98 History of successive landslides in Furenai, Saru River Basin
(沙流川振内地すべり地の変動履歴)

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Introduction

An examination of the history of landslide is important, particularly in an area with a potential risk of slope instability which might provide a significant information for the design of remedial measures to reduce the risk to acceptable levels.

This paper attempts to clarify the chronicle of landslide, zonation of mass movement on landslide scar and estimate of sediment production by landlide by means of the interpretation of time-sequential sets of aerialphotos and field survey.

Study area

The study area is located in the middle reach of Saru River. This river flows from the Hidaka mountain range (Central Hokkaido) and ends in the Pacific Ocean. Most of the Saru River Basin is underlain by sedimentary rocks including metamorphic rocks of the Createous period, with sedimentary rocks of the Tertiary period distributed in the riversides of the lower reaches.

Dam ("Nibutani Dam") is being constructed in the lower reach of this river to control the flood and sediment from two main sources, namely, the upper reach of Saru River itself and the Nukabira River. Stream-side sliding due to heavy rainstorms temporarily occurred in many areas of this basin. Rotational slides frequently combine with flows in compound slides or with lateral spread, producing complex landslides.

Chronicle of debris avalanche

The time-sequential sets of aerialphotos were available for 32 years (1956-1988). It was recognized that landslide had occurred before 1956. The tree growth-rings analysis was insufficient to date the initial occurrence of landslide, no radiocarbon dating method was applied as well.

Prior to 1956, surface erosion predominantly occurred as a main type of slope failure. Deep-seated landslide also occurred partially particularly on the left slope (Fig. 1a). Through these processes, the accumulation of debris was formed on the foot slope.

Based on the air photo taken in 1963, deep-seated landslide was found to be the major process of slope failure. Most of the landslide debris occurred on mid slopes and coalesce into main channel directly. Little of deposit perched on the scar. The previous debris deposit on the foot slope was chiefly washed away by fluvial transport. The transport capability seems to exceed the sediment discharge from hillslope. The river valley was extremely widened by down cutting as bank erosion continued headward (Fig. 1b). Strong lateral erosion of the river induced the failure of foot slope. It was suggested that the successive storms in the summer 1961 and 1962 were the major sediment transporting events.

Landslide was estimated to have occurred again in 1966 during a single heavy rainstorm. Extensive deep-seated landslide toward the upslope site was found in the right slope (Fig. 1c). The north portion of the headscarp was recognized to have retreated about 12 meters. The previous gully developed deepening and expanding toward upslope site after a debris avalanche from the upper scar. Landslide debris moved downward and most of them deposited in the foot slope forming a talus cone as large 1500 square meter with several meters thick.

The headscarp subsequently enlarged and deepened after successive deep-seated landslide in 1970 and 1973 (Fig. 1d). The former intersecting discontinuity planes was rebuilt to be a steeply dipping continuity plane during these times. Gullies continue to be an important source in discharging colluvial soil generated from the upper scar.

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It was suggested that, due to the successive heavy rains in the summer of 1974 and 1975, landslides have repeatedly occurred and resulted in the enlargement of headscarp. The headscarp overtopped about 15 meters from the previous scar (Fig. 1e). The talus cone in the foot slope became larger and larger due to the debris delivery from upper scar.

Subsequently, major enlargement by deep-seated landslide was recognized to have occurred in 1981. This intense failure was considered to have occurred during the 1981 typhoon. Voluminous colluvium soil either from the new failure or from the landslide deposit perched on scars moved downslope and deposited in the foot slope. No major lateral erosion of river on this site seemed to have occurred. As large as 5400 square meter of talus deposit distributed widely in the foot slope, dammed partially the river channel.

Zonation of mass movement

The mass movement displays at least three definite zones, occurring sequentially downslope (Aipassa, M. and Shimizu O., 1989). The zonation is shown in Figure 2.

Firstly, the failure area as "A" is mainly located in the upper slope forming a concavity plane. During the successive failures, the slide mass rotated backward so that the slope of the upper surface of block was diminished, while the displaced soils formed a block which slipped down along parallel slip surface, leaving a sharp cliff on the summit of the main scar. In the area of the largest deep-seated landslide, the failure area might have reached an area of about 0.3 hectare with a 40 meters failure-plane length. Cliff became gradually steeper as the scar overtopped, dipping at an inclination of around 43 degrees. The steep-sided inner scar reached a maximum depth of 5 meters, and it consisted of 4 meters thick sandy soil and a meter thick of stratified gravels as an upper and lower layer, respectively. Deep gullies, swales and scarps were formed in this area. The larger deep-seated landslide, however, was considered to be the primary source of sediment.

