Investigation on Slope Failures Caused by the 2018 Northern Kyushu Torrential Rainfall, Japan

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ABSTRACT: During June 28 to July 8, 2018 torrential rainfalls in most parts of Japan caused many slope failures and debris flows. In order to protect the lives and properties of residents from disastrous slope disasters, it is necessary to evaluate the risk of slope failures and to clarify the mechanism of failures to arrive at efficient and effective disaster prevention measures. This study covers the slopes that failed in Kitakyushu city, that composed of complex geological structures, during the July 2018 western Japan torrential rainfall. Through detailed investigations of the topography and geological conditions, the cause of such slope failures was ascertained. The investigations were conducted using both the topographical observation and UAV survey. Based on the investigation results, the mechanism of the slope failure was elucidated, and design procedures for the recovery countermeasures were arrived at.

Keywords: Torrential rainfall; Slope failures; Topographical observation; UAV survey

1. Introduction

The Japanese archipelago, located in the Pacific Rim orogenic belt, has a steep mountainous topography, and the geological structure is also complicated. In addition, because it is located in a warm and humid climate, the rainy season called the rainy season is from June to July (Fig. 1), there has been a huge disaster caused by geo-disasters every year since the past. Due to industrial development and technological development after the Second World War, many countermeasures against geo-disasters have been implemented, many of which have been controlled, and certain effects are expected.

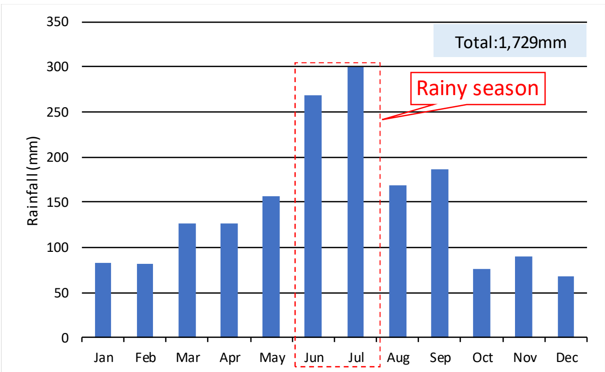

Figure 1. Average rainfall over the past 30 years (1981 to 2010) in Kitakyushu (Yahata)[1]

However, it is not realistic financially and temporally to take sufficient measures against slopes and mountain streams that are the source of all geo-disasters in the Japanese archipelago. In addition, geo-disasters still cause enormous damages every year due to the frequent occurrence of meteorological phenomena due to climate change in recent years, especially extreme precipitation events.

Based on this situation, we need to clarify the risk of slope failure and establish efficient and effective disaster prevention measures to protect the lives and property of residents from sediment disasters. As a research, it is important to clarify the mechanism of slope failure. Research on the mechanism of slope failure due to geodisaster caused by heavy rain that occurred in northern Kyushu in July 2017 is conducted by The Japanese Geotechnical Society [2], Hazarika et al.[3] and others[4]. These reports examine the mechanism of slope failure based on topography, geology, UAV images, rainfall conditions and field surveys.

From June 28 to July 8, 2018, mainly in western Japan, including Hokkaido and the Chubu region, a wide range of nationwide areas including typhoon No. 7 and the rainy season front caused torrential rain, causing slope failures and debris flows severe geo-disasters occurred in various places.

This study covers the slopes that failed in Kitakyushu city, that composed of complex geological structures, during the July 2018 western Japan torrential rainfall. Of these, the following three sites that show distinctive failure modes are targeted, and the topography and geological conditions that cause slope failures are investigated in detail by site surveys, topographic observations and surveys by UAV.

1. Mizumaki area
2. Tashiromachi area
3. Iwaimachi area

As a result, it was possible to elucidate the mechanism of the slope failures, and in particular, in Mizumaki, we were able to design the recovery countermeasures.

2. Overview of the Topography and Geology

The target site is located in the mountainous landforms of the southwestern part of Kitakyushu city area, including Mt. Fukuchi (901m above sea level) and Mt.

