Slip surface layer estimation of shallow landslides on Aso volcanic mountains in Japan based on tephra layer-soil properties

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Research

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Abstract

Shallow landslides are known to appear frequently on the Aso volcanic mountains. The soil material on the Aso volcanic mountains consists of tephra layers obtained from volcanic activities. This study is aimed at determining the soil property factors that correlate with the slip surface of a shallow landslide on the volcanic mountain area. Tephra layers consist of kuroboku and scoria layers and the differences between these layers have been determined using soil property tests. This study determined that the plasticity index and the fine fraction content can be used as factors showing the slip surface indication in the Aso volcanic area.

Introduction

Shallow landslides appear frequently on the Aso volcanic mountains. The same sediment disasters have repeatedly occurred in June 1953, July 1990, and June 2001, with the last one occurring at July 12, 2012 (Goto and Kimura., 2019; Higaki et al., 2019; Kimura et al., 2019; Miyabuchi et al., 2004) when a cumulative rainfall of 508 mm triggered numerous landslides and severe sediment disasters throughout the month. The soil materials in the shallow landslides on the Aso volcanic mountains consist of tephra layers from volcanic activities. The tephra distribution was studied by Miyabuchi et al. (2004) and Ono and Watanabe (1985).

The slip surface of the shallow landslides on the Aso volcanic mountains has been observed based on the difference in hydraulic conductivity (Shimizu and Ono, 2016). The layer below the slip surface had a lower hydraulic conductivity and the difference in the hydraulic conductivity was the dominant control on the slip-surface layer (Shimizu and Ono, 2016). Furthermore, Sato et al (2017 and 2019) observed that the gravitational deformation of the slope deposits on the Aso volcanic mountains resulted from the “flow” of the highly permeable kuroboku layer over the less permeable tephra layer.

However, the soil properties of the tephra layer have not been clearly explained. The purpose of this study was to determine the soil property factors that correlate with the slip surface of a shallow landslide on the volcanic mountain area. The soil materials were characterized using their volcanic activity periods, and laboratory tests were performed to examine the soil property characteristics of each layer. The dissimilar results of soil layer values obtained from the laboratory tests are observed to be related to the slip surface based on field observations.

Material And Methods

The methods utilized in this study include the soil hardness test as the field-based stratigraphic investigation and laboratory tests such as particle size distribution, liquid limit and plastic limit, the density of soil particles, ignition loss, and organic matter content. The tests in this study were performed to examine the soil property characteristics of each layer.

Field investigation

Two locations of the shallow landslide in Takadake were selected as the research area (Figure 1). Takadake 1 is located at 32° 53’ 54.06” N, 131° 7’ 33.47” E with landslide dimensions of 34 m in length and 10 m in width. The main soil layer was divided into 6 sub-layers from the surface down to a depth of 1.39 m (Figure 2). Takadake 2 is located at 32° 54’ 8.22” N, 131° 7’ 13.74” E with landslide dimensions of 18 m in length and 39 m in width. The main soil layer in Takadake 2 was divided into 7 sub-layers from the surface down to a depth of 1.37 m (Figure 2). The main soil layers in each area were defined from the surface down to 1.3 m because exposure of the lowest sub-layer, Ojodake (OJS) scoria, was difficult.

The tephra layers were exposed in each area. The soil hardness value was field measured using a Yamanaka-type soil hardness metre, which measures the soil strength in units of millimetres by pushing the device into the exposed soil layer at the site. In this study, the soil hardness values of each sub-layer at Takadake 1 and of several sub-layers at Takadake 2 were measured.

Laboratory tests

The soil property tests performed in this study include particle size distribution, liquid limit and plastic limit, density of soil particles, and ignition loss, which were performed according to the laboratory testing standards of Geomaterials Vol. 1. Japanese Geotechnical Society Standards (2015). Tests were performed to observe the soil property characteristics of the tephra materials.

A particle size distribution test was performed to observe the mass percentage of the materials (%) contained in the sample (JIS A1204, 2009 cited in JGS, 2015). Furthermore, the water content of the soil under different conditions, transition from plastic to liquid state (liquid limit), and transition from plastic to semi-solid state (plastic limit) can be obtained by the liquid limit and plastic limit tests (JIS A1205, 2009 cited in JGS, 2015). The density of soil particles test was also performed to observe the mass per unit volume of the solid part of the soil (JIS A1202, 2009 cited in JGS, 2015). Moreover, the percentage of the reduction in soil mass when heated (750(±50)°C) relative to the soil mass when oven-dried to a constant mass (110(±5)°C) can be obtained by the ignition loss test (JIS A1226, 2009 cited in JGS, 2015). The organic matter test was performed according to Condie (1993), where the organic matter was determined by using oven-dried samples in ceramic crucibles with a capacity of 50 mL at a temperature of 550°C for 4 h.

