Original paper

An Assessment of Shallow Landslides Mechanism Induced by Rainfall in Hakoishi Area [*1]

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Paudel, P. P., Moriwaki, K., Morita, K., Kubota, T. and Omura, H.：**An Assessment of Shallow Landslides Mechanism Induced by Rainfall in Hakoishi Area　kyushu J.For.Res. 56：122-128，2003**　The steep slope of eastern caldera wall of Mt. Aso region is dissected by a number of shallow landslides due to the heavy rainfall. The relief of the study area is 300 m and receives annual rainfall much more than 3000 mm. The land use of this area is mainly differentiated into forest and grassland. The mean slope angle is about 14^0 and 26^0 for grassland and forest respectively. Some of trees were uprooted and leaned due to the effect of flowing mass. Along the bed of stream there is a sediment deposition too. Majority of the shallow landslides were found to occur in between 30^0- 40^0 slope angles. Around the area the soil layers were piled from tephra and are differentiated each other by their distinct colors. In some sample sites the specific gravity, hardness, porosity, permeability, cohesion and internal friction angle of individual layer and surface soil were examined. The relative slope stability assessment was carried out for forest and grassland surfaces to know the relatively susceptible regions. The steep hilly topography, high precipitation and loosely bounded nature of soil grains are the prime factors of shallow land sliding.

Key words：shallow landslides, mechanism, slope stability, soil layer, mud flow

Ⅰ. Introduction

The Mt. Aso region is located around central Kyushu, the south - western part of Japan. Due to the heavy rainfall in 1990 July, there was a heavy landslide disaster around the Kumamoto prefecture including in the Mt. Aso region. Many shallow landslides have been occurred around steep slope of caldera wall. The slipped material flowed down along the valleys with runoff water and changed into debris flows with large amount of flowing tree trunks. Debris flows changed into flash floods through sedimentation of such solid content as blocks and gravels. The maximum daily precipitation was recorded up to 448 mm during heavy rainfall period and the landslide disaster has damaged seriously forest and grassland surface, sabo dam structures, other infrastructures and also has influenced the downtown of Ichinomiya (Kumamoto Prefecture, 1990). After this major disaster event also some shallow landslides have been occurred especially during rainy season in the eastern caldera wall of Aso volcano, near Hakoishi mountain pass. The shallow landslides in study area were occurred in between 1990 to 2001. The area broadly comprises the grassland and forest surfaces. The shallow landslides have been occurred in both forest and grassland slopes. The aim of this study is to present the case example about mechanism of shallow landslide induced by rainfall and to understand the relative slope stability of the study area to identify “relatively” prone regions for land sliding.

Ⅱ. Study area and Methods

The study area belongs to the eastern caldera wall of the Aso volcano ranging in between 32°53' 42" and 32°54' 50"N latitudes, and 131°7'47"and 131°10'18"E longitudes. The elevation ranges between 630 m to 930 m asl. The total study area is about 4.86 $km^2$and is covered mainly by forest and grassland. The trees in the steep forest slope are protected and in flat grassland animals are allowed to graze. The forest comprises about 9% of the total area. Mt. Neko dake, which is close to study site is an old volcano but now is dormant and sometimes receives fresh andesitic materials like tephra ash. The annual rainfall in the study area is much more than 3000 mm (Kumamoto meteorological station, 1990). During heavy rainfall period the soil has been changed into the mud containing high water content and some surface layers were slide down from both forest and grassland surface. The slipped mass was flowed through streams and valley channels. The shallow landslides were mainly concentrated at the ridge parts as shown in Photo 1. The study site is

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*1　ポウデル・プレム・プラサド・森脇康介・森田紘一・久保田哲也・大村　寛：降雨による表層崩壊のメカニズムに関する研究

