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Characteristics of surface soil creep on a forest slope in Japan

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ABSTRACT

Soil creep was monitored for 6 years using the strain probe method, and compared to soil moisture conditions in order to reveal details of the soil creep mechanism on a forest slope in a weathered granite area of Central Japan. The results revealed a relationship between soil creep and soil moisture changes. Bending strain of the topsoil was induced downslope by soil drying, and was reversed by soil wetting. However, an amount of bending strain remained, which accumulated annually to form net soil creep. On the upper slope, when rainfall exceeded a certain threshold, miniature sliding sometimes occurred, caused by soil destruction in areas where shear deformation became concentrated. On the middle slope, topsoil deformation was more complex. In order to monitor the soil creep phenomenon related to the concentration of shear deformation in a narrow zone, improvement of the strain probe method is needed.

1. Introduction

Soil creep monitoring has been performed in many studies, in particular by the marker method (e.g. Benedict, 1970; Finlayson, 1981), the Young's pit method (e.g. Young, 1960; Moeyersons, 1988; Clarke et al., 1999; Sonoda and Okunishi, 1999), and/or the strain probe method (e.g. Williams, 1957; Barr and Swanston, 1970; Mercier and Geissert, 1982; Auzet and Ambroise, 1996; Yamada, 1999). These studies have revealed soil creep rates and the distribution of soil creep in the topsoil. Mean downslope soil creep rates at the slope surface are on the order of millimeters to centimeters per year in many cases (Barr and Swanston, 1970; Jahn, 1989; Clarke et al., 1999), whereas the relationships between soil creep magnitude and other factors (e.g. elevation, geology, and vegetation cover) remain unclear (Kirkby, 1967; Clarke et al., 1999). Problems elucidating these mechanisms show that soil creep is affected by many factors and is most likely a complex phenomenon.

Furthermore, precise monitoring of soil creep has revealed complicated soil creep profiles. The maximum soil creep rate usually exists at the top of the topsoil, yet sometimes at greater depths (Clarke et al., 1999). In some cases, soil creep produces large displacements, with motions similar to that of flow (Moeyersons, 1988, 1989). Lewis (1974) indicated that shearing of the soil layer is induced by significant throughflow, but the detailed mechanism remains unclear (Moeyersons, 1988; Clarke et al., 1999).

The difficulty in understanding the soil creep mechanism relates to its very slow motion, necessitating a very long period of measurement. For example, Young (1978) and Clarke et al. (1999) measured soil creep for 12 and 23 years, respectively. In addition, if the marker method and/or the Young's pit method are used, it is necessary to disturb the soil in order to measure the displacement by soil creep. To solve this problem, an automatic and accurate (less than one millimeter) soil creep monitoring system is required. The strain probe method, in particular the improved strain probe method by Yamada and Kurashige (1996), can monitor soil displacement due to soil creep with sufficient accuracy, and does not need to disturb the soil. Thus, if the improved strain probe method can be combined with monitoring of the factors affecting soil creep and used on a slope where the soil creep mechanism appears to be fairly straightforward, the soil creep mechanism can be effectively determined.

Sonoda and Okunishi (1999) studied soil creep using the Young's pit method for 27 months at 15 sites on a forest slope 30 m long in Asuka Village, Nara Prefecture, Japan, and revealed that soil creep on the slope, particularly during periods of heavy rainfall, is characterized by shear deformation. In addition, Sonoda (1998) performed a numerical simulation on that slope and confirmed that shear deformation of the topsoil is caused by the force of saturated ground water flow during torrential rain induced soil creep. Further, Sonoda and Okunishi (2005) tested the improved strain probe method for 14 months at five sites on the same slope, combined with soil moisture monitoring by tension meters, and detected movements related to tilting and restoration of the soil induced by soil drying and wetting. However, the data were not clear enough to determine the relationships between soil creep and soil moisture conditions, potentially because the study slope faced northwest and soil drying was limited. In contrast, in this study, we chose a south-facing slope (where soil drying is clear), close to the previous study slope, and performed measurements at 12 sites along the

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33 m long slope over a duration of six years. These were combined with intensive monitoring of soil moisture to determine the relationships between soil creep and soil moisture conditions.

2. Regional setting

The study slope is located in the inland mountainous region of Asuka Village, Nara Prefecture, Japan (34°53′N, 135°26′E; Fig. 1a). Its elevation is approximately 300 m above sea level. The climate in this region is temperate humid, and the average annual precipitation is 1470 mm (at Oouda Automatic Meteorological Data Station, 10 km from the study area). The slope faces south and receives relatively high solar radiation, and soil freezing rarely occurs during the winter. The main vegetation cover includes Japanese cypress trees that have been planted and managed. Sufficient sunlight reaches the forest floor to support bamboo grass, bushes, and low broad-leaved trees. The base rock geology is weathered granite.