Results And Discussion

Stratigraphic analysis of the field observations

Figure 2 shows the tephra layer field observations. At each area, the kuroboku colour was nearly black, which is darker than the scoria layers. Kuroboku layers were located on the scoria layers in each area. Takadake 1 has two kuroboku layers with two scoria layers, both of which are located on scoria layers (N1 kuroboku is located on the N2 scoria and N3-4 kuroboku is located on OJS scoria). Furthermore, Takadake 2 has three kuroboku layers with two scoria layers: N1 kuroboku and N2 kuroboku are located on the N2 scoria layer and N3-4 kuroboku is located on the OJS scoria layer. N3-4 kuroboku layer was divided into 2 sub-layers in each area, N3-4 kuroboku (U) and N3-4 kuroboku (L), which aimed at simplifying the slip surface identification in this study.

Dissimilarity in soil hardness was observed between the kuroboku and scoria layers. The soil hardness in Takadake 1 showed that N2 scoria had the highest soil hardness value (average = 18.55 mm) and topsoil had the lowest soil hardness value (average = 12.6 mm). However, the soil hardness value in Takadake 2 showed that OJS scoria had the highest value (average = 23.9 mm) and N3-4 kuroboku had the lowest value (average = 18.1 mm). The low average soil hardness indicates the location of the slip surface.

Miyabuchi and Daimaru (2004) reported that the landslide slip surfaces were formed near the boundary between the kuroboku and scoria layers. In this study, the low average soil hardness value in each area was located at the N3-4 kuroboku layer; therefore, according to the stratigraphic analysis results of the field observations, the N3-4 kuroboku layer was a slip surface in the studied area.

Tephra layer soil properties

The particle size accumulation curve (Figure 3) showed no dissimilarities in the tephra layers in the research area and all the tephra layers indicated well-graded soil material. However, the tephra layer fine fraction content (less than 0.075 mm) (Figure 4) shows a difference between the kuroboku and scoria layers, where the kuroboku layers have a higher fine fraction content than the scoria layers in each area. Moreover, in Takadake 1 and Takadake 2 the N3-4 kuroboku (L) layers have the highest fine fraction content (Figure 4).

Based on the results, the particle size accumulation curve did not show any dissimilarity between the kuroboku and scoria layers; however, the fine fraction content showed a dissimilarity between them. For this reason, in this study the particle size accumulation curve is difficult to use for estimating the slip surface, but the fine fraction content can be used as a factor for estimating the slip surface.

Figure 5 shows the tephra layer soil property results, which generally showed that the scoria and kuroboku layers are different. Scoria layers have a low fine fraction content, plasticity index, ignition loss, and organic matter content and a high density of soil particles. Meanwhile, kuroboku layers have high fine fraction content, plasticity index, and ignition loss and low density of soil particles and organic matter content.

Ignition loss and organic matter content were performed to observe the tephra layer carbon content. Previous research performed by Kato (1964) described kuroboku as having humic acids, black in colour and high carbon content. Unfortunately, the density of soil particles, ignition loss, and organic matter content values presented in Figure 5 were not differentiated between the kuroboku and scoria layers in this study; therefore, these values could not be utilized as slip surface indication factors.

Figure 5 shows that the plasticity index was different between the kuroboku and scoria layers. The liquid limit and plastic limit test results were plotted on a Casagrande plasticity chart (Figure 6) to examine the soil property characteristics of each layer, which were separated between the sampling location

(Takadake 1 and Takadake 2) and the tephra layer type (kuroboku and scoria). The Takadake 1 and Takadake 2 tephra layer data are denoted by filled and un-filled symbols, respectively.

According to the Casagrande plasticity chart, the plotted data showed similar soil type results for Takadake 1 and Takadake 2. Figure 6 shows that all of the kuroboku layers were inorganic silts of high compressibility and organic clays and the OJS scoria layers plotted at the same location as the kuroboku layers. The N2 scoria layers, however, were inorganic silts of medium compressibility and organic silts.

Furthermore, the plotted data showed that the tephra layer could be separated into kuroboku and scoria groups according to the plasticity index and liquid limit values, and is denoted by the ellipse symbol in Figure 6. The plasticity index and liquid limit values of the kuroboku layers were different, but higher than the scoria layers. The Takadake 1 and Takadake 2 data both showed that the N3-4 kuroboku (L) layer had the highest plasticity index and liquid limit values, while the N2 scoria layer had the lowest plasticity index and liquid limit values.

The Casagrande plasticity chart (Figure 6) shows the differences between the kuroboku and scoria layers. Furthermore, Figure 6 shows that the N3-4 kuroboku (L) layers (slip surface layers) had the highest values and were located in the kuroboku group. Therefore, the plasticity index and liquid limit can be used as factors for estimating the slip surface.

According to the factors for estimating the slip surface, a correlation between the plasticity index and fine fraction content was observed (Figure 7), showing nearly the same result as the Casagrande plasticity chart. The correlation showed that the plotted data were distinguished between the sampling location (Takadake 1 and Takadake 2) and the tephra layer type (kuroboku and scoria). The Takadake 1 and Takadake 2 tephra layer data are denoted by filled symbols and un-filled symbols, respectively.

