Shallow Landslide Process and Hazard Mapping Using a Soil Strength Probe

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Abstract

The author proposes a hazard mapping procedure for shallow landslides using the newly developed soil strength tests, Soil Strength Probe Test (SSPT) for measuring topsoil thickness and Vane Cone Shear Test (VCST) for measuring cohesion and internal friction angle of topsoil. Topsoil thickness on natural slope is complexly distributed with a *patchwork structure*, and each patch roughly corresponds to micro-topography related shallow mass-movements such as shallow landslide scars, soil creep, erosion sites and debris deposits. For detailed hazard mapping, it is effective to identify *scab patches* with thick topsoil. SSPT and VCST will be able to distinguish and narrow problematic blocks from the vast extent of a slope.

Keywords

Hazard map • Slope disaster • Shallow landslide • SPT • Soil strength probe

166.1 Introduction

Shallow landslides occur in the upper meters of the topsoil and their extent exceeds usually not 100 m. Though the debris volume in each case is low, it accounts for most slope disasters in monsoon region. Also in Japan, shallow landslides cause 50–80 % of slope disasters (Sasaki et al. 2006). Nevertheless, evaluation of their hazard is difficult because it is impossible to distinguish potential shallow landslide blocks. Therefore, the author has proposed a method to investigate potential landslides by a newly developed soil penetration test, Soil Strength Probe (SSP, or *DOKENBO* in Japanese) (Sasaki 2010), which can rapidly measure not only topsoil thickness but also soil cohesion and internal friction angle in situ. The paper outlines the SSP method and the proposed hazard evaluation procedure.

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166.1.1 Type of Shallow Landslides

Shallow landslides are classified in several types. The first is hillside slope type. A hillside slope has several topographical nick lines or dissection fronts. These dissection fronts were primarily formed by strong erosion during interglacial stages and it is successively dissected even today. Therefore these dissection fronts fail easily during heavy rainfalls or earthquakes. The second type is the *valley head slope* type. Valley head slope means spoon shaped slopes located upper the headwaters of ravines/gullies. On valley head slopes shallow landslides often occur repeatedly during heavy rainfall because at the valley head accumulates rain water, ground water and topsoil from the upper slope. The third type is past landslide debris and talus re-failure type. Furthermore, there are some geologically specific types (fault type, etc.).

166.1.2 Process of Shallow Landslides

Weathering, sedimentation, soil creep, internal and surface erosion make slope topsoil instable in the long-term. From a short to midterm perspective, earthquake, wind, and change

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Fig. 166.1 SSPT (*left*), VCST (*center*) and cones (*right*)

of groundwater level by rain or snow also destabilize topsoil. Cycles of the above processes and mass movements lead to a highly complex topsoil thickness distribution (Sasaki and Fukuda 2012). We call this complex structure '*patchwork structure*' of topsoil which is illustrated in Chap. 4. These patches will become future shallow landslide blocks. Unstable blocks are relatively thick topsoil patches on a steep slope, called '*scab patch*'. Therefore is necessary to investigate topsoil thickness distribution and soil strength in detail in order to identify shallow landslide blocks and evaluate its stability.

166.2 Soil Strength Probe

A new test tool (Fig. 166.1), Soil Strength Probe (SSP), was developed to identify and estimate scab patches. SSP applied the following two measuring methods.

166.2.1 Soil Strength Probe Test

The first method is a penetration test using a normal cone (SSP Test, SSPT) to estimate topsoil thickness in several minutes.

166.2.2 Vane Cone Shear Test

The second method is a shear test (Vane Cone Shear Test, VCST) that can be used to estimate soil cohesion and internal friction angle of a sliding plane in situ in half an hour. A vane cone is used to shear the topsoil by rotating it under some normal stresses as shown in Fig. 166.2.

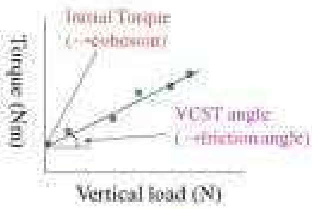


Fig. 166.2 Method of estimating cohesion and friction angle by VCST

166.3 Hazard Mapping Procedure

The proposed hazard mapping procedure includes the following sets as outlined below and in Fig. 166.3.

- Step A: Selection of investigation area.
- Step B: Detailed topographic interpretation and mapping.
- Step C: Landform unit zoning.
- Step D: Engineering geological unit mapping.
- Step E: Slope unit zoning using the above information.
- Step F: Selection of the unstable zone requiring a detailed topsoil investigation.
- Step G: Topsoil depth distribution mapping by SSPT and the clarification of the patchwork structure of soil depth.
- Step H: Estimation of probable shallow landslide blocks requiring stability calculation.
- Step I: Selection of unstable shallow landslide blocks by calculating stability using a soil shear test such as VCST.
- Step J: Evaluation of debris reach area by debris reach simulations (see Fig. 166.4).