Sarakura (622m above sea level)(Fig. 2). The Kitakyushu area is complex with diverse rocks and strata of a wide range, including Upper Paleozoic, Lower Cretaceous, Paleogene, Quaternary and Cretaceous plutonic rocks, Pliocene-Pleistocene basalts distributed in geological structure. Fig. 3 shows an overview of the geology of the Kitakyushu area.

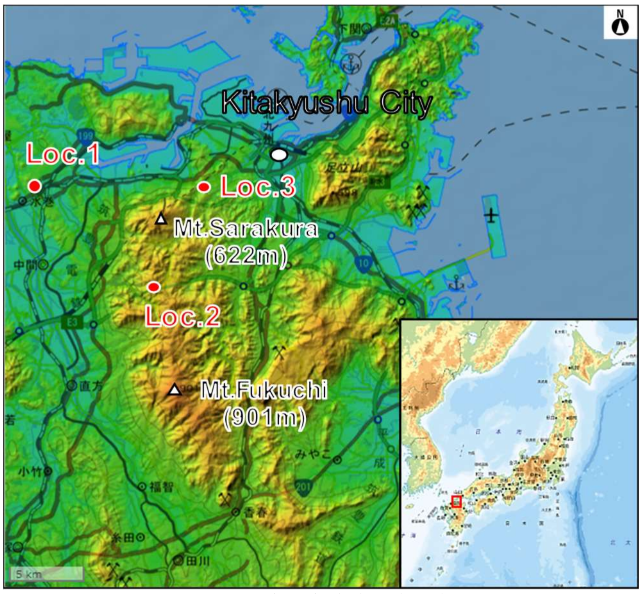

Figure 2. Topography of Kitakyushu City area [5]

Rainfall situation

From June 28th to July 8th, 2018, torrential rains occurred due to the influence of Typhoon No. 7 and the rainy season front in a wide area nationwide such as Hokkaido and the Chubu region, mainly in western Japan (Fig. 4). There was a record heavy rain in a wide range from western Japan to eastern Japan, and extensive damage occurred in various places. Fig. 5 shows the precipitation situation at the time of geo-disaster in Kitakyushu City.

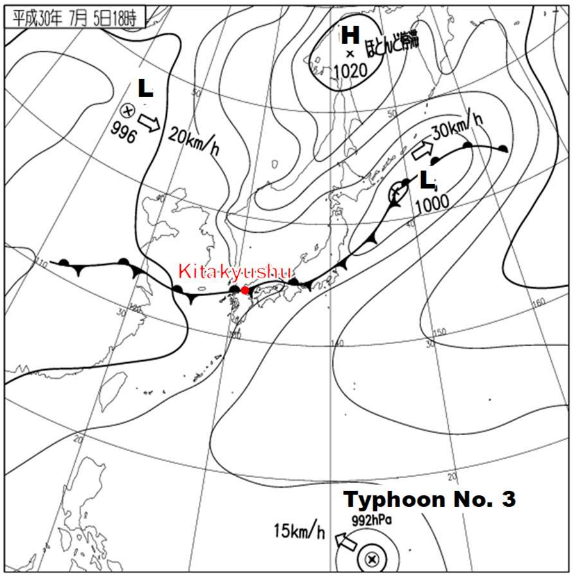

Figure 4. Weather map (July 5, 2018 18:00) [1]