Figure 7 shows the Takadake 1 data fitted to the Takadake 1 trend line, and the Takadake 2 data were also fitted to the Takadake 2 trend line. The trend lines show that the plasticity index is directly proportional to the fine fraction content. Furthermore, the correlation shows dissimilarity between the kuroboku and scoria layers. Scoria layers showed low fine fraction content and plasticity index values and kuroboku layers showed high fine fraction content and plasticity index values. The kuroboku and scoria layers were denoted using the ellipse symbol in this correlation. The Takadake 1 and Takadake 2 data both showed that the N3-4 kuroboku (L) layer had the highest plasticity index and fine fraction content values, while the N2 scoria layer had the lowest plasticity index and fine fraction content values.

The correlation (Figure 7) showed that the slip surface layers (N3-4 kuroboku (L)) were plotted in the kuroboku group. With respect to the sampling location, the slip surface layers have the highest plasticity index and fine fraction content values. However, the plots of this correlation have a wide scattering, which could be caused by the difference of period on volcanic activities in soil materials and the historical landslides in the Aso volcanic mountains.

Conclusion

The soil materials in the shallow landslides on the Aso volcanic mountains were divided by volcanic activity period and laboratory tests were performed to examine the soil property characteristics of each layer. The soil layer characteristics determined by laboratory testing were compared with the stratigraphic analysis of the field observations, which showed that the kuroboku layers were located on the scoria layers. Moreover, the average soil hardness value of the kuroboku layers was lower than the scoria layers and the low average soil hardness value indicates the slip surface location. The stratigraphic analysis results of the field observations showed that the N3-4 kuroboku layer was the slip surface in the study area.

The laboratory test results showed that the kuroboku and scoria layers have soil property differences. The kuroboku layers had higher fine fraction content and plasticity index values than the scoria layers. In the studied areas, the correlation between the plasticity index and fine fraction content clearly showed that the N3-4 kuroboku (L) (Slip surface) layer has the highest plasticity index and fine fraction content values and that was located in the kuroboku group. According to these results, the fine fraction content and plasticity index can be used as factors for estimating the slip surface in this study area. Additionally, the slip surface in the volcanic area may have high fraction content and plasticity index values.

Declarations

Availability of Data and Materials:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests:

Authors have no competing interests on this study.

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Authors’ contributions:

All authors went to the landslide sites, took a samples and did the field investigation. All authors analysed and interpreted the soil property tests regarding the soil layers at the landslide sites. All authors read and approved the final manuscript.

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References

Condie KC (1993) Chemical composition and evolution of the upper continental crust: Contrasting results from surface samples and shales. Chemical Geology 104(1–4):1–37. doi:10.1016/0009-2541(93)90140-E.

Goto S, Kimura T (2019) Introduction of the special issue on “Toward the prediction of shallow landslides induced by heavy rainfalls on tephra-covered slopes. Landslides Vol.56:211–217. https://doi.org/10.3313/jls.56.211 (in Japanese)

Higaki D, Li X, Hayashi I, Tsou C, Kimura T, Hayashi S, Sato G, Goto S (2019) Geomorphological setting of shallow landslides by heavy rainfall on tephra-covered slopes of Aso Volcano, southwest Japan. Landslides Vol.56:218–226. https://doi.org/10.3313/jls.56.218 (in Japanese with English abstract)

Kato Y (1964) Some problems on the genesis of “Kurboku” Soils. The Quaternary Research 3(4):212–222. (in Japanese with English abstract)

Kimura T, Goto S, Sato G, Wakai A, Hayashi S, Higaki D (2019) Evaluation of landslide susceptibility by slope stability analysis using an estimated distribution of tephra deposits–A case study in the northeastern part of Aso caldera–. Landslides Vol.56:240–249. https://doi.org/10.3313/jls.56.240 (in Japanese with English abstract)

Miyabuchi Y, Daimaru H (2004) The June 2001 rainfall-induced landslides and associated lahars at Aso Volcano, southwestern Japan: implication for hazard assessment. Acta Vulcanol 16(1–2):21–36.

Miyabuchi Y, Daimaru H, Komatsu Y (2004) Landslides and lahars triggered by the rainstorm of June 29, 2001, at Aso Volcano, Southwestern Japan. Transactions, Japanese Geomorphological Union 25–1:23–43. (in Japanese with English abstract)

Ono K, Watanabe K (1985) Geological map of Aso Volcano (1:50,000), Geological map of volcanoes 4. Geological survey of Japan. (in Japanese with English abstract)

Sato G, Goto S, Kimura T, Hayashi S, Istiyanti ML, Komori J (2017) Gravitational deformation as a precursor of shallow landslide within tephra-covered slope deposits in the Aso caldera, Japan. Landslides Vol.54(5):199–204. https://doi.org/10.3313/jls.54.199 (in Japanese with English abstract)

Sato G, Wakai A, Goto S, Kimura T (2019) Strength characteristics of gravitationally deformed slope deposits of tephra and kuroboku soils in the Aso caldera, Japan –Application of revised vane-shear-cone test for estimating shear strength–. Landslides Vol.56:250–253. https://doi.org/10.3313/jls.56.250 (in Japanese with English abstract)

Shimizu O, Ono M (2016) Relationship of tephra stratigraphy and hydraulic conductivity with slide depth in rainfall–induced shallow landslides in Aso Volcano, Japan. Landslides 13(3):577–582. doi:10.1007/s10346-015-0666-2.