Secondly, the earth-flow area is shown as "B". The landslide debris, which mostly consist of uncompacted clay fill, then moved downslope as a viscous mass, particularly on the steeper sites of the scar. In this area, many young invaded trees were displaced by the active flow which was generally accelerated by the increased water content on mass during heavy rains or by the thawing of snow cover. The displacement of colluvial deposit in this area was measured by installing several red-painted wooden stakes which were plunged vertically into the ground surface. Based on the measurement obtained for a one year period (1988-1989), the values ranged from 60 - 70 cm during the snow thawing and rainy periods (ground slope : 21 degrees). It was suggested that the displacement of colluivial deposit on this area could have been greater in the past decade during the heavy rainstorms. The maximum length of the earth flow area was about 80 meters.

Thirdly, the deposition area is shown as "C". The landslide debris was transmitted through the earth flow area and finally accumulated in the gentler slope that was located in the foot slope, forming a terraced-shaped talus, some of them dammed the adjacent channel. The displacement of landslide deposit in this area was relatively slower (4 - 6 centimeters) than that of the earth flow area. The maximum length of this area was about 40 meters with a 16-degree average inclination.

Landslide recurrence

At least 12 large landslides occurred in the 20-year period from 1961-1981. Most of the area of the previous landslide scar is prone to subsequent failure. The new failure occurs as the reactivation of loder phenomena. These phenomena might be most likely related to water concentration on soil and topographic condition. Some failures are initiated in partially filled hollows. These unchanneled swales are typically filled with a regolith of several meters thick. As a result of their subsurface topography, hollows concentrate abundant water, developing high pore pressures which can finally lead to failure of the soil mass. They might also be related to faults or cracks which were irregularly distributed among or on the older scar plane. These faults and cracks break the strata and accelerate the weathering process. Eventually, they provide a space for storage and movement of ground and underground water, which lead to failure.

Enlargement of scar by landslide

The expansion of headscarp and the extension of foot slope by the successive landslides is shown in Figure 3. The maximum length of the main scar was about 72 meters, being shorter than the former one. These might be caused by the intense lateral erosion of the river which washed out a large amount of either the previous debris perched in the foot slope or the debris produced during the landslides occurred in these times. Moreover, it was recognized that head scar did not overtop.

Subsequently, they became longer (92 meters) after landsliding during the single storm of 1966. This landslide caused the expansion of upper scar and the extension of foot slope. It was found that although the amount of landslide debris was smaller than that of the former (1961,1962), the area of talus in the foot slope was 6 times larger than the former one. The ability of fluvial transport was suggested to be insufficient to remove the voluminous debris from hillslope as fast as it has been discharged. As the result, accumulation of debris was built in the foot slope.

Expansion of headscarp and extension of foot slope were found during the successive heavy rains (1970, 1973, 1974, 1975). The latest occurrence of major landslide was in 1981. The headscarp retreated about 15 meters towards the uplope site. The total scar area after the latest landslide amounted 3.2 hectares. It had gradually been grown larger and larger since the first major enlargement particularly in 1970. Since 1981, no other major landslide was found.

Debris volume by landslide

The scar areas which were stripped by hillslope failures and the area of debris deposit which was located in the foot slope could be calculated well by means of the interpretation of time-sequential aerialphotos. However, the difficulty of determining the accurate thickness of the earth mass produced by landslide and of the debris deposition have been a continual problem in attempts to measure the volume of landslide debris.

Based on the field survey undertaken under present condition, it could be just assumed that earth mass produced by deep-seated landslide and surface erosion (includes shallow slide) might be similarly distributed with an average thickness of 3 meters and 0.5 meter, respectively. Consequently, the volume of landslide debris could be roughly estimated. Based on the recent field measurement, the thickness of landslide debris which accumulated in the foot slope was determined. The values ranged from 2.5 to 8.0 meters, averages about 5.2 meters.

Since the relation between the frequency of storm and of landslide was not well understood, the frequency of landslide could not be accurately assigned. Thus, the debris volume is considered to be the sediment production discharged by landslide ineternally over a studied period. The total debris production by successive landslide since 1961 was about 60,000 cubic meter. While half of this debris accumulated in the foot slope, some other still perched temporarily or permanently in the scar and entered the main channel.

Conclusion

The deep-seated landslide could produce large quantities of debris since they move with several meters sliding depth. This large quantities of sediment might be produced and transported episodically during major climatic events. On the contrary, shallow slides and creep, earth flow slides are persistent processes. These two processes cause the change of slope morphology.

