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RESIDENT PARTICIPATORY MONITORING OF SLOPE DISASTERS USING TILT SENSORS

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ABSTRACT: In recent years, due to the effects of climate change, slope disasters have frequently been occurring and causing severe damage in many places across the globe. To reduce the damage from slope disasters, residents need to correctly understand the hazards and protect themselves. In this study, we attempted to evaluate the risks of slope disasters in local residential areas and to analyze the residents' opinions gathered through a workshop on their participation in the monitoring of slope disasters using tilt sensors for prevention. As a result, the overview of the evaluation items for high-risk slopes and their contents was clarified, which had been tacit knowledge, as well as the structure of the local residents' concerns about the slopes and their expectations for monitoring utilizing tilt sensors to take evacuation action. To help solve the problems, we installed tilt sensors in areas with high risks of collapse, and we built a mechanism that allows the local residents to monitor the slopes and take evacuation actions. An alert is issued before a slope failure occurs, and it functions as an "evacuation switch", which leads to residents taking evacuation actions to protect themselves. It is expected that tilt sensor monitoring will be widely used in voluntary disaster prevention activities in the region.

Keywords: Evacuation, Resident awareness survey, Slope disaster, Tilt sensor, Monitoring

1. INTRODUCTION

In recent years, due to the effects of climate change, slope disasters have been frequently occurring and causing severe damage in many places across the globe. To reduce the damage from slope disasters, residents need to correctly understand the hazards and protect themselves. In Japan, there are about 2.7 million dwelling units in contact with the sediment-related disaster warning area, and even if the warning information is transmitted, there is the constant threat of damage caused by the delay in escape [1].

Various factors lead to damage from slope disasters, such as the tendencies to ignore warning information and avoid evacuation, as well as the problem of the normalcy bias [2,3]. We can install IoT tilt sensors to solve these problems [4]. The warning alarm for sediment-related disasters can directly notify the relevant residents and encourage them to take evacuation actions to protect themselves. The purpose of this study was to verify whether it is possible to build a connection mechanism. Therefore, after consulting with the local residents in the city of Fukuchiyama, Kyoto Prefecture, Japan (who had suffered landslides in the past) and informing them about the actual slope hazards, we proposed a "slope monitoring system by resident participation using IoT tilt sensors", in which the residents themselves monitor the slopes.

A field survey was conducted in the sediment-related disaster warning area from a geological expert's viewpoint, and high-risk slopes were selected. A workshop was held for local stakeholders to select the houses to be evacuated for the installation of the IoT tilt sensors [4] on selected slopes at high risks of slope failure. In the workshop, the characteristics of the tilt sensors, control thresholds, and lead times for evacuation were explained to the residents to foster their awareness. Then, a discussion was held with the residents regarding their concerns about the slopes and their expectations for monitoring utilizing tilt sensors to take evacuation action.

2. RESEARCH SIGNIFICANCE

In this study, the risks of slope disasters were evaluated, and the residents' opinions were gathered and analyzed through a workshop on their participation in slope disaster monitoring using tilt sensors for prevention. The significance of this study is the identification of the interests in and expectations of IoT tilt-sensor monitoring for slope disasters by local residents. If local residents have an interest in and expectations for IoT tilt-sensor monitoring, then a new system for risky-slope monitoring by local residents using IoT tilt sensors can be established. In addition, this new monitoring system using IoT tilt sensors can be installed in many high-risk places with dangerous slopes, which will save lives.

3. FUKUCHIYAMA, KYOTO

The Araki district of the city of Fukuchiyama, Kyoto Prefecture, is located along the middle reaches of the Haze River on the east side of the city. The number of households in the district is 67, the population is 157, and the population of elderly people aged 70 years and over is 42, as in [5]. As shown in Fig. 1, almost the entire main part of the area is designated as a sediment-related disaster warning area, and part of it is designated as a sediment-related disaster special warning area. The Araki area has three evacuation centers: Araki Public Hall at the foot of the mountain, Momijigaoka Hospital, and Toei Junior High School.