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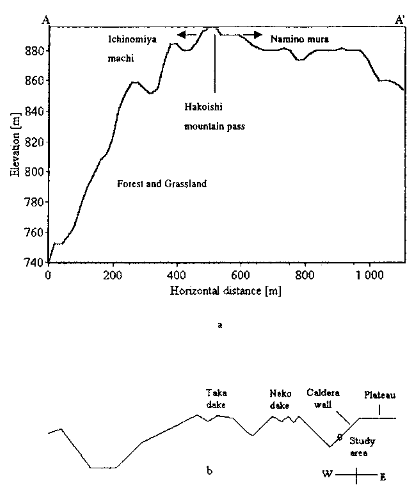
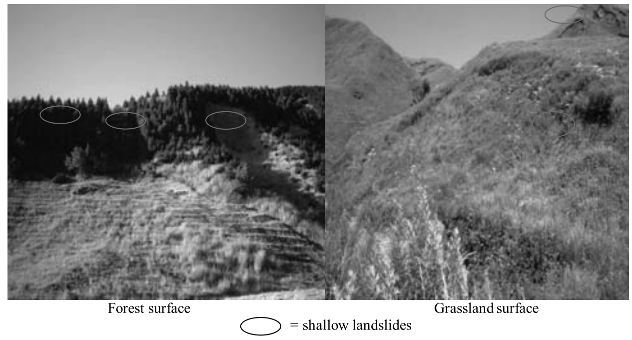
particularly characterized by many conditions like interaction of mass movement with the adjoining vegetation, sediment deposition over stream bed, bank erosion and held on of flowing mass to the branches of the adjoining trees. Some trees lying along the side of stream bank were uprooted and some were leaned due to the effect of mud flowed from upstream side as shown in Photo 2. The major tree in forest is coniferous species, *Cryptomeria japonica* (*Sugi*) mixed with *Chamaecyparis obtusa* (*Hinoki*). In grassland the densely covered grass species are *Miscanthus sinensis* and *Zoysia japonica*. The surface andisol has been differentiated into different layers as distinguished each other by their distinct color and were varied spatially. For the sake of convenience these are named as Ⅰ, Ⅱ, Ⅲ and Ⅳ layers starting from the ground surface respectively. The colors of these layers in the naked flank and surface base of shallow landslide scar are shown in Photo 3. The shallow grass's roots in grassland did not seen penetrating below the sliding plane, while in forest a few roots were seen penetrating below the sliding plane of shallow landslides. In the study area two different types of slope i.e. steep and gentle are remarkably exists. The landscape facing towards Ichinomiya is relatively steeper in compare to Namino village side, Figure 1a. The simple schematic profile of the study site is shown in Figure 1b. The schematic profile shows mainly two slope types. One is lava plateau-like gentle hilly slope originally produced by pyroclastic flow. Another is steep caldera wall slope, which dissects the gentle slope. Mainly the shallow landslides are concentrated in the steep slope surface.

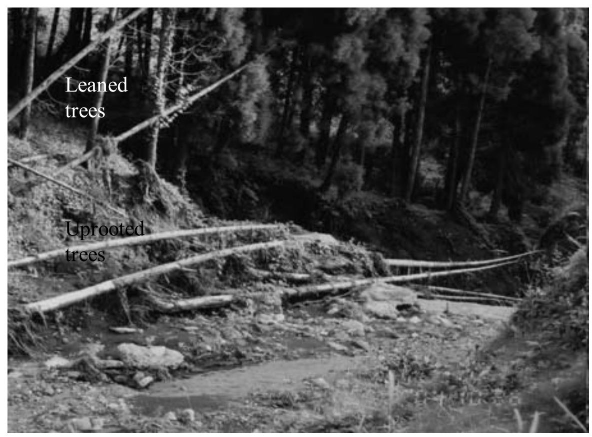
The study has focus on to Ichinomiya side, because of distribution of many shallow landslides. The height of dominant Sugi species in steep forest site varies from 4 to 8 m having diameter from 11 to 20 cm while in gentle slope the trees have grown up to 15 to 20 m in height with good ground coverage. The diameter of a few penetrated roots below the slip surface were measured only at the exposed points and has varied from



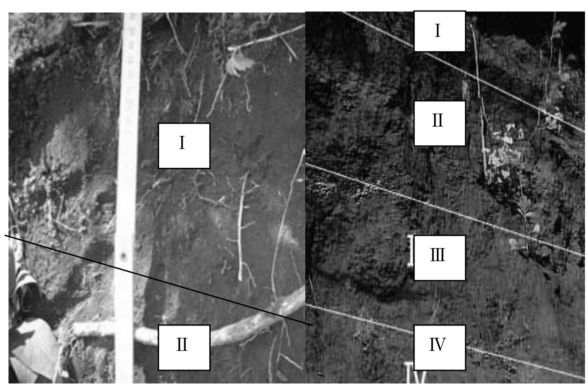
Fig－1. Cross section of the study area
a: near Hakoishi mountain pass　b: schematic profile