The Japanese Geotechnical Society (2015) Japanese geotechnical society standards laboratory testing standards of geomaterials, Vol.1.

Figures

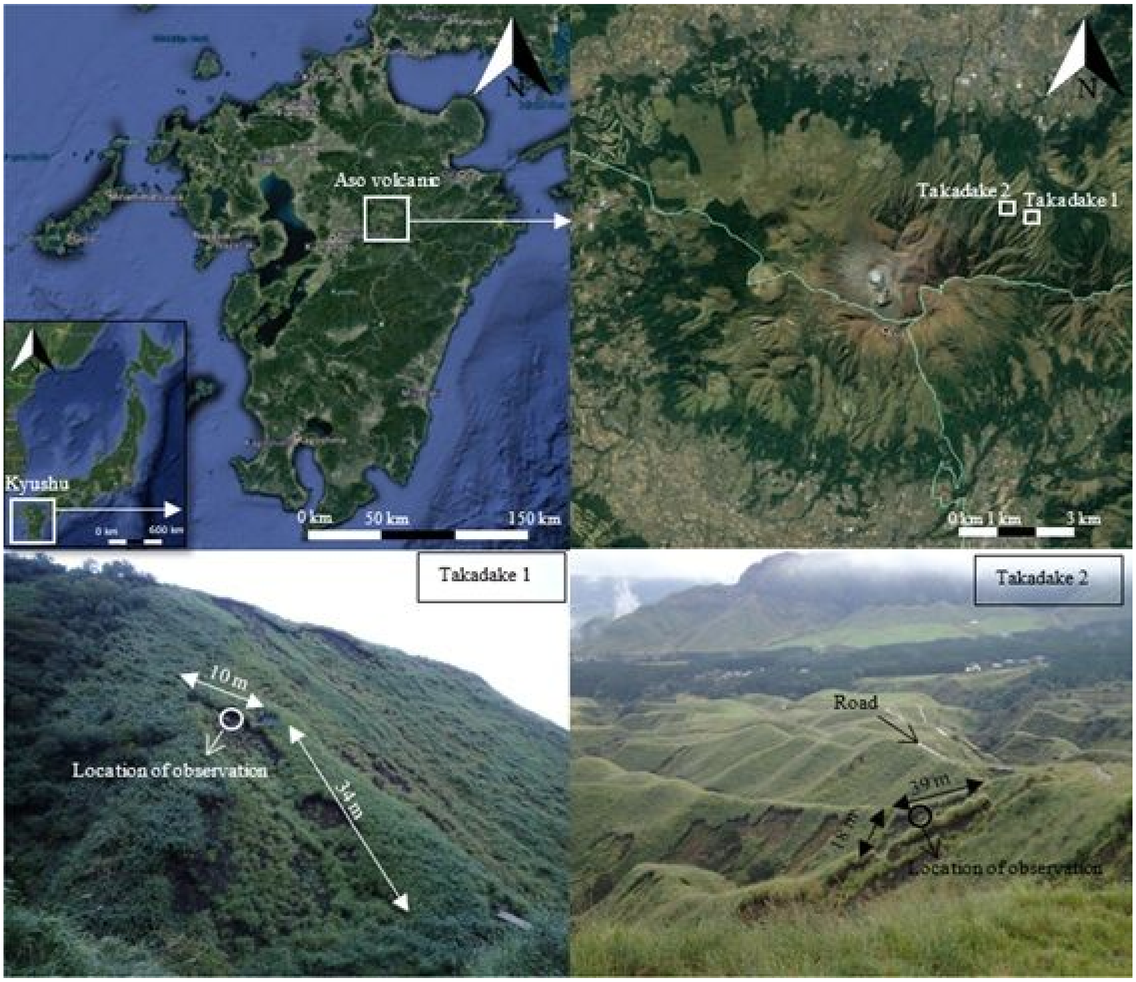

Figure 1

Shallow landslides in Aso mountains (Photos taken on October 2016) (Scale measured by geolocation software)

