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Estimation of 3D features of slip plane based on landslide micro topography

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地すべり地形の諸特性を用いて3次元的にすべり面を推定するための基本的な考え方

濱　崎　英　作*

Abstract

The author likes to try to think how estimates the slip plane structure in 3 dimensional image without borings. The contents of this paper are summarized as follows.

(1) A landslide is a three-dimensional phenomenon. It is therefore important to read aerial photographs and topographic maps, imagining their three-dimensional appearance.

(2) A slip plane is assumed to be present at the landslide body boundary in the landslide topography. This assists deduction of a slip-plane structure to some extent from a landslide body boundary. For example, the contour of a cliff can be understood as the extension of a slip plane.

(3) Various phenomena such as cracks tend to occur at places where relative displacement - relative displacement rate varies, such as at a landslide body boundary. Places where a slip plane lies shallow are candidates for cracks because the relative displacement rate varies easily there.

(4) Various phenomena such as cracks, depressions, and lift ups, are also apt to occur at places where the traveling speed of a slide varies (the uneven part of a slip plane).

本報告では，詳細なボーリングなどを実施しない段階で，地すべり地形を構成する微地形を観察することによってスベリ面の構造を推定することを試みる．地すべりの形状とスベリ面の構造とは，相応する部分があり，この形状を理解して観察することで地すべりの3次元構造をリアルにイメージできるばかりでなく，ボーリングサイトを決定する筋道を示すことにもなる．以下に，本稿の要約を示す．

1. 地すべりは言うまでもなく3次元の現象である．したがって3Dをイメージしながら空中写真や地形図を読むことが重要である．

2. 地すべり地形の移動体境界部では，そこにスベリ面が出現していると考えられる．こう考えると地すべり地形の主要要素である移動体境界からスベリ面構造をある程度推定できる．例えば崖のコンターはスベリ面の延長としてり理解が可能である．

3. 移動体境界など相対的な移動量もしくは相対的な移動速度が変化する場所でキレ

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ツなどの現象が現れる．したがって，地すべり移動体の一部にスベリ面深度が浅くなった場所などでは移動速度が変化しやすく，キレツが出現しやすい．
4．スベリ面に凹凸がある場合，その変化部ではスベリの移動速度が変化するためキレツや陥没，隆起などの諸現象が起きると考えられる．

Key words: *Landslide, Landslide topography, Slip plane, 3D structure, Moving Velocity*

1. Introduction

A landslide is a three-dimensional phenomenon. It consists of three elements called a “landslide body” and a “landslide main scarp or a separation scarp”, and also a “slip plane (surface)”. On the occasion of a landslide disaster, we start urgent investigation. It is needless to say the first purpose of investigation grasps the substance of a landslide. Above all, probably, presumption of a landslide slip plane is a problem of the utmost importance. This paper aims at presuming the structure of a slip plane from the form of surface topography.

Miyagi et al. (2005) systematically classified the micro-topography of the Ohokamizawa landslide, and investigated correspondence of stress field on the ground surface, shape of slip plane, and the materials of landslide body from states of fragments in borehole cores. Results showed excellent mutual correspondence, so that the comparative analysis demonstrated quantitatively that an intimate causal relation between surficial micro-topography of the ground surface and slip-plane. Watari (1975) conducted statistical analysis of a landslide configuration and structure, and presupposed a constant relationship between landslide width (W) and thickness (Depth:D). Recent studies (e.g., Ueno 1997; Hamasaki 2007) verified that the W/D ratio is able to explain by the relation of the lateral ratio and the degree of stability. Consequently, it is indicated that the lateral constraint effect in landslide motion is not negligible. These studies suggest which has been commonly used in Japan such as conventional stability analysis based on the two-dimensional cross-sectional shape might yield invalid result when evaluating landslide stability. Consequently, many researchers today admit the necessity for three dimensional stability analysis.