Photo－1. View of shallow landslides distribution in forest and grassland



Photo－2. Uprooted and leaned trees near the stream bank



Photo－3. Different colored soil layers as seen in the flank and landslide scar

0.5 to 1.5 cm. The slope map of the study area and cross section near Hakoishi mountain pass were derived from the topographic map of scale 1 : 25000 using Map-info professional, Vertical Mapper and Grid Analyzer program, a kind of GIS software. The andisol layer's differentiation, their perpendicular thickness were observed and measured during the field inspection. The color property of each soil layer was examined in the laboratory by using the standard soil color charts (Soil color charts, 1989). The hardness of each soil layer was measured in the field using Yamanaka System Hardness Tester (5550 type). The distribution of shallow landslides is plotted in the topographic map. The dimensions of 17 shallow landslides were measured in the field. The undisturbed surface soil samples were taken in cans having volume of 141m^3 from the surrounding areas of the shallow landslides selecting from five sampled sites representing from both forest and grassland surfaces as shown in Figure 2. Two sites F1 and F2 in forest and three sites G1, G2 and G3 in grassland are the selected sampling sites. From these sites surface soil was collected to understand the spatial variation of cohesion and internal friction angle. The color of the soil layers above the slip surface was closely observed at flanks in 3 different shallow landslides sites so as to understand the characteristics of each individual layer. The soil samples were collected from each delineated layer to examine the physical properties of individual layer. The soil samples collected from sample sites and from each soil layer were tested in the laboratory by the direct shear box at 0.4, 0.6, 0.8 and 1.0 kgf/cm^2 vertical stresses to determine the cohesion and internal friction angle. The permeability, porosity and specific gravity were also analyzed following the Japan Industrial Standard method.

Ⅲ. Stability analysis

The safety factor indicates the relative stability of slopes (Ziemer, 1981). Infinite slope stability model has often been used to investigate the stability of forest slope where shallow landslides are the main type of mass wasting (O' Loughlin, 1982). The relative stability of slopes has been assessed for the forest and grassland surface based on geo-technical properties of soil obtained from sampled soil and topographic steepness. At the saturated condition the value of cohesion, internal friction angle and density of soil were examined. The depth of slip surface for all shallow landslides were measured in the field and average depth was used during safety factor analysis. The Digital Elevation Model (DEM) of the study area was made with 20 m grid size by digitizing the 10 m interval contour lines. The slope map was derived from the prepared digital elevation model. To derive the stability assessment map the value of cohesion, internal friction angle, density, depth and slope steepness for forest and grassland were obtained in vector domain using Map info and Grid analyzer software. Further the physical properties of individual soil layer were examined. For limiting equilibrium of a soil layer lying on an inclined surface the shear stress (τ) on the potential sliding plane, shear strength(S) , and safety factor (Fs), are given by the following infinite slope stability equation (Brunsden and Prior, 1984). The value of safety factor is considered as the index of state for the shallow landslide prone area. The value < 1 and ranging in between 1 to 1.5 has considered as high prone and medium prone area respectively for shallow land sliding.

$$Fs = \frac{c' + (\gamma - m\gamma_w) Z \cos^2\beta \tan\phi'}{\gamma Z \sin\beta \cos\beta}$$, where,

γ : unit weight of soil (kN/m^3), γ_w: unit weight of water (kN/m^3), Z : vertical depth to the failure plane (m), β : slope angle (degree), ϕ': internal friction angle with respect to effective stress (degree),c': cohesion with respect to effective stress (kN/m^2), and m: ratio between height of water table to the depth of failure surface (dimensionless) and equals to unity when the soil above the failure surface is saturated with water.

