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Features and mechanism of slope failure induced by the 2017 July Northern Kyushu torrential rainfall disaster in Japan

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ABSTRACT

The torrential rain which occurred on July 5-6, 2017 in northern Kyushu (Fukuoka and Oita Prefecture), caused many landslides, debris flows and flooding of rivers. Especially, Asakura City in Fukuoka Prefecture suffered extensive damage, and a large amount of sediment movement was observed in the Akatani River and its tributary; the Otoishi River. In this research, detailed field survey in those areas was conducted and occurred slope failures were classified, then the mechanism of each failure was discussed. Based on the results, it is revealed that there was the difference of failure type between the distribution area of granite and crystalline schist. In the area of granite, it can be categorized into two types: surface failure of hardly weathered granite; and bedrock failure. On the other hand, in the area of crystalline schist, it can be classified into 3 types: collapse of surface failure; failure relating to fault; and large-scale of landslide. Among those types of failure, surface failure of weathered granite was mostly observed. Samples were also collected from the representative area and constant volume direct shear test was conducted. The test results revealed that the value of apparent internal friction angle was low, and it is found that the mass movement from the surface failure in granite areas can be highly fluidized soil. This is consistent with the result of observation which decomposed granite soil were flowed in the basin of those rivers. Therefore, it is considered that the mechanism of the slope failure in the region of granite is fluidized failure with long travel distance.

Keywords: deep-seated landslides; shallow landslides; weathered granite; decomposed granite; constant volume direct shear test; fluidized failure

1 INTRODUCTION

Due to the torrential rainfall that hit the northern region of Kyushu on July 5-6, 2017, various levels of landslides and debris flows occurred in Fukuoka and Oita Prefecture. It caused a large amount of sediment outflow into the downstream basin of the rivers (Japanese Geotechnical Society, 2017).

At present, disaster restoration projects are being carried out. Basically, it is restored to its original state. However, considering disaster management plan for future, understanding the features and mechanism of slope failure and classifying those types are important.

Hazarika et al. (2017) attempted to classify the types of landslides occurred from the geological and geotechnical points of view. In this research, the authors also conducted constant volume direct shear test with soil sampling in the region of granite, where the most representative slope failure occurred. In addition, the geological features of slope failures occurred in the basin of the Otoishi River, which is tributary of the Akatani River were analyzed and the mechanism of slope failure in the region of granite was discussed based on the results of field survey and soil test.

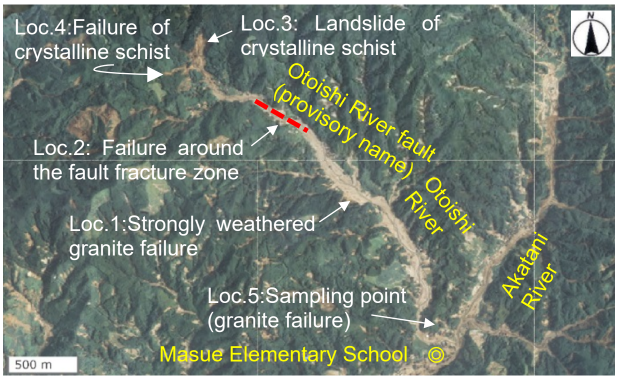


Fig. 1. Location map of the investigation (Modified from the Geospatial Information Authority of Japan (2017)).

2 TOPOGRAPHICAL AND GEOLOGICAL FEATURES OF THE SURVEY AREA

The Otoishi River is located in the southern area of the Sangun Mountains (Fig. 1). On the left side of the Otoishi River bank, valleys lay vertically in northeast–southwest direction, while on the right bank side, valleys lay horizontally in the northeast–southwest direction.

These directions are in line with the direction of the fault fracture zone in northern Kyushu. This suggests that the topography of this basin is vulnerable to discriminate erosion due to the geological structure (faults). Moreover, Asakura granodiorite is distributed in the middle-to-downstream basin of the Otoishi River, and Sangun metamorphic rocks are distributed in the upstream area. Mount Hiko volcanic rocks from the Pliocene epoch in the neo-tertiary period are distributed in the ridge, which is the drainage basin of the uppermost basin (Fig. 2).