Items that are necessary to elucidate and evaluate the stability of a slope are considered. We can propose the following four items at this point: (1) 3 dimension features of slip plane - the configuration of a landslide; (2) physical properties of a slip plane and landslide body - two material properties that constitute a landslide; (3) pore water pressure distribution (groundwater pressure distribution) - trigger of a landslide; and (4) stability analysis model (equation) - analysis tool. The “(1) slip plane structure” built by a landslide motion is the clearest proof of all. Determination of this structure is regarded as the most important approach. Moreover, “(2) Physical properties of a slip plane and landslide body”, and “(3) distribution of pore water pressure" are important to clarify the mechanism of landslide motion. However these items are effective only on the premise of a correct slip plane configuration. It is not until (1)-(3) are fully elucidated that "(4) stability analysis model (equation)" becomes applicable. Nevertheless, a safety factor is often assumed automatically in practice when planning immediate measures at the scene. This safety factor is based on the important premise that "a slide occurred because the safety factor was less than 1," when a landslide has actually taken place. Accordingly, stability analysis parameters c and ϕ are used as terms for determination of an inverse operation equation. This causes little difference between a simplified method and an exact method. It is only an urgent response to conduct stability analysis backward from the fact of having slide. If it is permitted to accumulate and analyze status of controlling factors logically, then it is considered reasonable to "analyze the slip plane structure of a landslide" first, and "elucidate the structure of the whole landslide" based thereon, to promote the most rational stability analysis.

Three-dimensional modeling of a slip plane is important, as described above, but few reports describe the methodology in fact. For example, the "Method of Deducing the Shape of Landslide Slip Plane" (Research Institute of Civil Engineering, 2013) explains a method for estimating feature of slip plane from the characteristic of surface displacement measured of a landslide. However, even such a proposal of latest technology in Japan makes no reference to three-dimensional modelization. A landslide is a three-dimensional phenomenon, and it is imaginable that flanks and lateral configuration greatly affect the characteristics of landslide motion. Consequently, it is a natural consequence of development in science and technology to assume that "three-dimensional analysis becomes common" in the near future.

Aerial photographic interpretation was adopted in the 1960s by geomorphologists in Japan. Efforts have been undertaken by many researchers and engineers to elucidate the three-dimensional characteristics of landslide phenomena. This history was reviewed by Miyagi and Hamasaki (in press), so this paper focusses on the framework of a procedure "to comprehend a shape formed by a landslide, to explore the initial structure of landslide body, thus provide in the most reasonable evaluation of slope stability."

Viewpoints on discussion are the following: 1) a premise is that landslide topography is extracted from aerial photographs or contour maps and the contour is shown; 2) the contour is assumed to have been formed as a result of direct motion of a landslide; and 3) these premises conclude that topographic features recognized as a cliff is classifiable into two categories: those with and without an exposed slip plane. These points include views based on the author's experience of promoting three-dimensional modeling for many landslides.

This article specifically examines modeling of slides observed by the initial field investigation after the occurrence of a landslide. Then this article presents a discussion of a procedure to infer a 3D slip-plane featured in the head, flank, and toe parts and landslide body surface based on the fact that the peripheral boundary of a landslide is identifiable as a part of exposed slip plane without boring exploration. This study is based on the premise that a landslide body micro-landform shows a sign that implies its characteristic internal structure.

Regarding the so-called "deep sheeted landslide" accompanied by formation of a slip plane, compilation of 1:50,000 Landslide Distribution Maps by NIED and various projects hosted by the Japan Landslide Society, its Tohoku branch, its Hokkaido branch, and even international collaboration with Vietnam or Croatia, all aim at the comprehension and reactivation risk assessment of landslide topography. Since landslide risk assessment was first advocated (Miyagi, 1991), the authors have promoted the study on estimation of slope stability that each landslide topography is inherent using various landslide topographic features.