Ⅳ. Results and Discussion

The shallow landslides were distributed more abundantly to Ichinomiya town side in compare to Namino village. The distribution pattern of shallow landslides in forest and grassland surface is shown in topographic map (Figure 2). This distribution pattern reflects the concentration of shallow landslides mainly in the steep slope. The study area of forest is comparatively smaller than grassland. In the steeper forest slope smaller sized shallow landslides are concentrated. The result of approximate area, depth and inclination of 17 shallow landslides are listed in Table 1. The majority of shallow landslides have approximate surface area less than 1000 m^2. The average depth of shallow landslides was found to be about 1.2 m. The approximate average sizes of shallow landslides were 201 m^2 and 305 m^2 in forest and grassland surface, respectively. The result of the slope map is shown in Figure 3. This reflects that the frequency distribution of gentle slope i.e. less than 20^0 is about 77% and 39% in grassland and forest respectively. In grassland the maximum slope angle reaches up to 57^0 while in forest it is about 62^0. The shallow landslides distribution in the same slope class for both forest and grassland surface was examined. The shallow landslides were not found in less than 30^0 slope angles and mainly occurred in between 30^0-40^0 slope angles. The number of shallow landslides observed in different slope class and their corresponding area (A), in forest and grassland surface are as follows,

Grassland: <30^0, A: 4.16km^2, shallow landslides no.: 0
30^0-40^0, A: 0.32km^2, shallow landslides: 16
Forest: <30^0, A: 0.17km^2, shallow landslides no.: 0

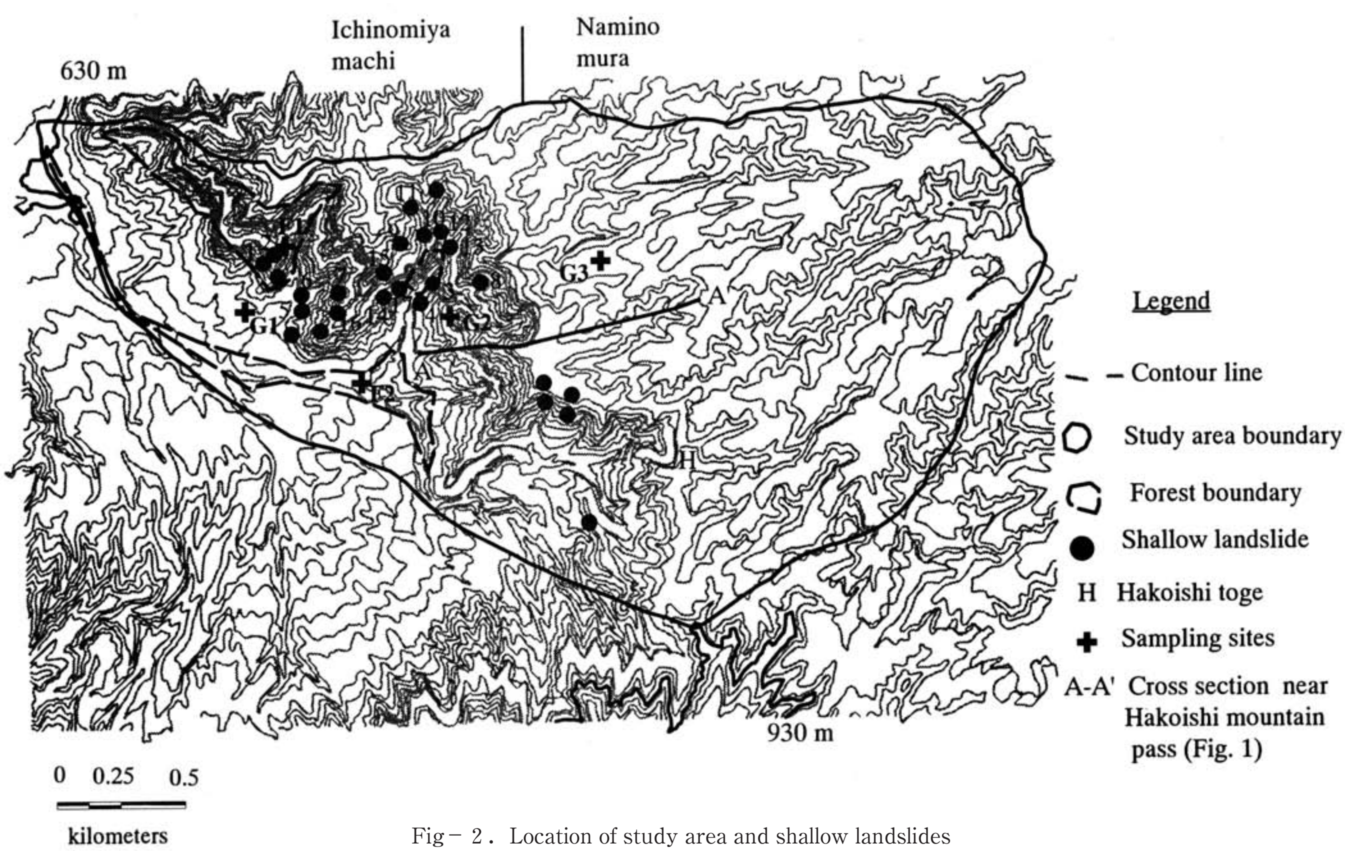
30^0-40^0, A: 0.07km^2, shallow landslides: 5