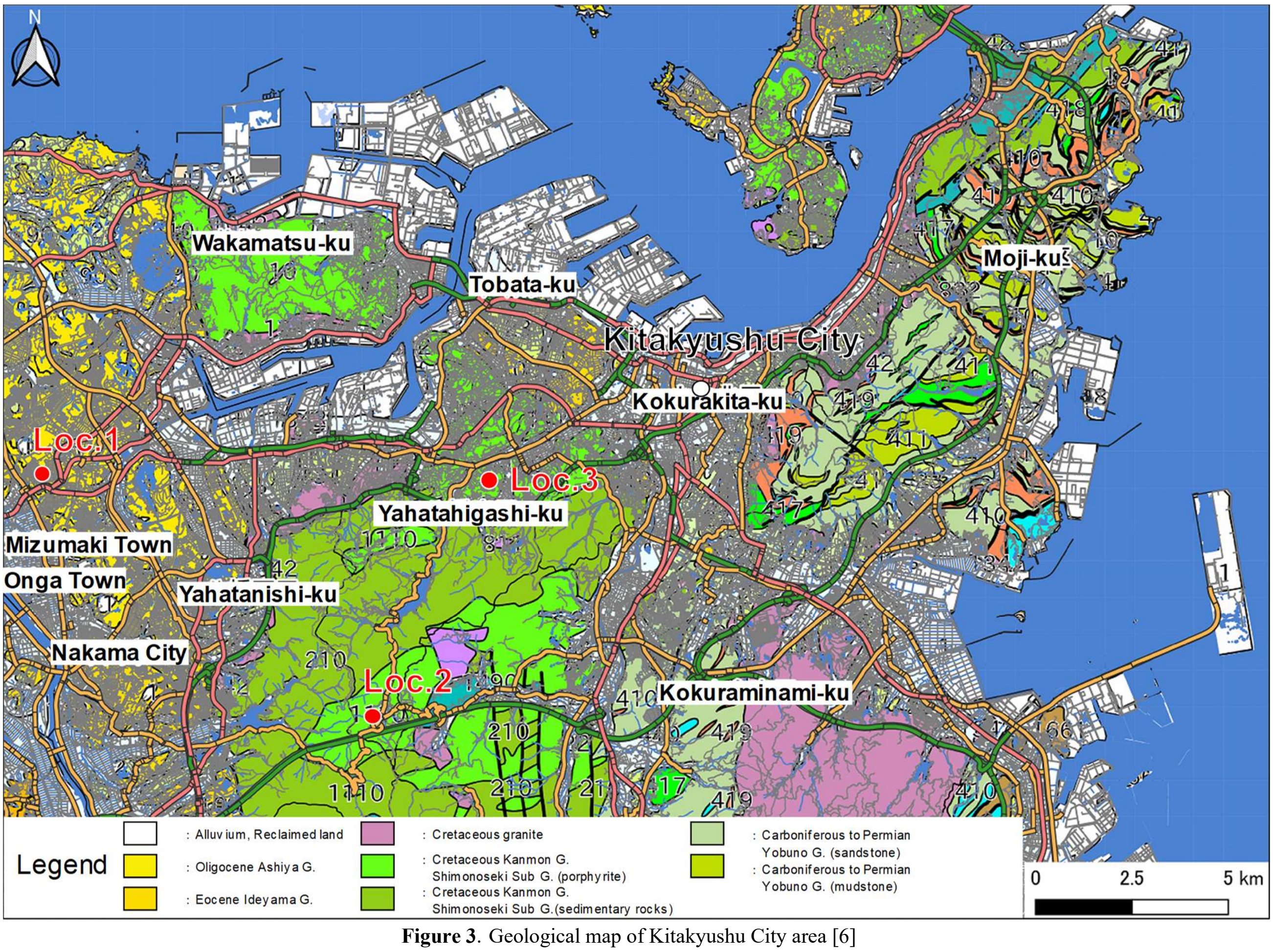

Figure 3. Geological map of Kitakyushu City area [6]