In the heavy rains in August 2016, moist air flowed into the stagnant fronts in the Kinki region, and locally heavy rains hit the area and Hokuriku. In Fukuchiyama, the 24-hour rainfall from the 16th to the 17th exceeded 300 mm. In addition, the Yura River temporarily exceeded the flood risk level, and many inland floods and landslides occurred. Evacuation advisories were issued to about 80,000 people throughout Fukuchiyama, and the Ground Self-Defense Force was dispatched to help. Furthermore, due to this heavy rain, the JR Fukuchiyama Line and San-In Line were cut off, which had a substantial social impact. In the Araki district, sediment-related disasters occurred in seven places, including the collapse of a mountain behind a private house. After this disaster, the voluntary disaster prevention organization of the Araki Neighborhood Association, with the cooperation of the Fukuchiyama government and Kyoto University, set up its own "evacuation switch" that defines the criteria for residents to start evacuating using landslide potential information and soil rainfall indices [6].

4. EVACUATION INFORMATION AND BEHAVIOR

Multiple studies on evacuation have confirmed the problem of the misalignment between evacuation information and the evacuation behavior of residents. In a study by Takenouchi et al., which took the case of the heavy rainfall in northern Kyushu in 2017 (Fig. 2), the authors considered that the criteria for judging the area are unique, such as the situation of the streams flowing through the district, the inundation situation of the houses beside them, the inundation situation of small bridges in the neighborhood, etc. [7].

This study also points out that, in addition to evacuation information, "external information/situations", such as loud voices, the voices of people close to us, the behaviors of people around us, and the inundating conditions, affect the evacuation. The research of Yamori et al. focused on the interiors of people who receive "external information/situation". Disaster information, such as disaster prevention weather information and evacuation information, is "advanced" and "complex". However residents want to know more about their safety or danger than detailed evacuation information. This is information that leads to the next action, as in [8].

When setting the "evacuation switch" for information that turns on/off the switch inside the person that leads to the next action, not only the disaster prevention weather information provided

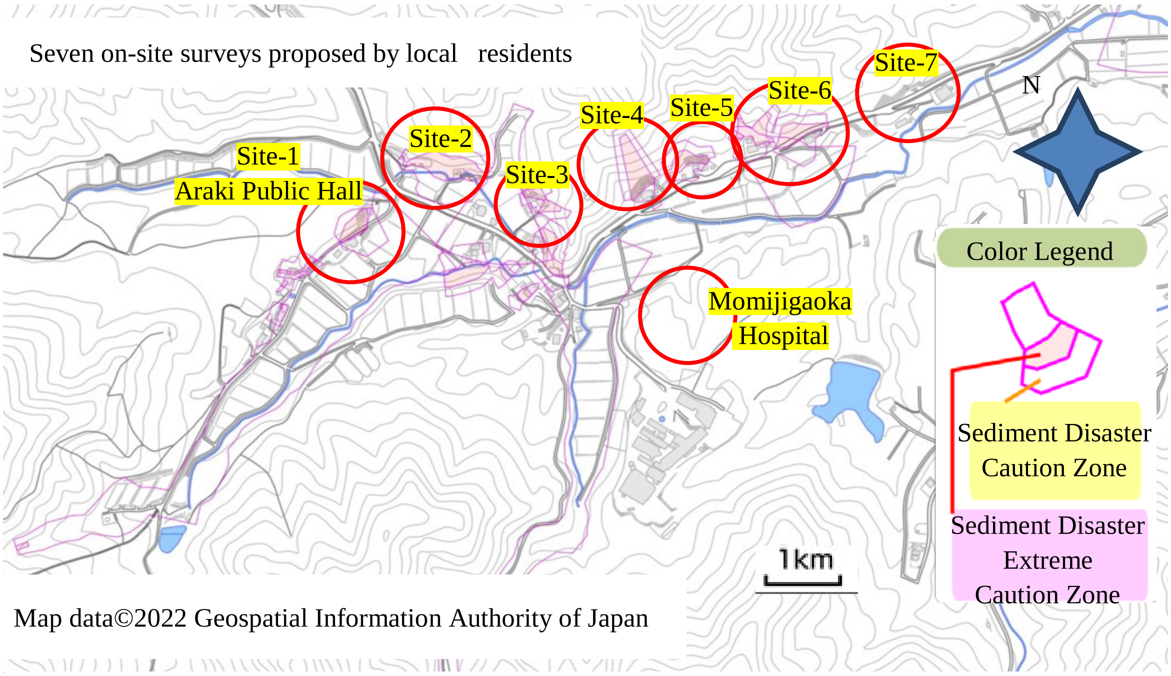

Fig.1 Araki district, Fukuchiyama City, Kyoto Prefecture

by the specialized agency, but also the local residents themselves. It is important to utilize a wide range of information, such as phenomena that local residents can observe and cases of historical disasters.