Altogether 25 shallow landslides were examined to see the distribution pattern. The rest of the shallow landslides were occurred in between 40^0-50^0 slope angle, two in each land use surface. The shallow landslides in between 30^0-40^0 slope class were more densely concentrated in the forest slope in compare to grassland. The mean slope angle in this slope class for forest and grassland were about 36^0 and 34^0 respectively. In general the steepness landscape of forest surface has thought to be one of the reasons for larger number of smaller sized shallow landslides.

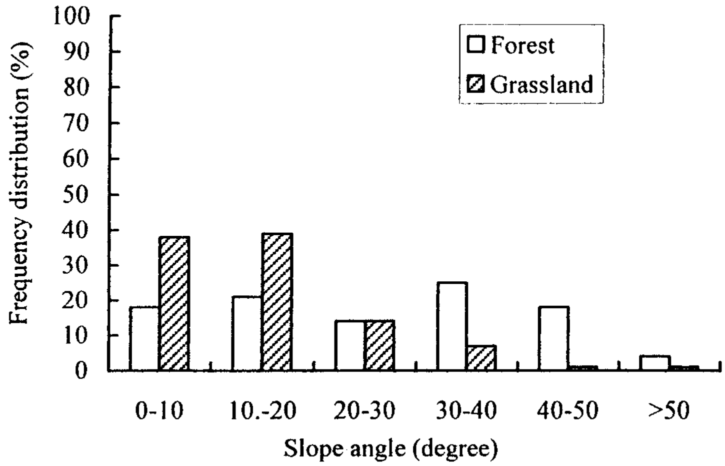
The general features of each individual soil layer as observed in 3 different sites are briefly stated in Table 2. The value of hardness for different layers was increasing downwardly. The perpendicular thickness of a particular layer also differs within the range of area. This might be due to the difference in erosion status and deposition of volcanic ash and other soil particles. A schematic view of a typical shallow landslide occurred in forest surface with its soil layers stratification is shown in Figure 4. In general the thickness of the top layer is relatively smaller than bottom layers. During sliding, the uppermost Ⅰ and Ⅱ layers were removed in most of the cases, but in a few cases it was observed up to Ⅳ layer too. The variation of some geo-technical properties of each layer as obtained from laboratory test is mentioned in Table 3. In general the lower layers are relatively less permeable in compare to uppermost surface layer. The water stored in the bottom layers might create the upward pressure and developed pore water pressure, which help to lower the soil strength. The development of an upward pressure may promote shallow landslide (Rogers, 1980).

The result of the surface soil collected from 5 different sample sites are shown in Table 4.