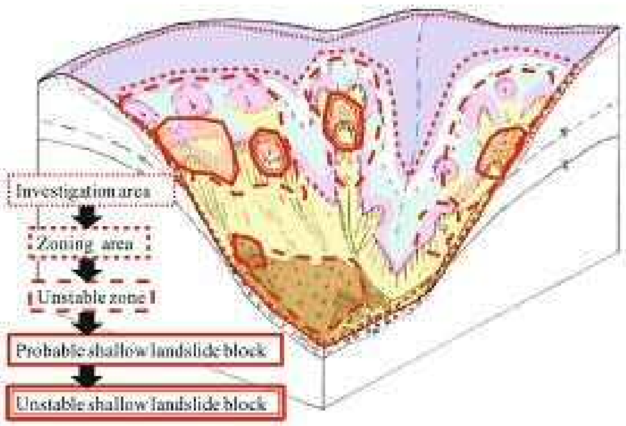


Fig. 166.3 Image of hazard mapping of a shallow landslide

166.4 Case Study

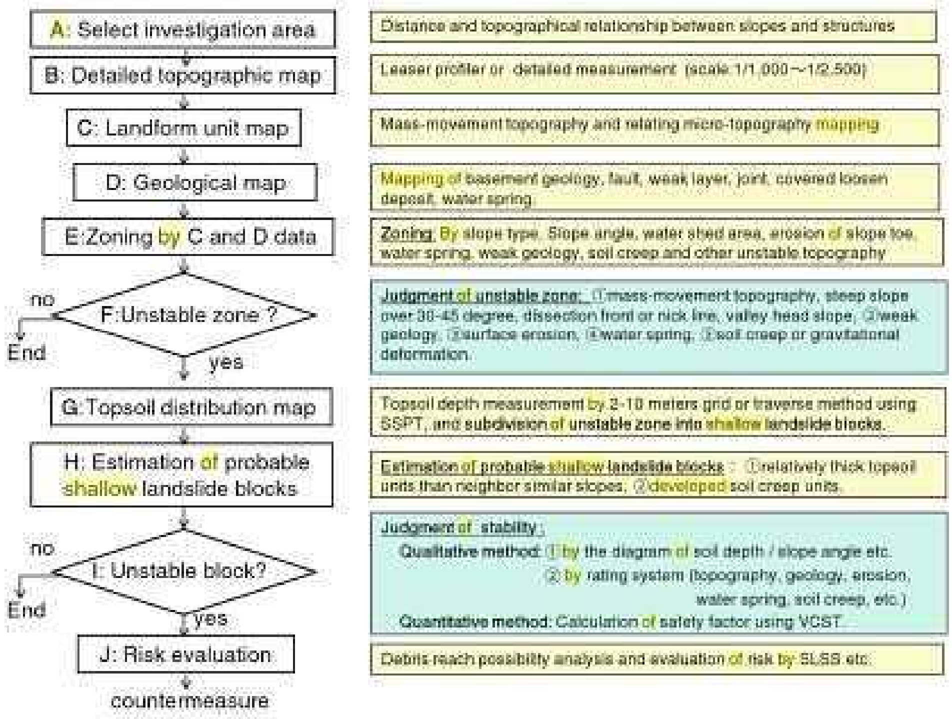
Hazard mapping by SSP was demonstrated at a hill slope covered by topsoil over granite bedrock and compared the results with micro-topography observed by field investigations and LiDAR measurements.

Topsoil thickness distribution showed different patterns according to landform units such as hillside slope units and valley-head slope units. The thickness of topsoil changes complexly every 5–10 m laterally, and it corresponds roughly to micro-topography of shallow mass movements such as shallow landslide scars, soil creep, erosion, and debris deposits topographies. So we call the complicated topsoil structure a *patchwork structure*, and call each unit a '*patch*'. Thick topsoil patches are often accompanied by soil creep topography. There are some recent landslide scars on lower steep slopes, and these scars have thin topsoil. The facts mentioned above strongly suggest that the repetition of these shallow mass movements forms the complicated slope topsoil distribution. From the point of view of topsoil thickness distribution and micro-topography, a hillside slope is divided into sub zones, i.e. upper slope zone (creep zone), knick line zone (failure zone), debris runoff zone, and debris deposit zone. Shallow landslides occur mainly at knick line zones, but also at other zones due to other destabilization processes. In a creep zone and knick line zone, in situ weathered soil destabilizes and fails as a result of creep, groundwater seepage, and piping. In the debris runoff zones and deposit zones, accumulated debris (secondary deposited topsoil) destabilizes and fails as a result of gully development and ravine erosion. Similar sub zones also exist on valley head slopes.