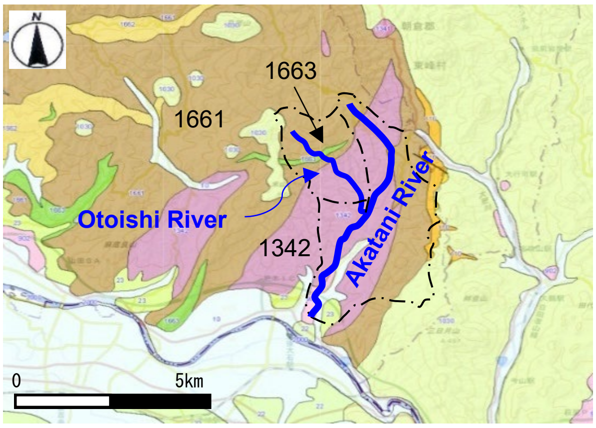


Fig. 2. Geological map around surveyed area (Japan seamless geological map).
Geological legend No.1342: Grenodiorite ,No.1661: Metamorphic rocks of mudstone origin ,No.1663: Metamorphic rocks of basalt origin

3 CHARACTERISTICS OF THE SLOPE FAILURES

3.1 Surface failure of granite

The most common failure form found along the basin occurred in the so-called strongly weathered “decomposed granite,” which transformed into soil (Location 1 and 5 of Fig. 1). The failure was roughly from 1 to 2 m deep, and many traces of springs are thought to be due to piping. Gully erosions had formed on the failure surface. Since there was little colluvial deposit at the toe of the slope, the base of the undercut slope had likely been eroded by the flowing water and it had lost the balance of clod. Later, it had been led to the failure (Fig. 3).

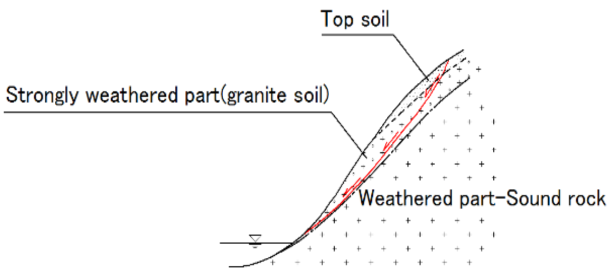


Fig. 3. Schematic profile (Surface failure of granite).

3.2 Bedrock failure of granite

In the middle basin of the Otoishi River, a 10 m wide fault fracture zone was found (Fig. 1). Multiple such formations were observed in the northwest–southeast direction, as well as the north-northeast–south-southwest and northeast–southwest directions. In some, fault fracture zones strongly crushed by fault gouge could be observed. In this location 2, at the end of the slope failure zone, a 1 m-wide gouge zone and a fault fracture zone with a crack zone with a large opening of around 5 m wide were verified. The direction of the fault was N54°W, 70°SE, and it worked as a receiving board to the slope. Furthermore, a substantial volume of groundwater was flowing from the crack zone on the slope side (around 50 l/min). A geological analysis of this failure mechanism based on the characteristics of the crush zone and flowing water suggests that the gouge zone, which normally indicates low permeability, became a cut-off wall, and the groundwater flowed from the crack zone. However, during the torrential rainfall event, a large volume of groundwater that accumulated in a short period of time likely raised the groundwater level inside the slope resulting in the increase of pore water pressure, and eventually led to a bedrock failure that included the crack zone (Fig. 4).

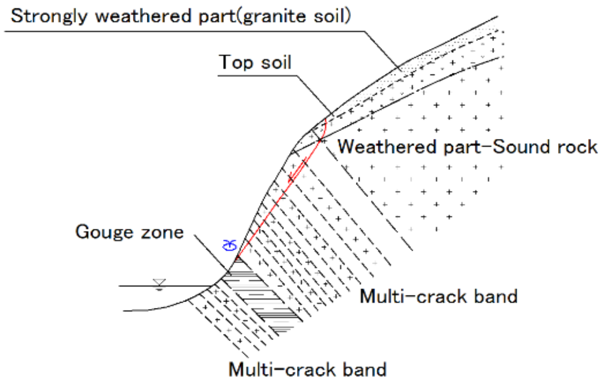
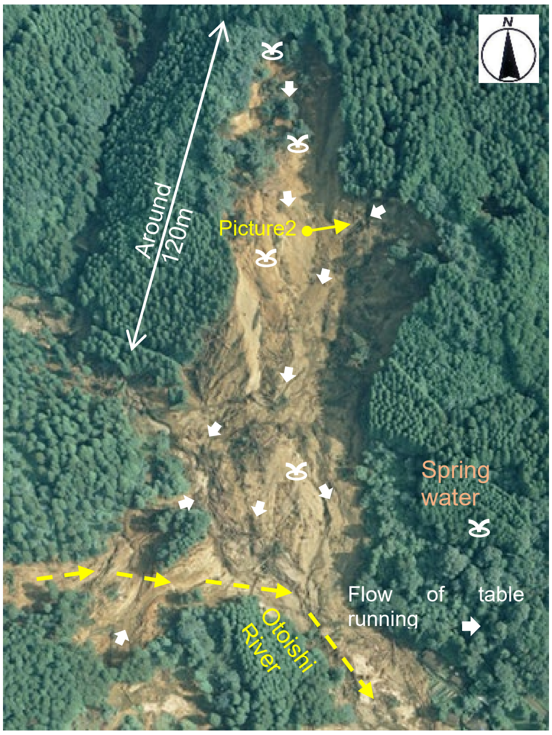


Fig. 4. Schematic profile (Bed rock failure of granite).