Landslide motion itself is movement to stabilize a unstable slopes. It serves as an opportunity for the subsequent motion. A landslide is a mass movement that breaks a slope. The landslide topography is formed as a result. This landslide topography further causes the subsequent movement. Such a process is designated collectively as an autonomous destructive process of the landslide topography (Miyagi 1991; Miyagi et al., 2004). It is considered reasonable that the topography reflect landslide motion for each stage of a landslide activity. Comprehending principal elements that constitute landslide topography, i.e., main sliding scarp, separation scarp, landslide body, and slip plane, is to understand the actual conditions of three-dimensional development of a landslide. It engenders more reasonable stability analysis. Additionally, it is presumed to provide hints to landslide engineers, about the matter such as "If only a single geological drilling is allowed for exploration, which location should be selected ?", or "If no boring exploration is possible, how can a slip plane be presumed?"

2. Displacement Late of landslide, and Formation of Slip plane

At first, landslide phenomena are discussed from viewpoints of a displacement field and traveling speed because it is assumed that this displacement rate are viewpoints related directly to the formation of a surface of rupture by a landslide.

Fig. 1 shows the modeled displacement zones constituted by a landslide body and the neighborhood of a slip plane. This is a visualization of the relation of a landslide body with little deformation, a shearing-deformation prevails zone, and an stable layer, based on the concept of "landslide observation method by creep well" introduced by Fujita (2000). Such a slip plane or slip zone exists underground, even though the deformation thickness of each landslide might differ. The bottom part of moving body of Fig. 1 visualizes displacement for the travel distance of each soil particle. Soil particle markers (filled) in this figure are stuck together and not separated initially (lower right), but each particle gets isolated completely as the landslide body is pushed forward and displacement progresses through elastic deformation - plastic deformation - shear fracture (lower left). Fig. 2 depicts the development of cracks in the early stage of a landslide. Progress of deformation of a landslide body keeps encouraging Riedel shear zones and conjugate Riedel deformation band shear zones. If a landslide body consists of brittle lithofacies, rough and irregular cleavage fracture surfaces might be dominant, whereas if they are argillaceous and ductile, slip planes with smooth and gloss surfaces might prevail. It is noteworthy that there occurs fundamentally no crack in moving body above the slip zone because no relative displacement is attributable to a uniform displacement rate.

Fig. 3 presents a schematic figure of the underground displacement for each landslide type. The landslide cross sections are shown: a rock slide on the top, a weathered rock slide, a debris slide in the middle, and a clayey soil slide in the bottom. A displacement model chart was attached to the right of each figure. Because a rock slide is mostly occurred as a primary landslide, the slip zone itself is thin. The landslide body travels as a whole, although the slide zone of a debris slide is thick. Regarding a clayey soil slide, most landslide bodies have become plastic, and the whole body makes up a slip zone.

Empirical observations of how these are reflected to phenomena seen on the ground surface reveals that micro topography, such as cracks, level differences, lift up, and surficial

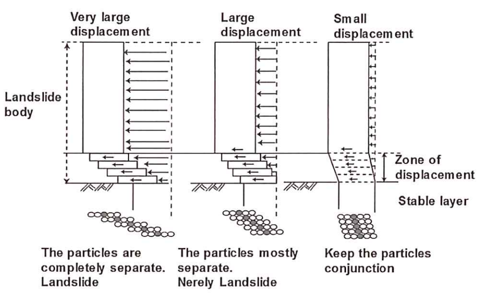


Fig. 1. The image of the deformation by creeping at liner plates wall of well in the landslide area. A series of deformation from the weak creeping to the shear destruction.