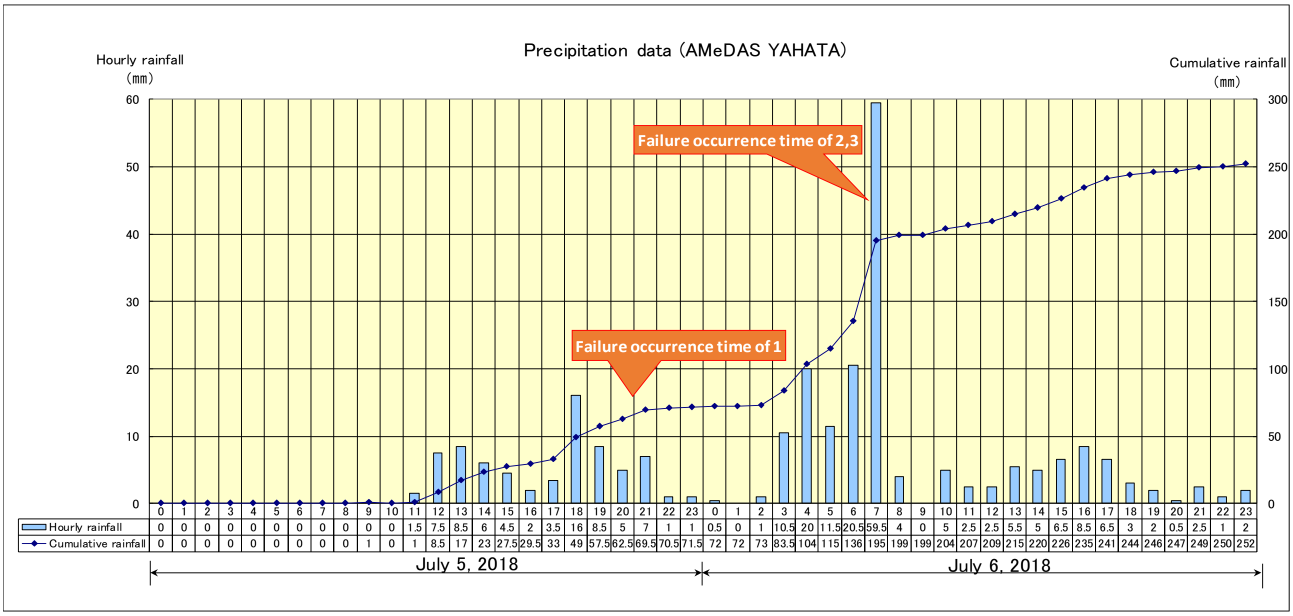

Figure 5. Precipitation data (AMeDAS YAHATA) [1]

4. Slope failure situation and examination of mechanism

4.1. Mizumaki area

The slope failure occurred around 20:00 on July 5. The slope failure scale is 15m in height, 12m in width, 2m in average slope failure depth, 360m^3 in slope failured soil volume (all approximate) (Fig. 6).

The slope failure part is continuous with the cut slope of the main line. Before the slope failure, part of it was protected by a mortar sprayer, forming a steep cliff near the vertical and exposing the rock mass with many cracks (Fig. 7).

The slope failure partly reached the road, but because it was mainly directed to the adjacent primary school parking lot side, it did not cause major damage.

The geology of the slope is equivalent to the Orio sandstone of the Paleogene Ashiya Group, and is composed of massive sandstone with cracks. Although the weathering of the rock is weak, the cracks are square and open. No spring water was seen from the slope failure surface. An unstable rock mass remains on the slope failure surface, and an overhanging rock mass is seen at the slope failure head. Even after several hours of slope failure, small rockfalls (about the size of a human head) have occurred, and there is a possibility of expansion. On the slope of the road side, there was no expansion of deformation that was a sign of slope failure.

Based on the topographic and geological conditions of the slope, the failure mechanism is assumed as follows: (Fig. 8).

1. Longitudinal cracks have developed in the natural grounds, and tree roots have invaded some of them.

2. A lot of water flows into the crack surface due to heavy rain

3. Water pressure is generated in the crack, and the adhesion of the crack surface decreases, so stability is lost and slope failure occurs.