3.3 Landslide failure of crystalline schist

In the upstream area of the Otoishi River with crystalline schist, a landslide with a length of approximately 120 m (landslide scarp to clod end), width of 110 m, and average depth of 15–20 m occurred. This landslide formed large landslide scarp, and a landslide clod that still remains in the slope. The frontal part of the landslide clod traversed the road below, reached the Otoishi riverbed and stopped, blocking most of the river channel. However, there was no evidence that this moving clod turned into a debris flow (Fig. 5).

The thickness of this landslide mass was estimated to be 15–20 m on average, with a maximum of 25 m. However, because landslide clods remained on the failure surface, there was no geological weak line that could act as a sliding surface. Multiple points of outflowing water were observed in the area from the landslide scarp to its end, where the flow increased. Such outflowing water gushed out after the landslide clod yielded. Since it has been estimated that the landslide occurred at a depth of approximately 20 m, the deep



groundwater likely contributed to the landslide movement (Fig. 6).

Fig. 5. Large-scale landslide in the crystalline schist-distributed area (Source: GIJ).

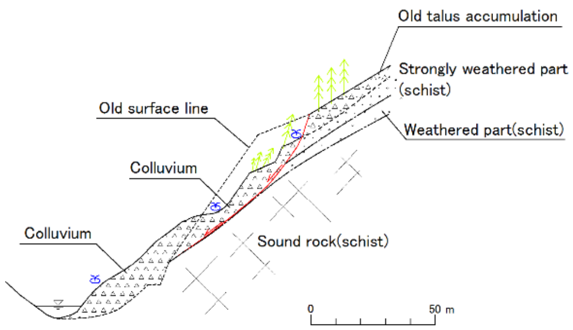


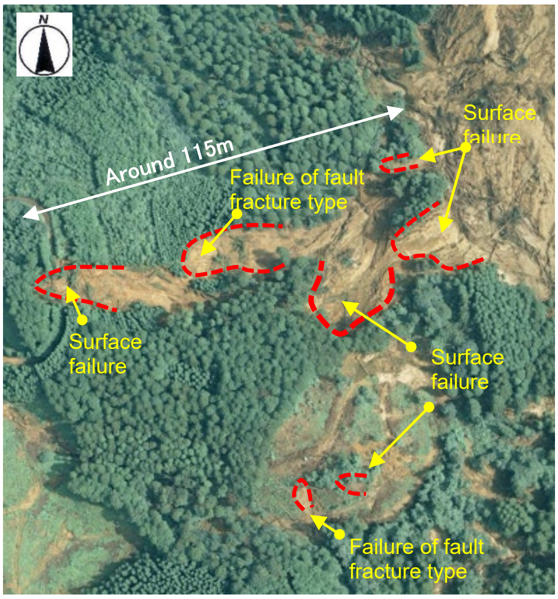
Fig. 6. Schematic profile (landslide of crystalline schist).

3.4 Surface failure of crystalline schist

In location 4, multiple slope failures occurred opposite to the landslide in location 3 of the Otoishi River bank. The failures were smaller than the landslide of the opposite bank (left side of the bank) and around 5 m deep, but different types of failure forms were found, including failure of colluvial deposit that filled the valley, failure of schist that weathered and transformed into soil, and failure dominated by a fault fracture zone (Fig. 7).

Since there were fault fracture zones of almost the same formation as in the granite-distributed areas, as well as schists full of cracks and aplite formations in some parts of the failure surface, the primary cause of the failure was likely controlled by these complicated geological structures.

In this way, the failure mechanism in this location can be classified into two groups. The first failure mechanism (Fig. 8) is caused by fault fracture zones, where the bedrock around the fault fracture zone weakened, likely resulting in the failure in this part. The second failure mechanism (Fig. 9) is caused by highly



weathered rock. Soft sedimentation of bedrock from aging due to weathering likely caused the failure of highly weathered rock due to the heavy rainfalls.

Fig. 7. Group of slope failures on the right side of the upstream bank (Source: GIJ).

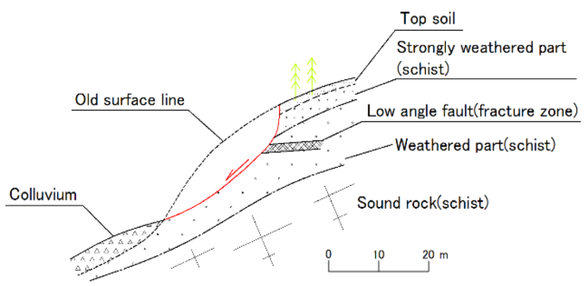


Fig. 8. Schematic profile (Bedrock failure of crystalline schist: fault fracture type).