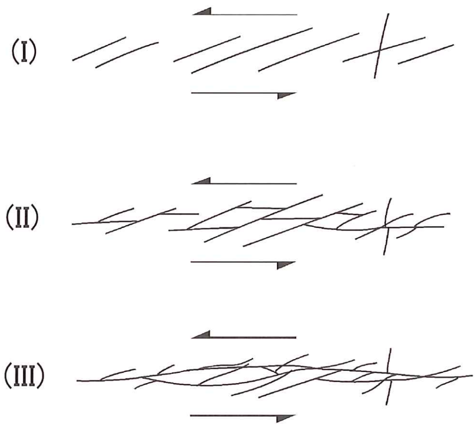


Fig. 2. The development of the slip plain by landslide. (After the Civil Engineering Research Institute, 2007)

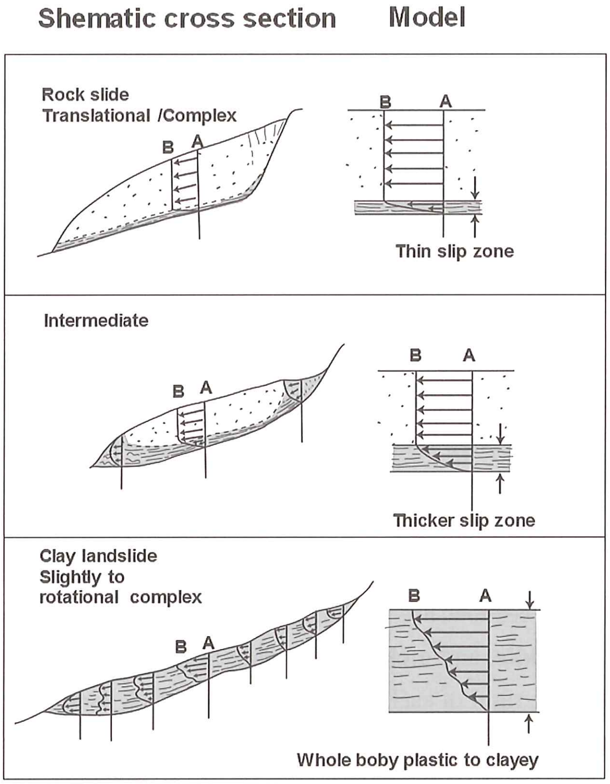


Fig. 3. The images of the slip plain or slip zone in landslide by type.

failure tend to appear easily in places near the shear zone of a landslide and where a slip plane reaches the ground surface. This suggests that cracks are apt to occur over the whole landslide body because of the small distance from the ground surface to the slip plane and a close slide zone, when the in a shallow landslide depth is shallow. In other words, a slip plane lies shallow where cracking phenomena prevail on the ground surface. Figure 4 is a flow chart indicates that the relative displacement rate between the interior of a landslide body and a landslide body boundary is closely related to landslide phenomena which appear based on the discussion presented above. This figure demonstrates that the shape of a slip plane dominantly determines the relative displacement rate at a landslide body boundary (relative velocity between the stable layer and a landslide body boundary). In addition, the physical properties of a slip plane control relative displacement rate. Moreover, the physical properties of a landslide body act as other factors that control the fracture mode of a landslide body. It occurs quite often that tension and compression features occur alternately at a location where a slip plane is convex, even within a single landslide motion, as shown in Figure 5. Such repeatedly occurrence the tension and compression phenomena in one

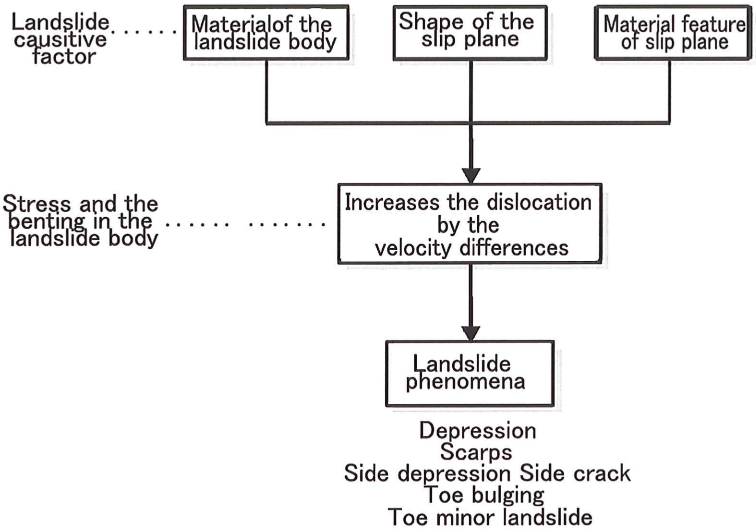


Fig. 4. The process of the landslide actualization and the related phenomena. In relation with the boundary of landslide body, the contributing factor of relative velocity in the landslide body.