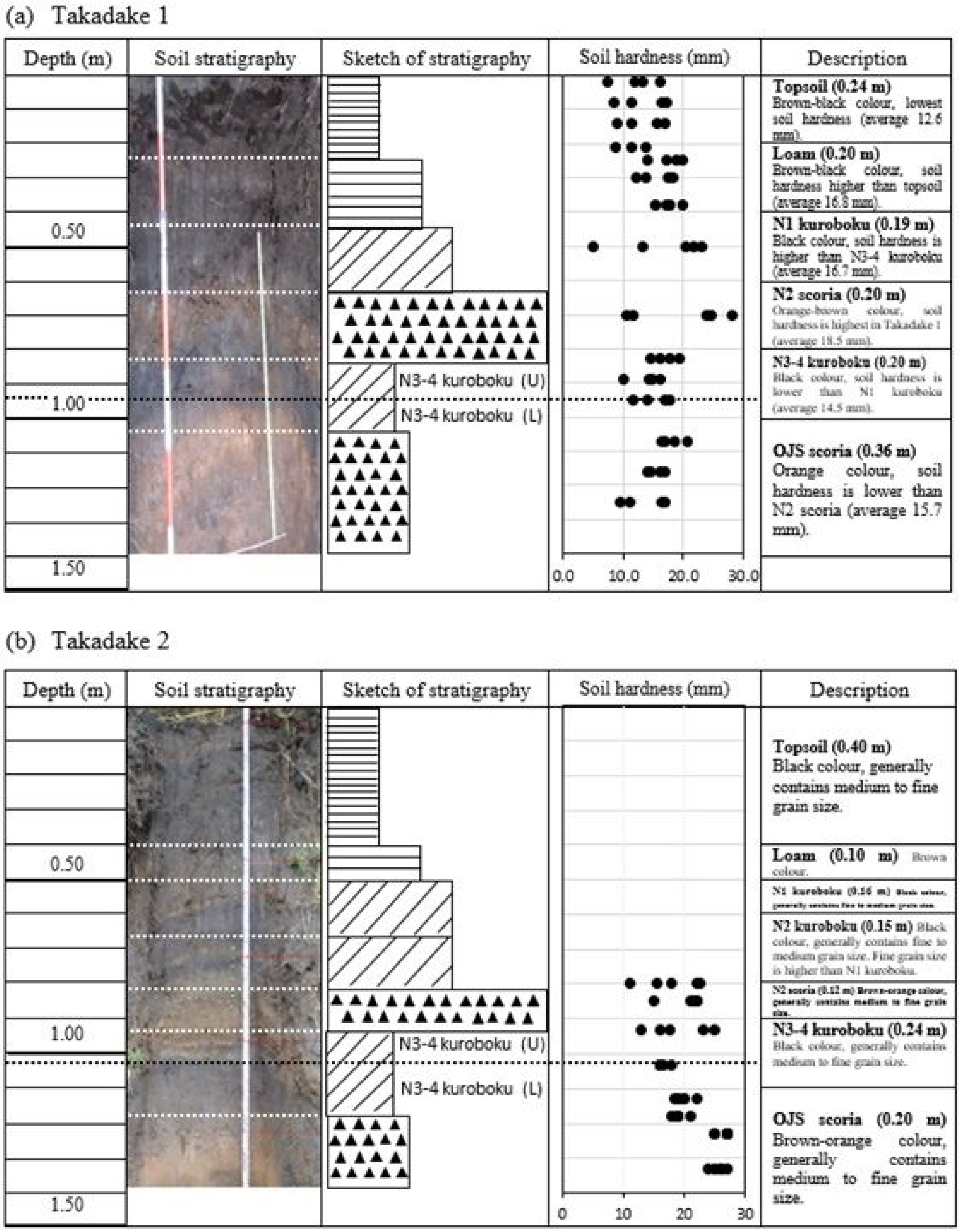

Figure 2

Soil stratigraphy; dotted lines indicate slip surface by field observation

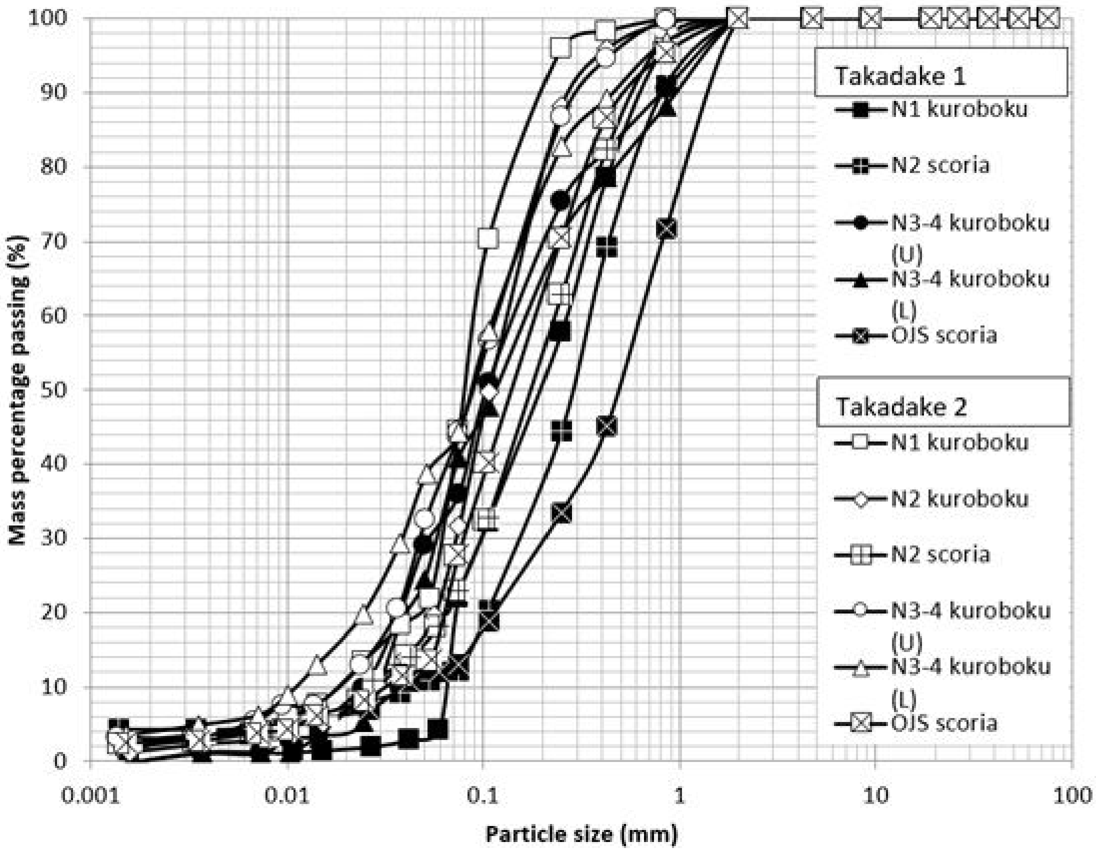

Figure 3