A total of 12 observation sites (P1 to P12; Fig. 1c, d) were spaced at 3 m intervals. The study slope can be divided into two parts: the upper slope (P1 to P9) and the middle slope (P10 to P12; Fig. 1d). The upper slope has a gradient of approximately 35°, while the middle slope has a gradient of 46° to 47°. A steeper slope exists just below P12, and represents a collapse scar formed by a landslide in 1982. The slide regolith has formed a 30° talus slope, located about 10 m downslope of P12, which passes through an outcrop of weathered rock (with a gradient of 60°). Relatively gentle slopes of 27° and 30° occur near P6 and between P8 and P9, respectively (Fig. 2). In contrast, steep slopes exist near P5 and between P7 and P8 (46° and 45°, respectively). This experimental slope is steeper than other soil creep measurement slopes in previous studies (Eyles and Ho, 1970; Finlayson, 1981; Moeyersons, 1988; Jahn, 1989; Clarke et al., 1999). However, the slope studied in Barr and Swanston (1970) was equivalent to that used in this study.

The characteristics of the topsoil on this slope are as follows, with the exception of relatively clay rich soil distributed between 42 and 92 cm depth at P8. The porosity ranges between 48 and 62%, (41% to 47% at P8) and the hydraulic conductivity ranges between 1.8×10^{-3} and 8.1×10^{-2} cm s^{-1} (5.8×10^{-4} to 1.9×10^{-3} cm s^{-1} at P8). The weight percentage of particles smaller than 63 μm is 10–29%, including at P8 (21–27%).

3. Materials and methods

We used the Yamada and Kurashige (1996) type strain probe to measure topsoil creep displacement. The direct value measured by the strain probe is bending strain. The definition of 'strain' is the ratio of the transformed length to the original length of the object. Since it is non-dimensional and very small, the value is shown on the order of micro-strain (1×10^{-6}) in this study. Soil displacement was calculated from the bending strain values using the formula of Yamada and

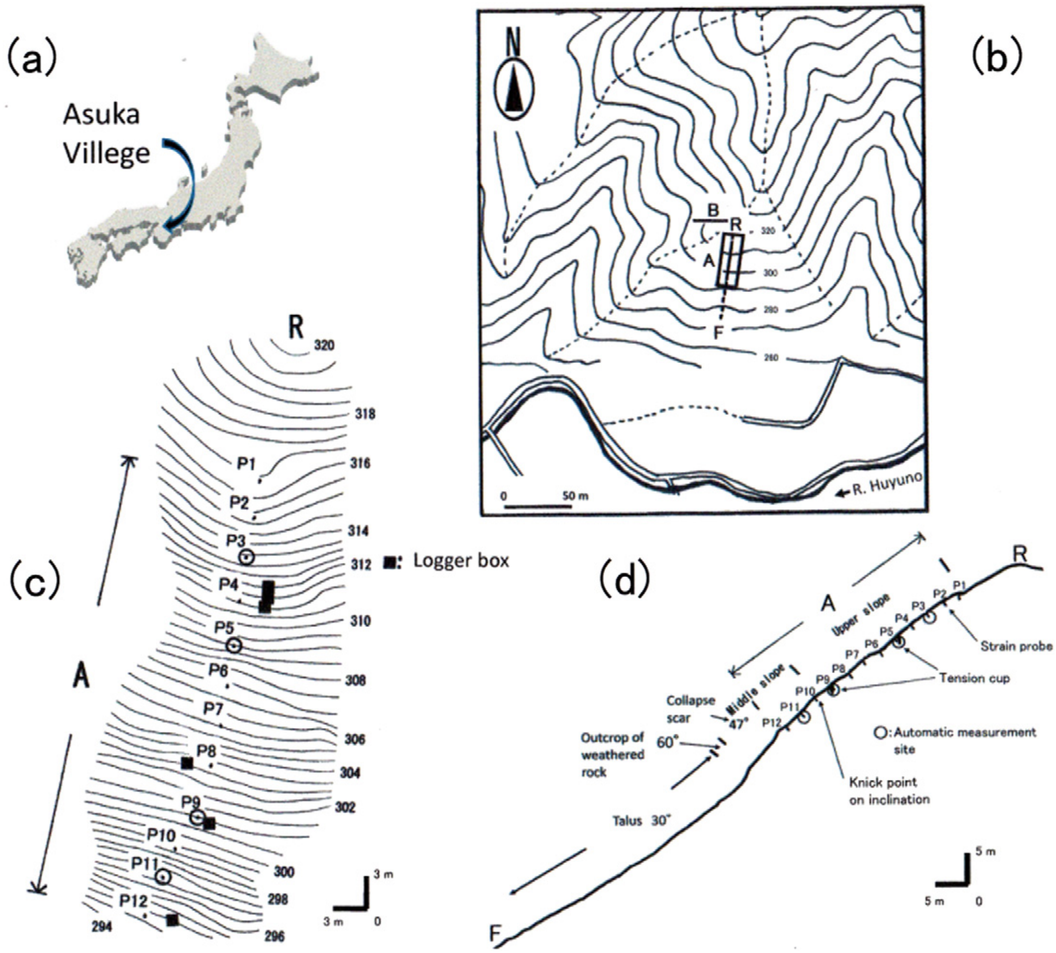

Fig. 1. Maps of the study site. (a) Location of the study area. (b) Topography of the study area with the locations of A (study slope), R (ridge of the study slope extension), F (end of the study slope extension), and B (experimental study slope of Sonoda and Okunishi, 1999). (c) Topographical survey map of the study slope, including the locations of automated logger boxes (black squares), observation sites (P1–P12), R, and the approximate position of profile A. (d) Longitudinal profile down the experimental slope (R–F), with the 12 observation sites (P1–P12) of profile A marked, along with the positions of automated logger boxes (white circles).