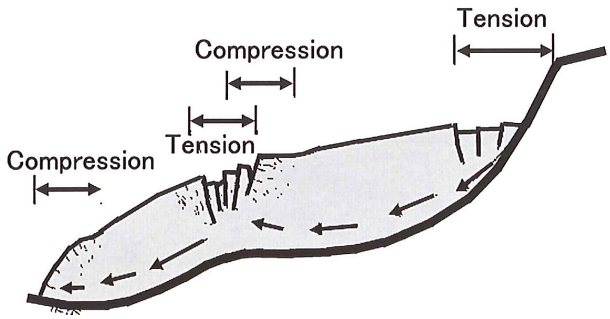


Fig. 5. The image in relation between the velocity of moving and the surface displacement controlled by slip plane form.

landslide body, which might be exist the "A convex profile" at slip plane in a landslide body. This incident will be recognized with the differences of relative displacement at some locations in the landslide body as follows; the moving speed is reduced at Loc. B, D. So that compression occurs at that position, although the speed is increased down at Loc. C. Because of the local change of slip plane gradient. Therefore, tension takes place, and a landslide body is decelerated gently. Thus the compression increases again at the toe. Such a case is often observed.

The moment of landside disaster at Kosei landslide moving in 1983, such complex distribution of tension and compression features appears.

Such a difference in displacement rate might be generated if there is a resistance zone in physical properties as well as a slip plane gradient. For instance, some phenomena might occur by which a landslide body rotates horizontally because either flank has difficulty in sliding when physical properties are not uniform.

It is noteworthy that even if a clayey soil slide once in the past brought about a fine partial phenomenon inside a landslide body, if it was later covered with a hard layer by volcanic origin, then the movement mechanism might have been altered (Fig. 6). Accordingly, if a ductile object such as a clayey layer is covered using a brittle object like thick volcanic materials, then the stress state inside a landslide body is expected to be renovated. At this time, the original thin landslide body is forced down and changed to a gigantic body that moves like a rock slide. This can be regarded as returning to the initial layer of a rock slide again, based on the development of a rupture surface, as shown in Fig. 6. Consequently, it might be designated as "rejuvenation." There are many such examples, such as in the Tohoku district, as the Dozangawa landslide (Yamashina *et al*, 2004), the Hirane landslide (Abe *et al*, 2002), and the Aratozawa landslide (Hamasaki *et al*, 2009).

A base rock is fundamentally vulnerable to tension. Accordingly, a tensile crack occurs in a zone covered when the early stages of a slide are initiated from a fragile layer in the