Most of the subsequent landslide occurred repeatedly at the area of previous failure. They might expand by overtopping upslope or reactivate intensively at the same slope plane.

Reference

Aipassa,M. and Shimizu,O. : Landslide and its effects on channel morphology in forested drainaged basin. Proceeding of the International Symposium on Erosion and Volcanic Debris Flow Technology. Yogyakarta-Indonesia S32.1-9. 1989.

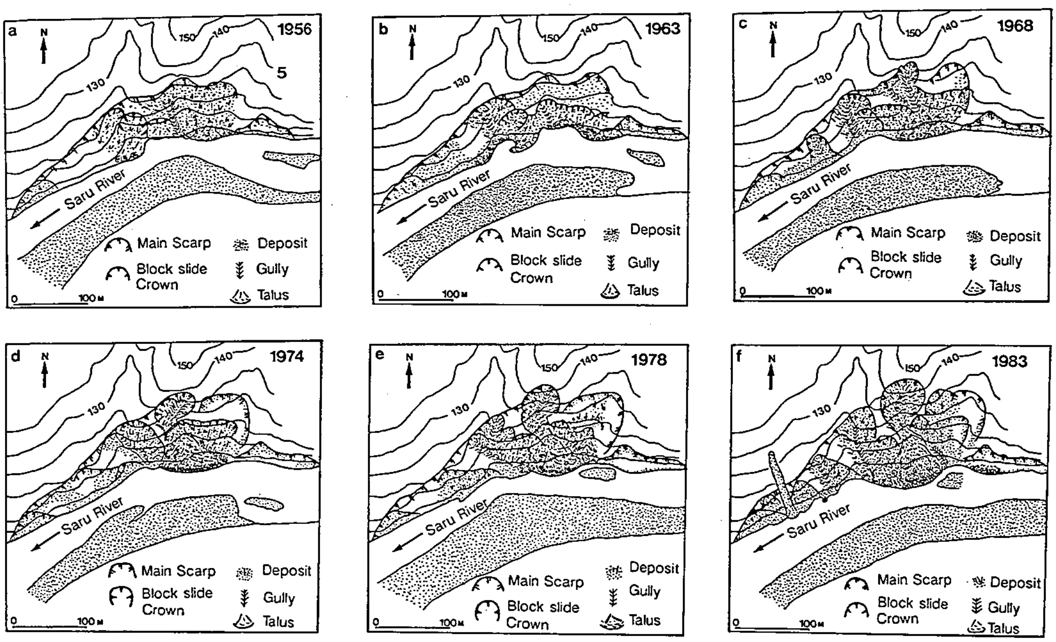

Fig. 1 Landslide scar based on the interpretation of the time sequential sets of air photos.

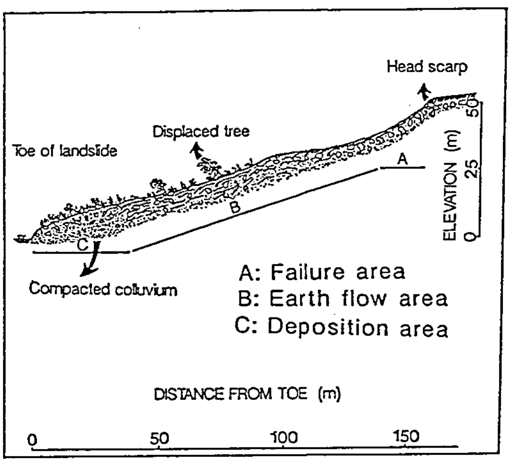

Fig. 2 Longitudinal profile of landslide scar, showing mass movement zonation.

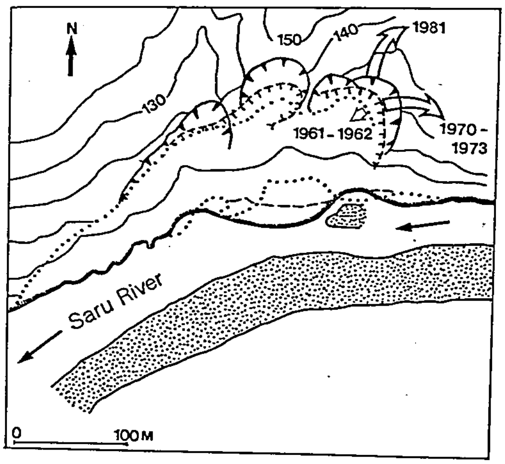

Fig. 3 Expansion of headscarp and extension of foot slope by successive landslide.