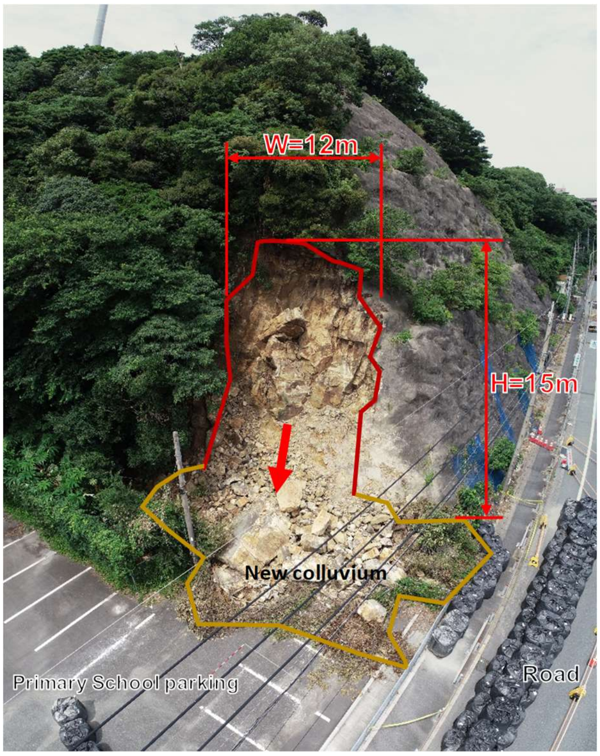

Figure 6. Bird's eye view of the collapsed slope

Figure 7. The outcrop of the slope before the collapse

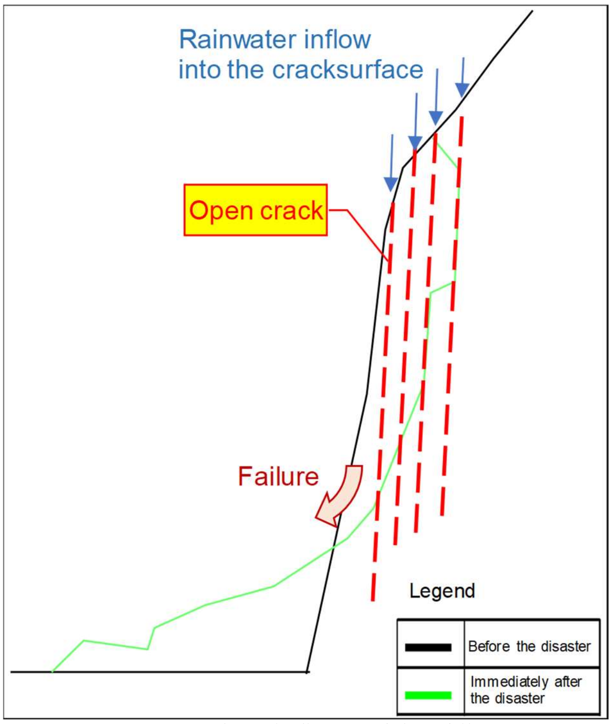

Figure 8. Schematic diagram of slope failure

4.2. Tashiromachi area

The slope failure occurred early morning on July 6.The scale of slope failure is 10m in height and 20m in width, from the embankment slope to the natural slope below the road (Fig. 9). Fig. 10 shows the topographic map around the target site, and Fig. 11 shows a photograph and sketch of the slope failure slope.

On the failure slope, weathered porphyrite, talus accumulation and embankments corresponding to the Lower Cretaceous Kanmon Group and Shimonoseki Group are confirmed. The natural ground at the slope failure site is composed of porphyrite that has been earthen by strong weathering. Although it is weathered to sandy soil, the original rock texture is clear and no slope failure has occurred.

It can be seen in the lower part of the talus accumulation on the left side of the slope. Talus accumulation can be seen on the right side and on the left side of the slope. It contains a large amount of breccia with a maximum gravel diameter of about 20cm and has a light reddish brown color. The humus soil, which is supposed to be part of the old topsoil, is thinly distributed on the surface of the cliff-cone deposit, and a blue glue deposit is characteristically seen.The embankment is found in the middle of the landslide slope. It is reddish brown, contains a lot of soft gravel, and is a loose clay soil. It is distributed so as to cover the cliff cone deposit. The origin of the talus accumulation and embankment is thought to be the same weathered porphyrite, but the embankment is soft with gravel and loose matrix, the cliff-cone deposit contains a lot of rubble, and some of the surface has old topsoil. Characterized by remaining.