Yamori et al. also argue that diversification and the double tracking of the information that contributes to "switches" are more important than the sophistication of the disaster prevention weather information itself when looking at disaster prevention and mitigation in the coming decades. Tang Z et al. (2021) forwarded the Proposal of Isolation Measures for Mountain Villages Based on Analysis of Disaster Prevention Drills (2021) [9]. Based on the above discussion, this paper considers the addition of evacuation switches in slope hazards to the currently applied landslide potential information and soil rainfall indices.

Methods of measuring the groundwater level and soil moisture content cannot be confirmed without the installation of measuring equipment. These data include uncertain factors because they are indirect methods of observing the slope failure potential. In addition, it is dangerous to confirm the flooding, inflow of water from slopes, and falling pebbles on site. To solve such problems, many studies on the direct monitoring of slope behavior using sensors have been conducted [10-14]. However, there are few studies and investigations on the application of these systems to the evacuation of residents from slope disasters through resident participatory monitoring. For these reasons, we studied whether alerts from IoT tilt sensors that directly measure the slope degree can be used as evacuation switches.

Fig.2 Photo after the disaster (Site-3)

5. METHOD OF SELECTING SITES FOR TRIAL MONITORING

The selection of sites for trial monitoring was conducted at candidate sites in the Araki area. Seven sites proposed by local residents were inspected together with the residents to evaluate the degree of the risk of disaster on the slopes. There are no established methods for evaluating slope hazards. thus, the following six items were identified based on the results of the inspection. Slopes with relatively high levels of each of these six items were evaluated on a three-point scale, and slopes with relatively high levels of each of these items were evaluated as having high risk. As a result, the slopes at Sites 2 and 3 were selected for trial monitoring (as shown in Table 1 and Fig.1).

Table 1. Evaluation sites for trial monitoring.

Evaluation Items	Site						
	1	2	3	4	5	6	7
(a) Slopes with no exposed base rock and collapsible surface soil	△	◎	◎	-	◎	△	△
(b) Evidence of past collapse or cracks	-	◎	○	-	-	◎	◎
(c) Relatively tight slope	◎	◎	◎	◎	○	◎	○
(d) Possibility of collapsed sediment reaching houses, etc.	○	◎	◎	△	◎	△	-
(e) Facing a public building	◎	-	-	-	◎	-	-
(f) The degree of damage is assumed to be above a certain scale	○	◎	◎	△	◎	△	○

Note: ◎ : much applicable ○ : applicable
△ : a few applicable - : not applicable.

5.1 Slopes with no exposed base rock and collapsible surface soil

Talus deposits are present on the slope, or surface soils formed by the weathering of base rock or other processes [15]. If the surface soil is not sufficiently covered with forest vegetation, then it is particularly vulnerable to collapse [16]. If exposed hard basement rock is on the slope, then it is unlikely to collapse, except by landslides.

5.2 Evidence of Past Collapse or Cracks

If there are traces of collapse or cracks in or near a part of the slope, then it is likely to easily collapse. If the entire slope has collapsed in the past and no surface soil is present, then the risk of another collapse may be low.

5.3 Relatively Tight Slope

Natural slopes collapse more easily if the slope is relatively tight (greater than about 30°). However, even if the slope is relatively tight, it will not easily collapse if there is no collapsible surface soil.

5.4 Possibility of Collapsed Sediment Reaching Houses

The risk is high if there is a possibility that the sediment from the slope is expected to collapse houses and other structures that are to be preserved. Even if collapsible surface soil is distributed, it is not a disaster if it is not expected to reach houses and other structures.

5.5 Facing a Public Building

If the conservation target to be damaged in the event of slope failure is a public building, such as a shelter, community center, government office, or nursing care facility, the damage may be larger and the risk of disaster higher.

5.6 Degree of Damage Above a Certain Scale

If the slope collapses, the risk of disaster is considered significant if the damage is expected to be above a certain scale, such as when sediment reaches multiple houses, roads, or other public facilities, or when there is the possibility of further damage. These evaluation items and scales are based on the tacit knowledge of experts and have not yet been established. Thus, we will apply them to many slopes to establish them from now on.

After selecting the location, we held on-site discussions with the house owner (also the landowner of the slope), listened to the situations of past slope disasters, installed a tilt sensor in consideration of the microtopography of the slope, and examined the position where it was to be located. Then, at the position where there was a possibility of collapse, two tilt sen8 were installed at Site 2 and three at Site 3, and the trial monitoring began (Fig. 6).

