Landslide disaster and its prevention works in Shikoku region of Japan

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Abstract. This study introduces two examples of landslide countermeasures in Shikoku, Japan. The first case is a landslide that occurred in the Chichibu belt. This landslide was characterized by loose rock mass (past landslide mass) distributed at a maximum thickness of approximately 30m. As a result of comparing and examining the three types of construction methods as countermeasures against this landslide, it was judged that the countermeasure works combining the anchor works and the drainage boring works was the most appropriate. This landslide experienced the largest downpours since the completion of the countermeasures, but no landslide activity has been confirmed. The second case is a landslide that occurred in the Mikabu belt. This site was a place where fragile geology was distributed, but a cut at the lower end of the slope was implemented for road construction. After this cutting work, landslides occurred on the slope during heavy rain. Two landslides occurred step by step with the rainfall. As a result of a comparative study of the two countermeasures for this landslide, it was determined that the countermeasure that combined earth removal, anchoring and drainage boring was the most appropriate. The landslide activity was stopped after the countermeasure work was completed, and road construction was completed safely.

1. Introduction
Landslides are one of the slope movement phenomena and occur frequently in mountainous areas. It is known that landslides are intensively distributed in specific geological zones, and many landslide disasters occur in Shikoku, Japan (Fig.1) [1] [2] [3]. When landslides occur, houses and roads would be damaged for a long period of time, which will greatly affect the daily lives of the residents. Since Japan is a landslide frequent area, many types of landslide measures are being implemented. In landslide areas, landslide surveys are made, and landslide prevention works are undertaken.

In this presentation, I introduce examples of the occurrence of landslides in Japan's Shikoku and examples of landslide countermeasures.
2. Case study
Two case studies are introduced as case studies.

2.1. Case 1 (Landslide in Chichibu belt)
Case 1 is the case of a landslide occurred in the mountainous regions where the Chichibu Belt is distributed. Geologically, muddy mixed rocks in the muddy melange are distributed, and the inclination direction of the bedding surface is orthogonal to the slope gradient, which does not tend to cause big landslides. The distribution of such cracked rocks is special in this area only. Considering the geomorphological development history of this site, the distribution of this cracked rock mass in the depth direction is thought to indicate the thickness of the previously activated landslide mass. Since this old landslide mass has many cracks and is more vulnerable than its surroundings, this landslide is considered to be a landslide where part of this old landslide mass was reactivated.

![Figure 2. Shape of landslide on plane and layout of landslide survey (Case 1).](image_url)
Figure 3. Main cross-section of landslide (Case 1). It is important to note that there are two major slip surfaces in the landslide.

Figure 4. Landslide observation result by ground extensometer (S-1, S-2). It is important that the speed of the landslide accelerates during rainfall.
The activity of the landslide in Case 1 was confirmed after the occurrence of a seismic intensity 4 earthquake on a Japanese scale. The scale of the landslide confirmed after the earthquake was landslide width 120 meters, slope length 150 meters, and landslide thickness 22 meters (Fig.2, Fig.3, Fig.5). This landslide fluctuated greatly due to rainfall immediately after occurrence, and a clear sliding cliff was formed in the landslide head. The maximum displacement during rainfall was 86 mm/day (Fig.4). If landslide activity continued at such a rapid rate, the entire slope could collapse in a matter of days. To mitigate this rapid landslide activity, we first embanked a 5 meters high embankment as a counterweight to increase landslide resistance at the lower end of the landslide (Fig.6). This embankment has the merit of being able to be constructed on roads, has a shorter construction period than other countermeasures, and has steadily improved landslide resistance. As a result of the work, landslide fluctuation temporarily fell.

As a result of the landslide survey, it was found that this landslide has two slip planes, shallow and deep (Fig.3, Fig.5). We needed to select effective landslide prevention works for both landslides.

We considered three ways to stop landslide activities. The first method is to remove the soil from the landslide head to reduce the landslide load. The second is a deterrent pile method in which steel deterrent piles are placed in the landslide area to increase the resistance to landslides. The third is an anchor work to counter the landslide force by using the tensile strength of the anchor body installed on the immovable bedrock deeper than the landslide mass. As a result of comparing the economics, workability, construction period, etc. of these methods, the anchor works were selected.

The specifications of the anchor works were determined from the calculation results for the main cross sections of the landslide. As a result of the calculation on the main cross section, it was necessary to construct 11 steps of anchor works with a tensile strength of 542 kN to stop the landslide activity this time (Fig.6, Fig.7). The horizontal installation interval of the anchor works was 4m, the length of the anchor works in each step was 20.5-32.5m, and a total of 330 anchor works were constructed in the landslide area (Fig.6). In addition to this major countermeasure, a horizontal boring operation was undertaken to quickly remove groundwater rising during rainfall from the landslide area (Fig.6). In this landslide area, it was found that the rise of the groundwater level during rainfall was remarkable in the upper part of the landslide mass, so the horizontal boring work was placed above the center of the landslide. These landslide prevention works stopped landslide activities. At present, approximately three years have
passed since the completion of these countermeasure works, and the landslide movement has stopped.

**Figure 6.** Plane layout of landslide prevention works. Anchor works are concentrated in the lower half of the landslide, which is the compression zone.
2.2. Case 2 (Landslide in Mikabu belt)

Case 2 is the landslide occurred in the Mikabu belt. In Shikoku, it is generally known that the Mikabu belt has many geologically vulnerable areas. In particular, the distribution area of schist rocks is a landslide-prone area. In this area, the basement rock is composed of black phyllite and green phyllite, flaky rocks distributed in the Mikabu belt. Unconsolidated sediments such as talus deposits are distributed over the basement rock.