The topography of the slope failured land is a parallel slope on the side of the ridge topography and does not show a typical water collection topography. The slope on the mountain side of the road is an untreated cut slope, and a part of the slope failured horseshoe-shaped depression (valley-like landform) is seen.

Slope failure has occurred in embankments and cliff deposits. On the left side of the landslide slope, erosion marks due to water leakage from the broken road gutter are seen.


Figure 9. Bird's eye view of the failure slope

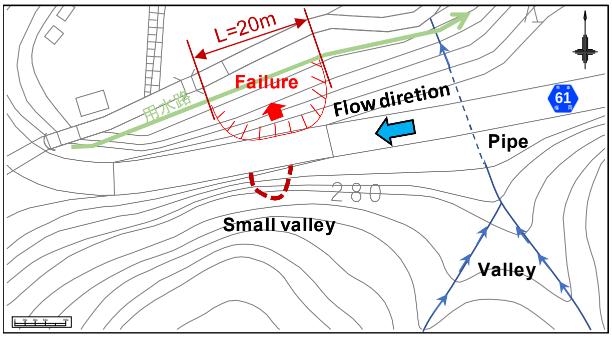

Figure 10. Topographic map around the failure slope [7]

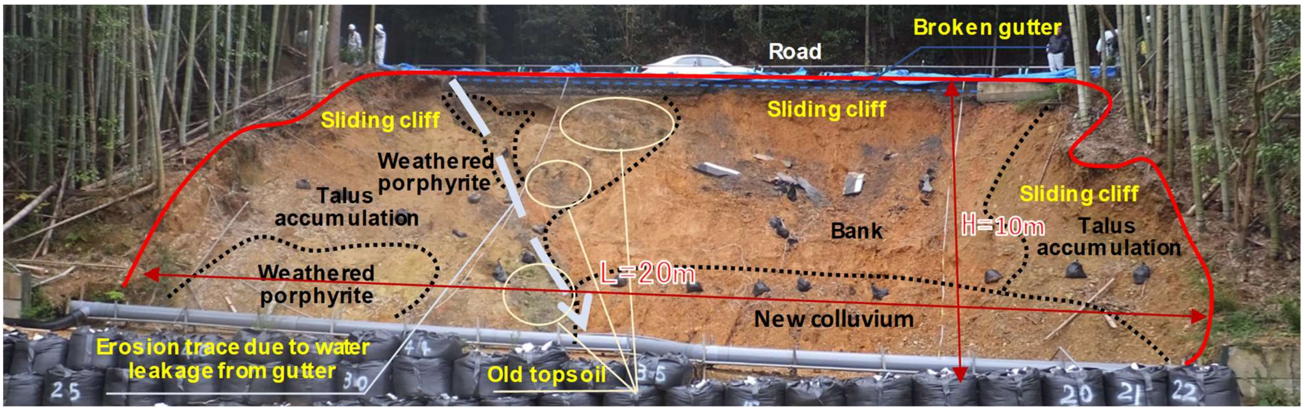

Figure 11. Photograph and sketch of the failure slope [7]

Based on the topographic and geological conditions of the slope, the failure mechanism is assumed as follows (Fig. 12).

1. Rain infiltration concentrated on the embankment filled with a small catchment topography, and when it saturated, the surrounding talus accumulation also involved and collapsed (collapse on the right side from the center of the collapse).

2. At that time, water leakage occurred due to the rupture of the shoulder-side gutter, and talus accumulation on the left side of the collapse, surface layer collapse of weathered pophyrite, and erosion occurred (collapse and erosion on the left side of the collapsed part).