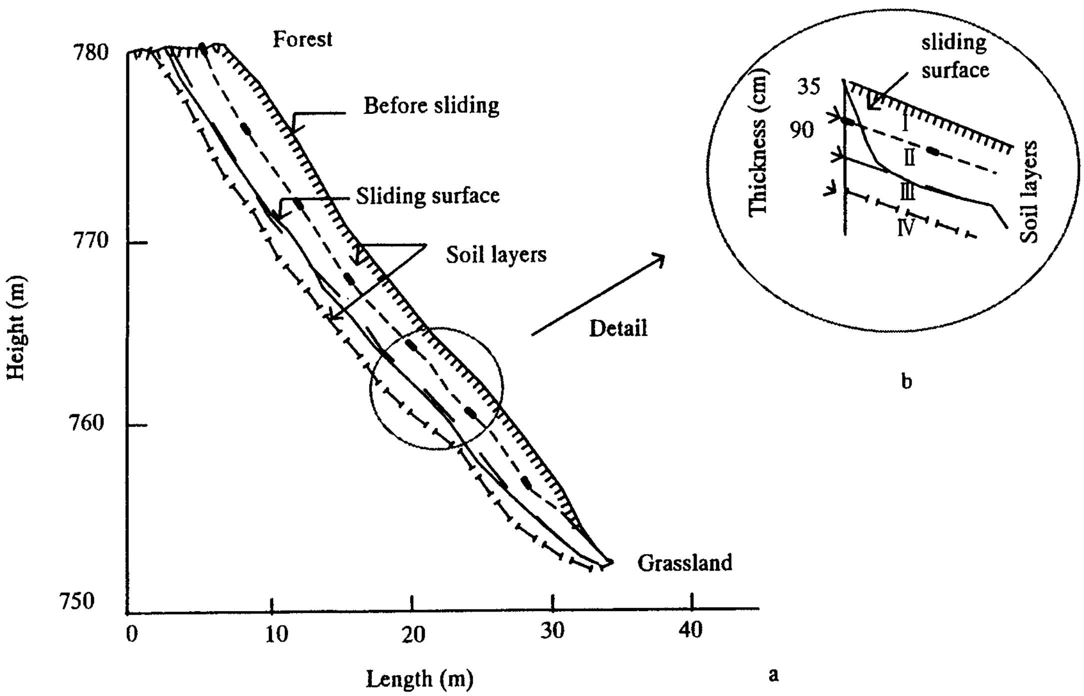
The Table shows that the internal friction angle has ranged in between 34^0 to 37^0 and has not shown marked differences in both surfaces while the average cohesion for forest and grassland were 9.1 kPa and 6.4 kPa respectively. The reason for this difference might be either due to effect of root hairs mixed in the soil mass or due to the difference in soil quality. The trees in steep forest slope are still in growing stage and height and diameter of trees are not fully developed. The root development and its influences are associated with stand quality. The soil properties might vary depending upon the source and deposition period. Due to this it might be difficult to point out the sole responsible factor for difference in cohesive nature. The sufficient data are intended to find the dominant cause. Here in this study the intention of slope stability assessment is to identify primarily the regions of relatively prone area based on a few sampled data where further detail study can be focused. The results of the stability assessment map in the form of relative frequency distribution of safety factor values in forest



Fig－２．Location of study area and shallow landslides



Fig－３．Frequency distribution of slope angles



Fig－４．Schematic section of a shallow landslide

and grassland surfaces are shown in Figure 5. The selection of the break points of safety factor values in the figure are just the subjective judgments to show the relative magnitude of stability indices, safety factor of the area. In grassland it has ranged from 0.94 to 8.47 while in forest it has been found in between 1.2 and 8.47. The cumulative frequency distribution of safety factor having value less than 1.5 in forest and grassland surface comprises about 43% and 10% respectively. The larger proportion of forest surface is under the moderately susceptible areas. The calculated values of the safety factors are not intended to be interpreted as numerically precise and are most appropriately interpreted as best compromise for indicating “relative” hazard of the area under the saturated condition of soil mass. Because the sample sites are limited and the sites might not be adequate to represent the whole area. The preliminary information obtained here might be useful to find the relatively homogeneous sites. The shallow landslides observed in the field were verified with the susceptible area of the prepared stability assessment map. This has shown that most of the shallow landslides have been found in the identified relatively susceptible area. During the field observation the slipped surface was seen mostly around the Ⅰ and Ⅱ layer in most of the

