly when the tilt angle exceeds 1/100 rad. The curves based only on the resent survey are rather different from those constructed from the three survey data. The main reason of this difference is probably related to the span of age and gender of the examinee as well as the span of the tilt angles; in the present survey, majority of the data are concerning relatively small tilt angles compared with the survey of the past literatures.

CONCLUSIONS

A questionnaire survey was conducted through a interview to liquefaction victims of the 2011 Great East Japan earthquake, who lived in Mihama Ward, Chiba City. Based on the survey data, the logarithmic probit models of health disturbances, i.e. vertigo, headache, and insomnia, were constructed, in terms of the maximum tilt angle of a house due to liquefaction. In the present survey, the data of the 77 examinees who replied about the tilt angle were available.

In order to complement this data, the data of past literature, Kitahara and Uno (1965) and Uno and Endo (1996), were also considered; the data of 66 and 42 persons were available in these two surveys, respectively. It is suggested that the tilt angle exceeding approximately 1/100 rad cause health disturbances. However, as the deviation of this tendency is not negligible, it is important even if the maximum tilt angle is smaller than 1/100 rad to investigate conscientiously all the households to prevent health inconveniences.

The challenge for the future is to improve the reliability of the probability model to increase the confidence of the final results. In addition, as the age of the respondents in Kitahara and Uno (1965) are unclear, those in Uno and Endo (1996) are women between the age of 18 and 27, and those in the present survey are men and women of age 30 or over, a survey concerning a young adult segment, i.e. less than 17 years and more particularly children, is expected.

ACKNOWLEDGMENTS

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