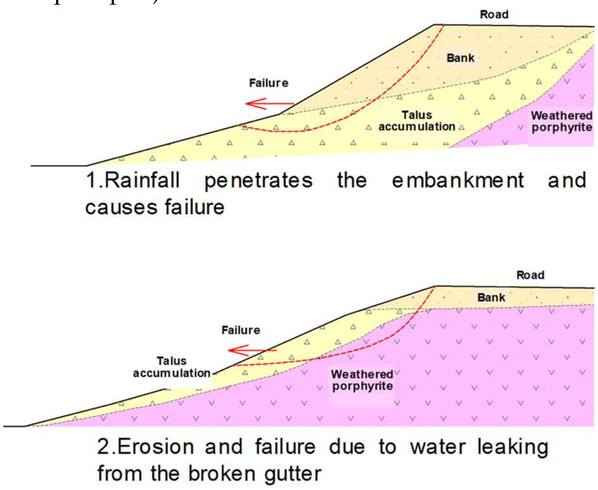

Figure 12. Failure form and assumed geological section

4.3. Iwaimachi area

The slope failure occurred early morning on July 6. The scale of the failure is a cut slope with a height of 10m, a width of 20m, and a valley formed by the creation of the primary school.

Fig. 13 shows the topographic map around the target site, Fig. 14 shows the aerial photograph, and Fig. 15 shows the photograph and sketch of the failure slope. The failure slope is located in a low mountainous area with small undulations where residential land development has progressed, and on a straight ridge topography. In the borehole survey, fresh rock mass has not been confirmed, and there is no outcrop nearby, so the relationship between geological structure and topography and failure is unknown. Since it is located on the east side of the ridge topography and surface water is not easily collected, it is thought that the influence of surface water on the collapse is small.

The geology of the failure slope is composed of strongly weathered sandstone corresponding to the Lower Cretaceous Kanmon Group and the Shimonoseki Group, and exhibits a reddish brown to yellow-gray sandy cohesive soil. As a result of the survey, weathering progressed at a thickness of 10 m or more (Fig. 16).

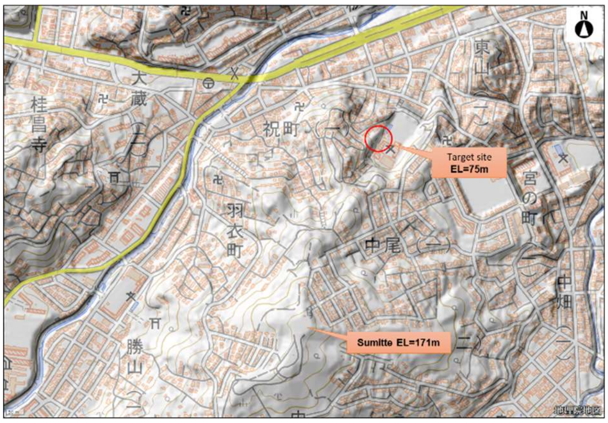

Figure 13. The topographic map around the failure slope [5]

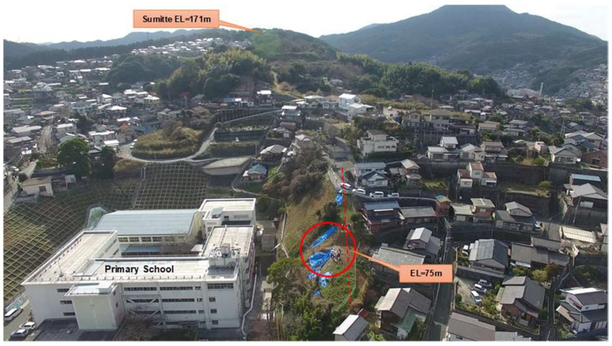

Figure 14. Bird's eye view of the failure slope

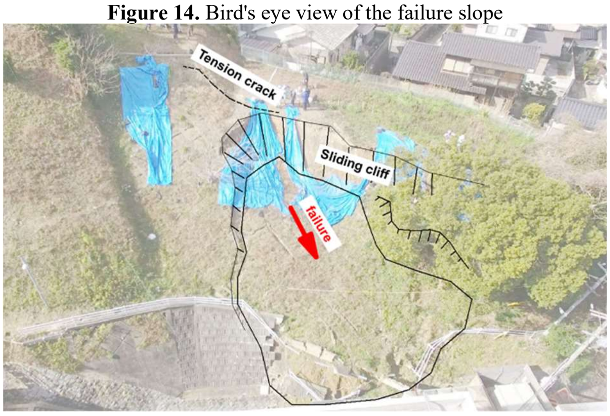

Figure 15. Photograph and sketch of the failure slope

The failure mechanism is assumed as follows based on the geological condition of the slope (Fig. 16).