Soil stratigraphy; dotted lines indicate slip surface by field observation

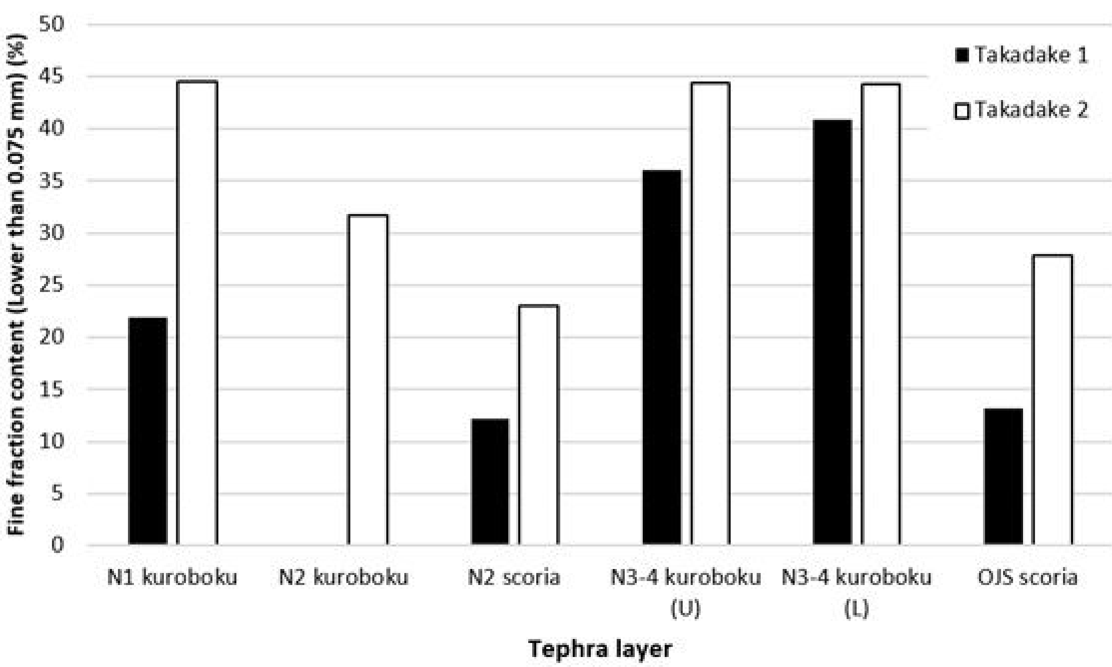

Figure 4

Fine fraction content on research area shows the dissimilarity between kuroboku and scoria layers