From these observations, probable shallow landslide blocks are defined as *patches with steep slope angle, thicker topsoil than on neighboring slopes, and soil creep topography*. The total area of such probable shallow landslide blocks is only 6 % of whole investigated area (Fig. 166.5).

From these data, a debris reach potential map was made using the Shallow Landslide Simulation System (Fukuda et al. 2005), which estimates probability of debris runout by shallow landslides using Monte-Carlo simulation based on

Fig. 166.4 Procedure of hazard mapping of shallow landslide



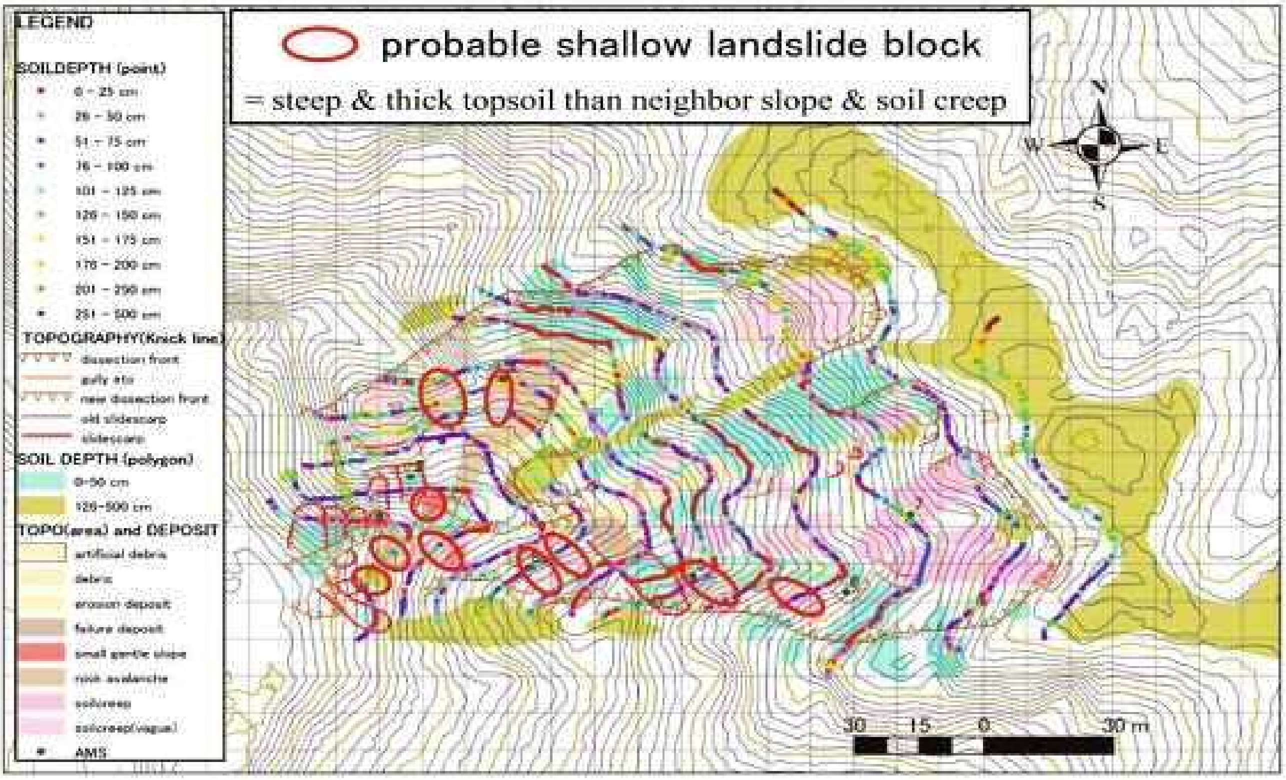


Fig. 166.5 Probable shallow landslide blocks estimated from topsoil depth and micro-topography (Topsoil depth was measured by SSP and micro-topography was described by surface survey using LiDAR)

the relationship data between debris runout of historical shallow landslides and these geological and topographical properties.

166.5 Conclusion

Topsoil thickness on natural slopes is complexly distributed with a *patchwork structure*, and each patch roughly corresponds to micro-topography related shallow mass-movements such as shallow landslide scars, soil creep, erosion sites and debris deposits. For detailed hazard mapping, it is effective to find *scab patches* with thick topsoil. SSP will be able to distinguish and narrow problematic blocks from the vast extent of a slope.

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