Fig.3 A Workshop in Araki

6. WORKSHOP

A workshop on slope disaster evacuation using tilt sensors was held at Araki Public Hall with local residents, the Fukuchiyama government, and Professor Yamori of Kyoto University. During the workshop, local residents were made aware of the characteristics and dangers of the slopes, the handling of the tilt sensors and control thresholds, and the evacuation lead times. Afterward, discussions were held on the residents' concerns about the slopes and their expectations for the tilt sensors (Fig. 3).

6.1 Local Residents' Anxieties and Concerns about Heavy Rain/Sediment Disasters

Anxieties and concerns about heavy rain/slope disasters are deep-rooted, especially among local residents. From the workshop, the opinions on the anxieties and concerns of the local residents regarding heavy rain/sediment disasters were analyzed using the co-occurrence network of text-mining analysis [17].

6.1.1 Analysis method

By performing co-occurrence network analysis, it is possible to visualize word-to-word connections (co-occurrence relationships). The circles in the figure represent the extracted words. The sizes of the circles indicate the frequencies of the appearances of the words. The higher the frequency of the appearance, the larger the circle. In this paper, we used subgraph detection, which automatically detects and groups words that are relatively strongly connected. The lines in the figure represent the strengths of the co-occurrence relationships. The darkness of the line indicates the strength of the co-occurrence relationship: the stronger the connection, the darker the color.

In addition, the Euclidean distance coefficient ("similarity" for words similar to distance) is used on the line representing the co-occurrence relationship. The Euclidean distance coefficient shows the relationship between the similarity and distance:

Similar = high similarity = close distance (small).

Dissimilarity = low similarity = strong characteristics because it is far away (large) [18].

6.1.2 Analysis results

As a result of a morphological analysis of the nine answers obtained in the workshop, 220 total words and 88 different words were extracted. Figure 3 presents a diagram showing the co-occurrence network with a minimum number of two occurrences for the remarks of the local residents in the workshop.

The contents of the remarks obtained in the workshop were divided into groups through the automatic detection of strongly connected words, and the results are shown by color coding. A total of five words were extracted as the answers characteristic of the yellow system: "slope," "collapse," "heavy rain," "road," and "scary." As the answers characteristic of the light-blue system, a total of six words were extracted: "Araki district," "disaster," "mountain," "feeling uneasy," "house," and "disaster prevention information."

This is a visualization of the co-occurrence relationship between the yellow system and light-blue system, and the difference in viewpoint depending on the degree of similarity and distance.

In this study, the following four points were clarified as a result of the co-occurrence network analysis of text mining about the anxieties and concerns of the local residents regarding heavy rain/sediment disasters at the workshop conducted for the local residents in the Araki area (Fig. 4):

(a) Regarding the workshop, the contents of the remarks automatically detected relatively yellow words and connected and divided them into yellow and light-blue groups. The representatives of the words are "heavy rain," "slope," "collapse," and "feel uneasy".

(b) Regarding the workshop, it was recognized that the network of words characteristic of the light-blue system had a coefficient of 1.0 for "mountain" and "disaster", and the darker lines indicated a strong connection between these two terms.

It was recognized that the network of words characteristic of the yellow system had a coefficient of 0.60 for "slope" and "collapse". The thicker the line, the stronger the degree of co-occurrence, which means that there was a heavy correlation between "slope" and "collapse".

(c) The connection between "slope," "collapse," "road," and " uncanny" was also observed around "heavy rainfall." It is thought that heavy rain, specific objects, such as slope collapse and roads, and the fear of these objects have a strong relationship.

(d) Focusing on the relationship between the light-blue colors, a network of "Araki District" and "disaster," "mountain," "anxiety," "house," and "disaster prevention information" can be seen. This is thought to represent the relationship between the Araki district's elements for disaster anxiety and prevention.