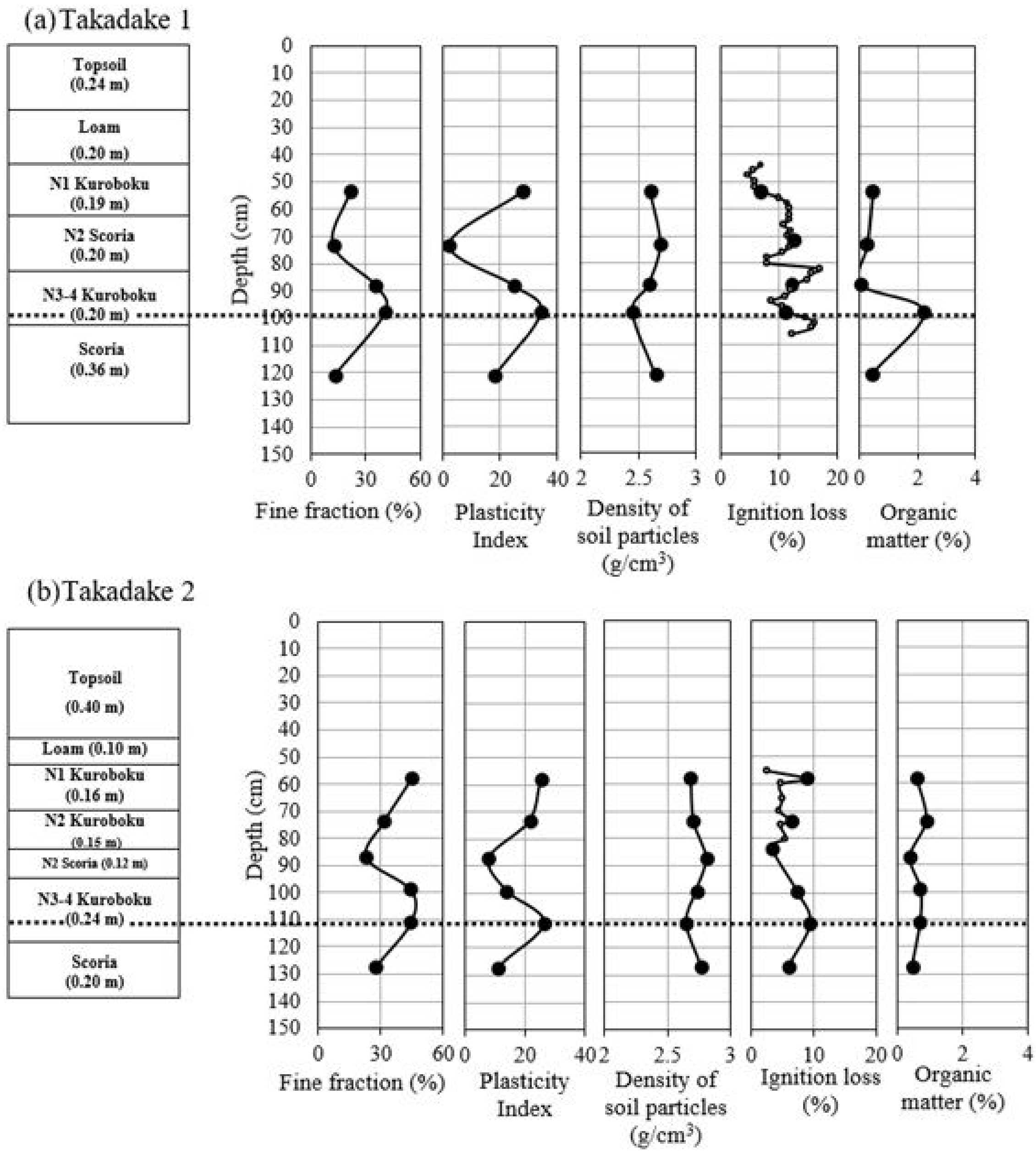

Figure 5

Soil properties and slip surface; dotted lines indicated location of slip surface by field observation