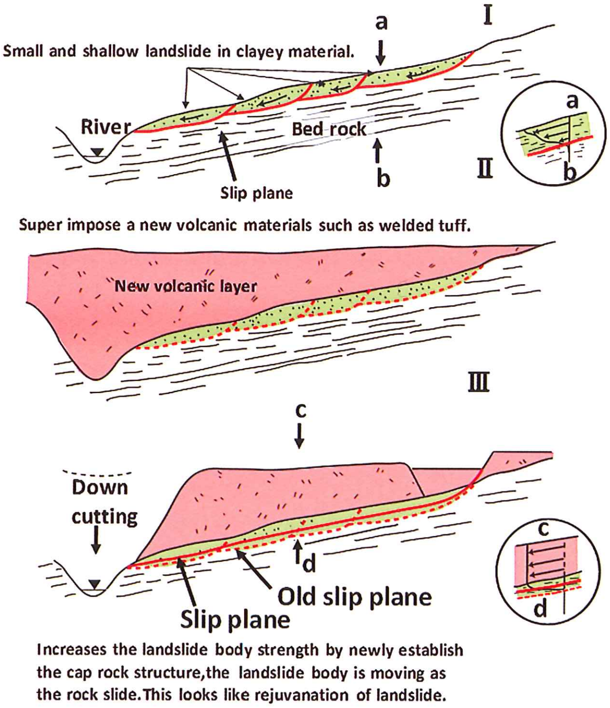


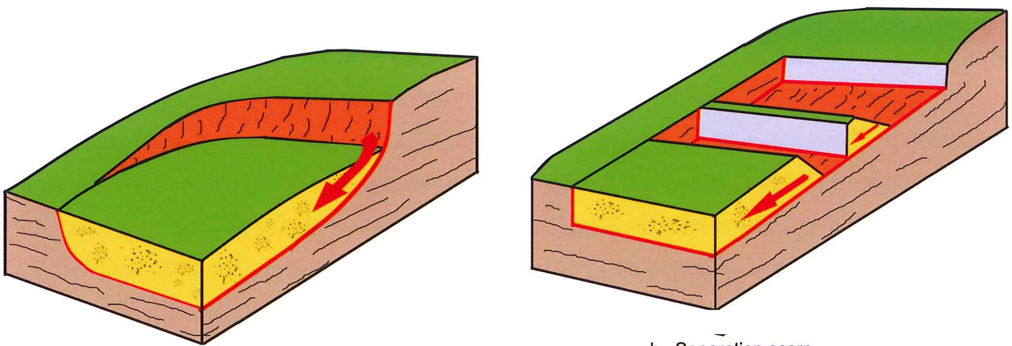
Fig. 6. Rejuvenation from the clayey viscous landslide to rock slide.

depth of a landslide body. This tensile crack often takes a shape projected as an arc on a horizontal plane. This is presumably due to the fact that true volcanic rocks accumulated over a short time commonly have uniform physical properties: it is hypothesized that a stress applies uniformly to the slip direction and arc-shaped cracks and that depression occurs like a rotational slide taking place in uniform banking.

3. Points of Emphasis for Each Part of Landslide Slope

Figure 7 shows a schematic diagram by Suzuki (1982) as an example that indicates characteristics of the landslide typically, to understand systematically the relation between landslide movement and the deformation topography and characteristics of slip plane. Here are listed important viewpoints for understanding a landslide by three-dimensional view by combining observation of aerial photographs and topographic maps and strategic field reconnaissance survey.

It is necessary to begin with defining the boundary of a landslide body (zones of depletion-accumulation) from an stable areas as a prerequisite. Identification of this boundary line is the most important because "the boundary of a landslide body" is an important phenomenon in which "a slip plane appears on the ground surface explicitly." First, this landslide body boundary is split into three parts. The implication of each shape is analyzed and used as a hint for slip plane estimation: many symptoms that engender deduction of the motion mechanism of a landslide are represented in these parts. This boundary is classified as (1) landslide head, (2) landslide flank, and (3) landslide toe in this article, and the characteristics of each are illustrated as follows. Next, (4) the ground surface of a landslide is specifically addressed. Information in connection with physical properties



a Sliding scarp
(Main scarp is a part of slip plane)

b Separation scarp
(Main scarp is not a part of slip plane)

Fig. 7. Schematic illustration of typical landform at crown part in landslide. Red colored is the part of slip surface by shear cracks Brown colored is part of separation surface by tension.

and slip-plane depth is expressed in this part, and some portion thereof is visible in cracks and a deformation structure that appears on the ground surface of a landslide body. Strategic comprehension and understanding of them shall be linked with the presumption technology of "the thickness and structure of a landslide body."