6.2 Factors of Expectations and Expected Utilities by Residents

The opinions of the local residents regarding their expectations for tilt sensors, gathered from the workshop conducted in the Araki district, are shown in a structured diagram (Fig. 5). This structural diagram visualizes the local residents' statements by

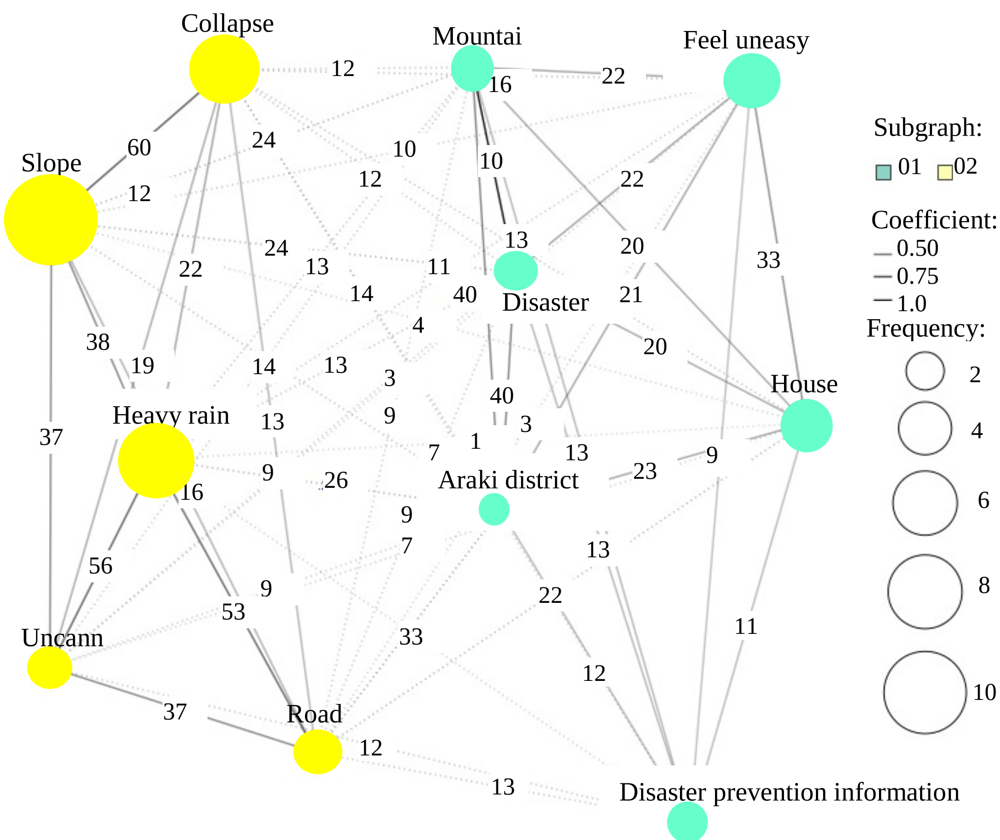

Fig.4 Results of co-occurrence network analysis

breaking them down into their constituent elements and connecting them with the arrow lines considering their contexts. As a result, the statements can be categorized into "factors of expectations" and "expected utilities".

In this diagram, the expected elements of the tilt sensor are as follows: (a) the information can be received by a cellular phone. (b) the risk can be visualized. (c) the information on a specific site can be checked.(d) the information is about a nearby slope. In these elements, (a) and (b) are the factors of expectations for the characteristics of the system provided by the tilt sensor. In addition, (c) and (d) are considered the reason for the expectation that the information on the behavior of the slope itself where the tilt sensor is installed can be obtained, compared with disaster information issued for a wide area, such as disaster potential information and landslide warning information.

These factors lead to the expectation of utility: (a)–(e) evacuation can be planned. (b) and (c)–(f) serve as the basis for evacuation decisions. (d)–(g) early evacuation can be taken into consideration. In other words, slope monitoring with tilt sensors is expected to increase the utilities for evacuation planning, early evacuation, and evacuation decisions by local residents, and there is also the opinion that "(i) It is a reference for deciding when to return home".

These factors of expectations and expected utilities of residents should be fully considered when developing a system for participatory slope monitoring.

7. DISCUSSION

In addition to providing accurate information on landslide disasters caused by heavy rain, local slope disaster alerts become evacuation switches to publicize the danger, judge the situation, and decide whether to take evacuation action. Therefore, in this study, we attempted to apply a resident participatory early warning system using real-time tilt sensors for evacuation due to slope disasters, which functions as an evacuation switch.

(1) Through the workshops, it was apparent that the issues of the residents and municipalities regarding landslide warning information could be improved, including "improving prediction accuracy" and "narrowing down the areas (units) of announcements".

(2) It turns out that there are many slopes that the residents feel are dangerous. Through the field survey and workshop, real-time tilt sensors, rain gauges, and soil moisture meters were installed in selected sites that evaluated the risk of a slope becoming dangerous based on six items based on interview surveys with residents and field surveys by geological experts (see Fig. 6).