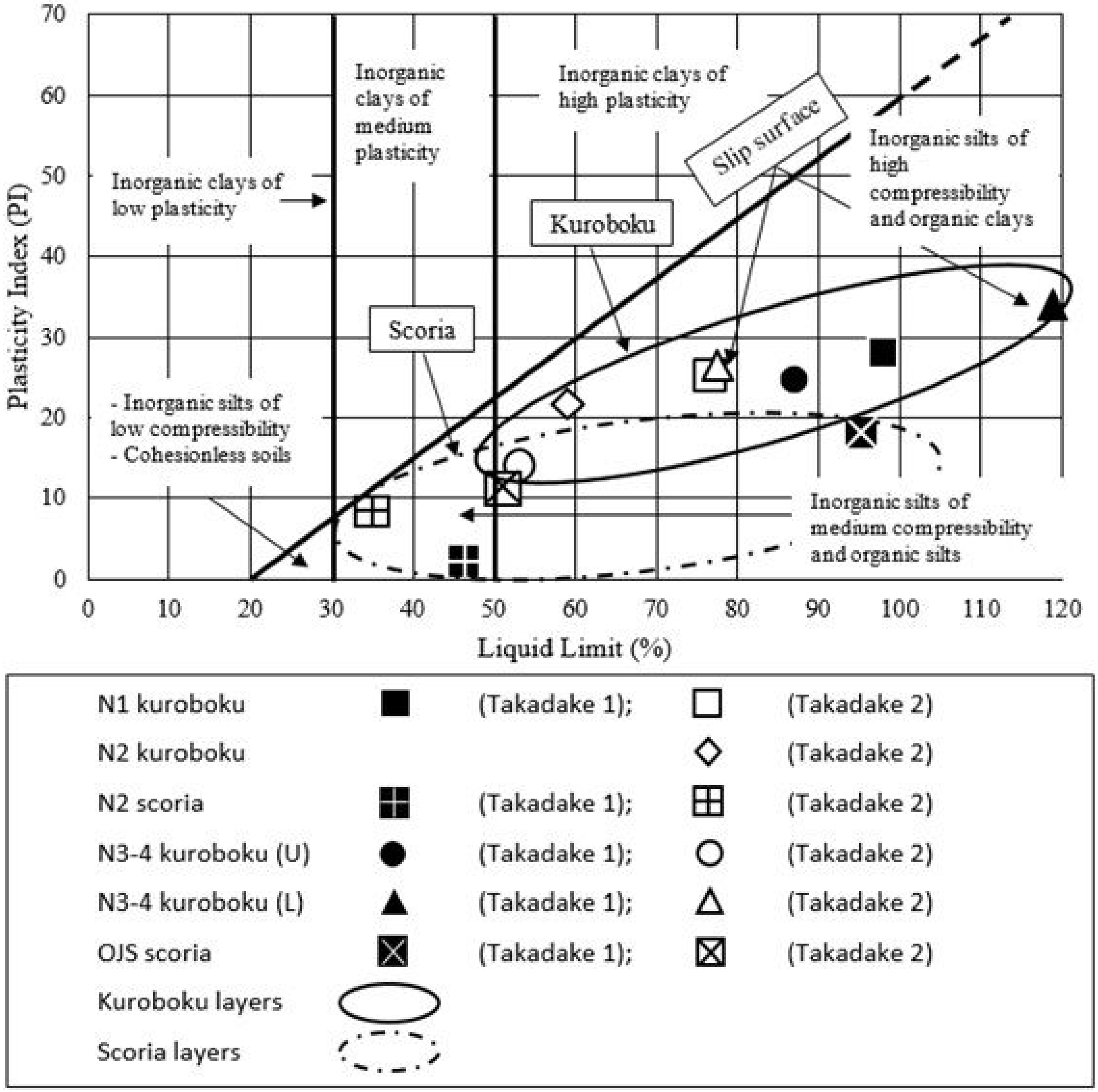

Figure 6

Casagrande plasticity chart shows the dissimilarity between kuroboku and scoria layers

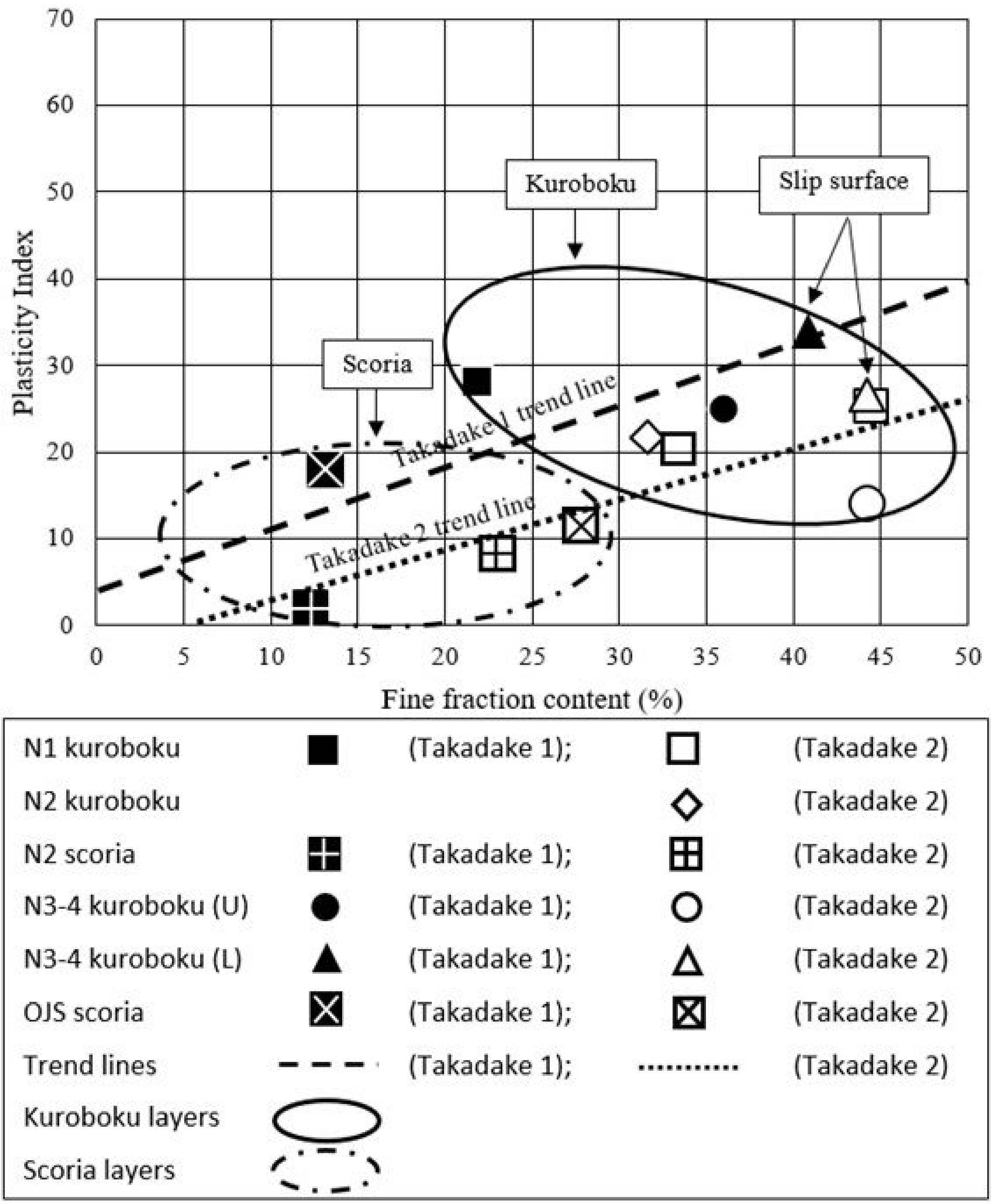

Figure 7

Correlation between fine fraction content (%)-plasticity index shows dissimilarity between kuroboku and scoria

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