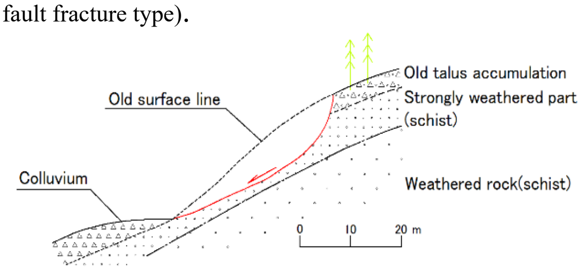


Fig. 9. Schematic profile (Surface failure of crystalline schist).

3.5 Classification of failure patterns

Table 1 shows the various failure forms found in this investigation. The classification in the Table summarizes the failure forms according to the geology and geological structure. The granite group can be sub-divided as shallow landslides of decomposed granite (Ia) and bedrock failures (Ib) dominated by the presence of several fault fracture zones. On the other hand, the crystalline schist group can be sub-divided as failures of

Table 1. Classification of failure patterns.

Classification symbol		Geological features/ Geological structure	Slope failure characteristics
I (Granite)	Ia	Strongly weathered granite soil	Surface failure
	Ib	Fault fracture zone	Bedrock failure (fault fracture type)
II (crystalline schist)	IIa	Soft sedimentation of bedrock from aging due to weathering	Surface layer failure
	IIb	Fault fracture zone	Bedrock failure (fault fracture type)
	IIc	Old talus accumulation and strong-to-weak weathered schist	Deep-seated landslides

strongly weathered rocks distributed at the surface (IIa), bedrock failures (IIb) controlled by the geological structure, and failures caused by large-scale landslides (IIc).

4 MECHANISM OF THE SLOPE FAILURES

The failure form observed the most along the Akatani River and the basin of its tributary; the Otoishi River was surface failure of Granite (Table 1: type Ia). In order to elucidate this mechanism of surface failure, the soil samples were collected in the surface failure area (Fig. 1: Loc.5), where the same geological features can be seen, and then constant volume direct shear test was conducted. Figure 10 showed the results of constant volume direct shear test under normal stress of 100 kPa and 50 kPa. The trend of curve represents undrained and saturated state. When each curve moves to the left, it means that the pore water pressure in these samples is increased. Finally, slope failure occurred with 38 degrees of internal friction angle.

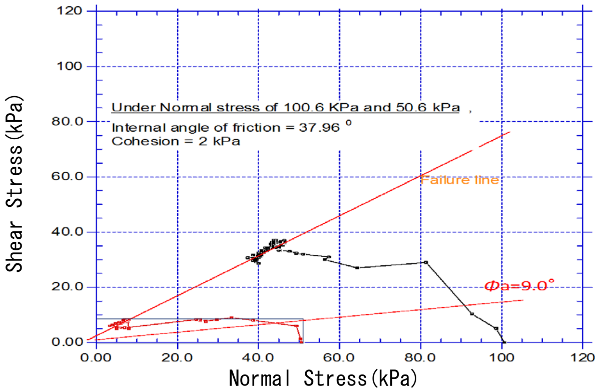


Fig. 10. Results of constant volume direct shear test.

According to the definition of apparent internal friction angle, if the slope with 20 m height is collapsed, its mass movement may move 130 m horizontally (9.0 degrees of apparent internal friction angle). As a result, it is assumed that the slope failure occurred in the region of granite is fluidized failure with long travel distance.

5 CONCLUSION

Following are the few important findings from this study:

(1) The slope failures in the granite-distributed areas can be classified into two groups: surface failure of highly weathered granite (decomposed granite) and bedrock failures (a type of failure around the fault fracture zones driven by the geological structure and groundwater).

(2) Slope failures of highly weathered granite along the river were focused in the area of the undercut slope. Its mechanism was that the base of the undercut slope had likely been eroded by the flowing water and it had lost the balance of clod, and ultimately led to the failure.

(3) The failure form of the crystalline schist-distributed area on the left side of the upstream bank suggests that it was a landslide failure. Judging from the topographic form before the failure, this area had likely suffered repeatedly from gravity transformation.

(4) In the crystalline schist-distributed area on the right side of the upstream bank, multiple failures of strongly weathered areas were found at topographic conversion point. In addition, a bedrock failure near the fault fracture zone was observed.

(5) The result of constant volume direct shear test revealed that the apparent internal friction angle was 9.0 degrees. This represents highly fluidized mass movement in the region of granite, which may have led to fluidized failure with long travel distance. In this torrential rainfall disaster, a large amount of sediments of granite origin was observed in the mouth of each river. This fact is consistent with the result of this laboratory test.

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