(1) Landslide head

There is usually formed a sliding scarp and separation scarps which is indicated as depression zone in the main failure region at a landslide head, with schematic diagrams depicted in Fig. 7. The sliding scarp, a) fundamentally presents an arc shape (horseshoe shape), and the relative height of the sliding scarp is the greatest in the central part and decreases gradually toward the flanks. In this case, the plane of the sliding scarp can be understood to be nothing but a slip plane. Contour lines drawn near the landslide boundary at the head are the greatest hints for presuming a slip plane. It is necessary to observe directions, such as those of scuffing, carefully in the field survey. Separation scarps of rectilinear feature, b) accompanied by a great depression might be formed at a head. A principal scarp formed uppermost at the mountainside is a cliff formed by the movement of a landslide body, but is not a slip plane. It is a cliff pulled apart from the landslide body, and is a plane separated by tension. This cliff is not the trace of the slide. Consequently, it is inappropriate to call it a sliding scarp, but it should be designated as a separation scarp. In such case, the scratch of slip plane of the side sometimes appears under a separation scarp.

A motion mechanism presumed from this head scarp topography and depression topography is rotational sliding for a) a sliding scarp and translational sliding for b) a separation scarp.

(2) Landslide flank

Figure 8 presents a horizontal projection of the flanks of a landslide, and Figure 9 shows a cross-sectional view of a landslide corresponding to Fig. 8 and the schematic diagram of the relative-displacement rate (This figure is not necessarily typical. Because a landslide phenomenon ordinarily presents the complexity, anisotropy, and asymmetry of a geologic structure, asymmetry might be observed, even on a cross section). Capturing a flank as the extension of a slip plane as in the case of (1) landslide head helps drawing the contour lines of a slip plane: if the gradient of a side cliff (flank) is steep, then a slip plane is also assumed steep; and if it is a gentle slope, then the surface of rupture is also regarded as existing in a gentle shape. Moreover, fracture and deformation phenomena, such as cracks and bulging, are easy to be observed on the ground surface at a flank with shallow slip-plane depth. This figure particularly suggests that "a slip plane lies shallow when a tension crack tends inward." Depression might occur at a flank. This case suggests that the principal axis (the central axis of movement) of a landslide lies inside the appearance position of depression.

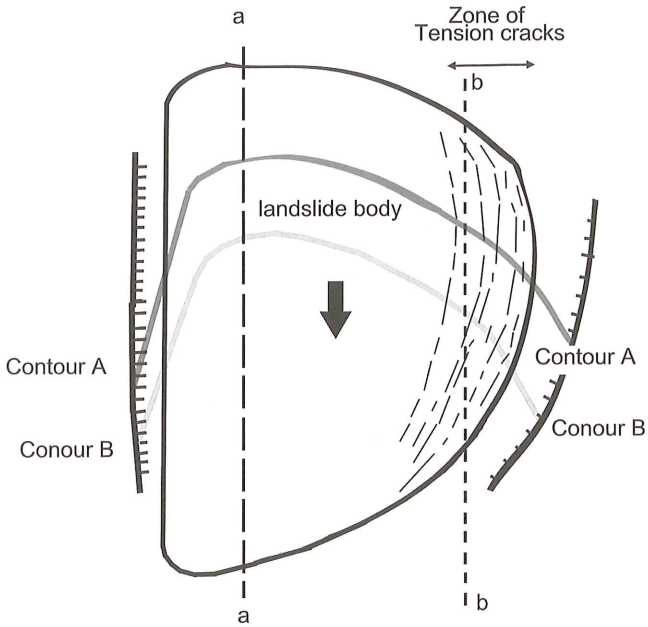


Fig. 8. Basic images in case of asymmetrical landslide.