Table－１．Result of shallow landslide inventory

S.n.	Length (m)	Width (m)	Depth (m)	Area (m^2)	Volume (m^3)	Inclination (degree)	Land use type	Length/Width ratio
1	12	12	0.85	144	122	40	Forest	1.0
2	34	8	1.25	272	340	42	Forest	4.3
3	44	17	5	748	3740	30	Forest	2.6
4	13.7	14	1.5	192	288	36	Forest	1.0
5	8.5	8.0	0.95	68	65	40	Grassland	1.06
6	36	17	1.0	612	612	37	Grassland	2.1
7	4	5	1.25	20	25	34	Grassland	0.8
8	34	17	1.8	578	1040	39	Grassland	2.1
9	17	12	1.2	204	245	36	Grassland	1.4
10	19	14	1.3	266	346	38	Grassland	1.4
11	14	13	0.9	182	164	37	Grassland	1.1
12	14	12	1	168	168	38	Grassland	1.2
13	13	12	0.8	156	125	39	Grassland	1.1
14	12	14	1.5	168	252	38	Grassland	0.9
15	20	18	1.2	360	432	39	Grassland	1.1
16	10	9	0.8	90	72	36	Grassland	1.1
17	13	85	2	1105	2210	37	Grassland	0.2

Table－２．Salient features of soil layers

Soil layer	Thickness (cm)	Color Identified	Description
Ⅰ	20－40	10YR；2/1 black	This layer looks black due to accumulation of humus. The roots of both trees and grass species were seen penetrating this layer. This layer is relatively more permeable in compare to bottom layers.
Ⅱ	28－90	10YR；5/6 Yellowish brown and 10YR；4/4 brown	In few sites yellowish colored glassy materials was observed. The color of this layer was varied from yellowish brown to brown. This layer has lower permeability than uppermost layer. The thin shallow roots of trees and grass species were observed in this layer too.
Ⅲ	17－30	10YR；2/2 Brownish black	In some shallow landslides this layer was observed as brownish black and black color. Only few roots of grass species were seen in the layer. The thickness of this layer was smaller as compare to other layers.
Ⅳ	62	10YR；4/6 brown	This layer contains weathered volcanic soils and ash deposits. This layer was observed in the few shallow landslide sites only.

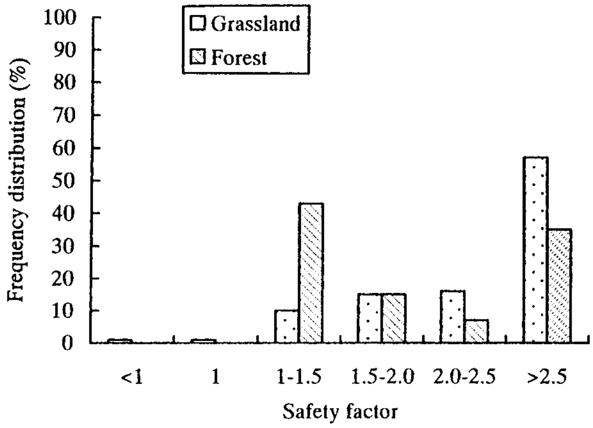
Table－３．Spatial variation of physical properties of soil layers

Site No.	Land Use	Soil Layer	Thickness (cm)	γ *sat* (gm/cm^3)
1	F	Ⅰ	20	1.4±0.05
		Ⅱ	65	1.45±0.0
2	F	Ⅰ	35	1.37±0.04
		Ⅱ	90	1.49±0.03
5	G	Ⅰ	40	1.56±0.05
		Ⅱ	55	1.58±0.15

F：forest G : grassland γ *sat* : density of soil at saturated condition

Table－４．Value of cohesion and internal friction angle of surface soil

Sampling sites	Land use	Cohesion (kPa)	Friction angle (degree)
F1	Forest	8.91	36
F2	Forest	9.36	35
G1	Grassland	6.64	34
G2	Grassland	6.27	37
G3	Grassland	6.49	35



Fig－５．Frequency distribution of safety factors

shallow landside sites. The lower permeability and cohesive nature of soil grains might be one of the reasons for development of slip surface. The effect of the rainfall on the properties of loosely bound surface soil layers and steepness of the slope have considered as the prime factors for shallow land sliding in the study area.

Ⅴ．Conclusion

The soil layer differentiation and their physical characteristics have shown variation. In most of the cases the slip surface lies in between Ⅰ and Ⅱ layer and found to vary spatially. The cohesion nature of soil was found to be scattered and sufficient date might be needed to conclude concretely. In the site the shallow landslides distribution was highly associated with the topographic steepness. This is one of the reasons for the concentration of maximum shallow landslides towards Ichinomiya side in compare to Namino village side. This study is the preliminary stability assessment of the area and based on basic information about the stability of the site and soil layer characteristics the detail focus on the interested sites can be carried out.

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