The use of real-time monitoring to increase the accuracy of estimating the occurrences of sediment-related disasters from real-time inclination angles, rain gauge data, and soil moisture meter data measured in the field is valid.

(3) It was also obvious that the residents had substantial interest in the slope monitoring system using IoT tilt sensors, as well as expectations, such as receiving the information by cellular phone, the visualization of the risk, the ability to check information on a specific site, and ensuring that the

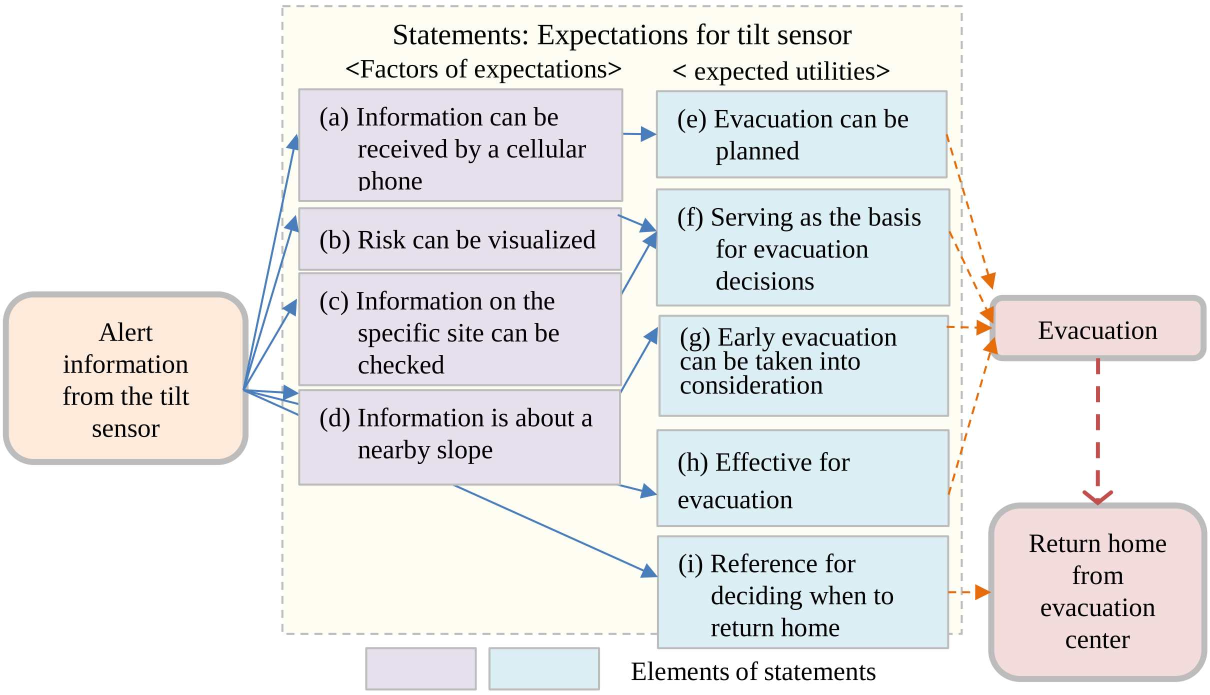

Fig.5 The Structure of factors of expectations and expected utilities by local residents

information is on nearby slopes. These factors lead to the expectation of utility, such as evacuation planning, serving as the basis for evacuation decisions, and considering early evacuation as well as the decision to return home. These achievements are useful in developing a system for resident participatory slope monitoring.

8. CONCLUSIONS

In this paper, the overview of the evaluation items for high-risk slopes and their contents was clarified, which had been tacit knowledge, as well as the structure of the local residents' concerns about heavy rain, disasters, slopes, and others. In addition, we obtained the structure of the residents' expectations for monitoring utilizing tilt sensors to take evacuation action.

There are many slope/sediment disaster risk areas due to heavy rain, and it can be said that the risk of slope disaster is topographically high. In fact, slope disasters caused by heavy rain inevitably occur almost every year. The roles of self-help, mutual assistance, and public assistance are also important for reducing the damage caused by slope disasters. Among them, the basic one is self-help, and by acquiring knowledge about slope disasters, correctly understanding them, and thinking about what to prepare for, residents can protect themselves. To encourage such self-help efforts, we would like to develop a monitoring system using IoT tilt sensors with the participation of residents, and to provide them with assistance so that they can take appropriate evacuation actions.

Fig.6 Photo after installing the tilt sensor

9. ACKNOWLEDGMENTS

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