1. Saturation of the surface sediment increases due to heavy rain.

2. The weight of the surface soil increases, the strength constant decreases, and failure occurs.

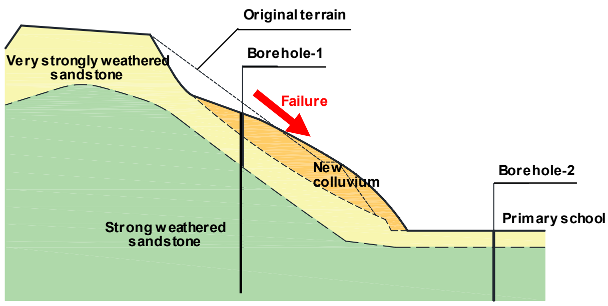

Figure 16. Failure form and assumed geological section

5. Recovery countermeasures

In the Mizumaki area, it was necessary to remove the collapsed sediment that had reached the road as soon as possible. The slope was steep and many unstable rock blocks were seen on the failure slope, making it difficult to approach for topographical survey. Topographic plan and cross-sections were created by aerial photogrammetry using UAV, and countermeasures were examined. It was judged that the slope stability countermeasure work requires a structure countermeasure because it is difficult to secure a stable slope by cutting (re-cutting is difficult) due to site restrictions.

In addition, as a result of UAV images and telescopic observation, it was confirmed that an unstable soil mass (failure residue) remained above the failure site. Therefore, a reinforcing bar insertion work was adopted as a measure for stabilizing the remaining block. In addition, the wire net work will be installed for the purpose of integration by connecting the heads of the reinforcing bar inserts to ensure stability and to prevent the falling of small pieces of unstable soil blocks.

On the other hand, since many cracks develop in the lower part of the collapsed part, it was decided to stabilize by grating crib work.

6. Conclusions

We investigated the failure mode and mechanism of three slope failures that occurred in Kitakyushu city area due to heavy rain in July 2018.

Table.1 summarizes the differences between the three slope failures.

Mizumaki area is a slope of about 60degree composed of sedimentary rocks of Paleogene, and block-like rock failures occurred. The failures occurred at a relatively early stage after rainfall.

In Tashiromachi area, a surface failure occurred on a slope of about 30degree composed of colluvium and embankment. The failure occurred on the morning of July 6 when the cumulative rainfall was close to 200 mm.

The Iwaimachi area is a slope with a slope of about 35 degrees, consisting of a strong weathering zone of lower Cretaceous sedimentary rocks. The collapse occurrence time is the morning of July 6 when the same cumulative rainfall as Tashiromati is close to 200 mm.

Table 1. Characteristic of the three slope failures

Locality	1.Mizumaki	2. Tashiromachi	3. Iwaimachi
Geology	Sandstone	Colluvium and embankment	Sandstone
Age	Paleogene	Present	Cretaceous
Type	Bedrock slope failure	Surface failure	Surface failure
Gradient	60degree	30degree	35degree
time of ccurrence	July 5 20:00	July 6 7:00	July 6 7:00

In the slope failure surveyed this time, there is a difference in the form of the collapse and the time when the collapse occurred depending on the geological age and geology. This is thought to be due to differences in slope gradient, ground (collapse surface) strength, weathered zone thickness, drainage (permeability), and effects of vegetation. This time, we did not investigate the strength constant of the slip surface or analyze the stability. Future research investigate slope failure model and will be directed towards create hazard maps and build an early warning information provision system.

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