The landslide occurred at a cut construction site along the road. In this area, twice landslides occurred gradually in accordance with the rainfall (Fig.8, Fig.9). The scale of the first landslide was about 30 meters in width and about 40 meters in slope length. A landslide cliff with a height of 2 meters was formed at the top of this landslide. This landslide cliff was located 5 meters above the top of the cut slope. Landslide cliffs with a step could be confirmed continuously from the head to the side, and the outline of the landslide was clear. The road located at the lower end of the landslide was covered with sediment due to the slope failure and could not pass. Some of this sediment reached rivers farther than roads.

The second landslide occurred one week after the first landslide. The landslide cliff of the second landslide was found on the upper slope than the first landslide cliff (Fig.8, Fig.9). The size of the second landslide was approximately 30 meters in width and approximately 15 meters in slope length, with a new clear sliding cliff was formed in the landslide head.

After the second landslide occurred, embankment of approximately 5 meters in height was implemented near the lower end of the landslide as an urgent countermeasures (Fig.9). This urgent embankment temporarily reduced landslide movements.
As landslide countermeasures for this landslide, we basically considered two countermeasures. One is the removal of collapsed sediment near the landslide head and the stabilization of landslide mass by anchor works. The second method is to stabilize the landslide mass with landslide piling works and to install a displacement restraint anchor at the head of the pile. As a result of comparing these landslide countermeasures in terms of economy, workability, construction period, etc., it was judged that the countermeasures based on the combination of removal of landslide sediments and anchor method was the most suitable.

For the removal of the landslide head collapsed soil, as a result of the calculation in the main section, the slope gradient was set to height: width = 1: 1.2 (Fig.11). As a result of detailed calculation of anchors, the anchor arrangement on the cross section was set below the center of the landslide, and five steps were installed (Fig.10, Fig.11). The horizontal distance between the anchors was 4 m, and the anchors were arranged over the entire width of the landslide. With the anchor method, a large load...
continues to be applied to the anchor fixing body at underground. Therefore, it is necessary to carefully determine the installation depth of the fixing body.

At this location, the strongly weathered rock (W1 layer) in the Mikabu Belt was weakened like sediment, making it unsuitable for installing anchor fixing body (Fig.12). Therefore, in consideration of the long-term stability of the anchor work, the location of the anchor was set to weathered rock (W2 layer) harder than W1 layer or hard basement rock (W3 layer).

In addition, when the groundwater level rose due to rainfall, the displacement speed of the landslide accelerated, so a horizontal boring method was used to lower the groundwater level.

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**Figure 10.** Layout plan of landslide prevention works.
Figure 11. Main cross section showing landslide prevention works.

Figure 12. Drilling core from a landslide. It is important to confirm that there is a significant difference in the degree of weathering.
3. Result and Discussion

The fact that the originally stable slope has collapsed as a landslide means that the slope has been destabilized for some reason.

The causes of landslides can be broadly divided into "Predispositions" and "Incentive". "Predispositions" refers to the specific characteristics of the land, such as terrain and geological conditions. "Incentive" refers to the direct cause of a landslide, such as a heavy rain or earthquake.

The "Predispositions" and "Incentive" in each case are shown below.

3.1. Case 1 (In Chichibu belt)
"Predispositions"
(1) Rocks with many cracks due to past landslides were distributed and were geologically more vulnerable than other places.
(2) The lower half of the landslide had a steep slope with a slope of about 40°, and was easily collapsed.

"Incentive"
(1) The first trigger of this landslide was a seismic intensity 4 earthquake.
(2) Groundwater rise due to heavy rainfall during a typhoon accelerated landslide movement.

3.2. Case 1 (In Chichibu belt)
"Predispositions"
(1) The landslide area was on the slope side that was eroded by the river, and the erosion below the slope caused destabilization of the upper slope.
(2) The rock near the surface of the ground was weathering, and the fragile stratum was distributed approximately 5m thick.
(3) The slope above the landslide area had a gentle slope, making it easier for surface water to collect during rainfall. Water that infiltrated from this became groundwater and accelerated landslide fluctuations.

"Incentive"
(1) The cut work for road construction is located near the lower end of the landslide mass. The landslide mass that lost the counterweight due to the cut work lost stability, and landslide fluctuations became active.
(2) The rainfall precipitation during the 10 days before the first landslide was 64 mm, which caused the groundwater level to rise at the landslide site.

By understanding the features of each landslide occurrence in this manner, an effective countermeasures could be considered.

4. Conclusions

(1) In Shikoku, geological zones where landslides are likely to occur are distributed, and landslides of various sizes and types occur.
(2) By clarifying the cause of the occurrence of landslide, it is possible to select appropriate countermeasures suitable for each field site from many landslide countermeasures.
(3) It is possible to alleviate or stop a landslide activity by performing an appropriate landslide countermeasure work.
In Case 1, landslide measures based on anchor works were implemented against large landslides caused by the earthquake occurred in the Chichibu Belt. As a result, the landslide activity ceased, and now it is in a stable state.

In Case 2, we conducted anchor works and lateral boring works as a landslide prevention works against landslides caused by rainfall occurring in the Mikabu belt. The landslide countermeasures provided safe traffic for the roads below the landslide.

Acknowledgements
We are grateful to Professor Masayuki Sakakibara for giving me the opportunity to make this presentation at TREPSEA 2018.

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