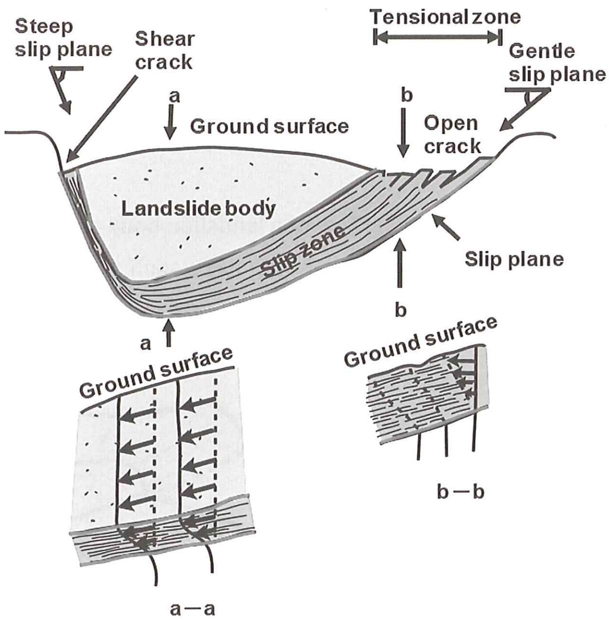


Fig. 9. The images of the cross section of asymmetrical landslide and the possibility of relative velocity at the part.

If depression is observed on both flanks, it is likely that a slip plane lies deep at a broad depression zone according to the relation between a depression width and a slip plane depth described in (1).

(3) Landslide toe

Figure 10 depicts a simple schematic diagram of a toe configuration. A landslide body is stopped if it reaches the mountain side or collides with the opposite bank. Then a compression fold – pressure ridge is formed or the landslide is uplifted or tilts greatly toward the mountainside. Cracks might be oriented to intersect normally or to be parallel to the direction of the landslide.

A landslide with a toe on the riverside is easy to collapse at the toe. A slip plane might be exposed on the ground surface on such an occasion, examination of a cliff surface is important.

In most cases, when a slip plane appears on a cliff surface, the toe of a landslide body of a past landslide is left at the middle of a river valley wall by river erosion as depicted in Fig. 11. The rupture surface was exposed on the toe cliff facing the river; from which the moved materials fell into a river in the Dozangawa landslide(Yamashina, 2004).

The toe movement is smaller than that of a head in many landslides. Especially in such a case, compression is observed at a landslide toe.

(4) Landslide body surface

Typical micro-landforms ordinarily observed as earth surface phenomena in a landslide body include minor sliding scarp, depression, slight projection, tilt, compression wrinkles, and cracks.

Little deformation of the ground surface of a landslide body occurs in translational slides with uniform displacement. For example, standing trees such as trees move upright without falling in many cases. In the Aratozawa landslide in case of the 2008 Iwate Miyagi Nairiku

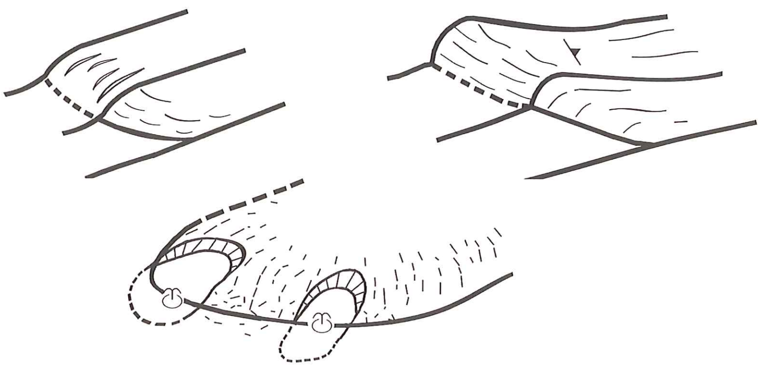


Fig. 10. The schematic image of the toe of landslide.

Earthquake, a part of landslide body of a 500-m square traveled no less than 300 m without being accompanied by large deformation (Hamasaki, 2009). Nevertheless deformation and fracture of forests or roads was limited. A rotational slide is accompanied by tilting motion, which also tilts trees. Furthermore, trees incline confusedly and micro-landforms such as cracks and depression are densely formed if a slip plane lies shallow as described in Chapter 2. A clayey soil slide with high fluidity might yield flow marks, hummocks, and separated mounds appear after moving, and a pond often appears in a depression of a landslide body.

(5) Relation between landslide depth (D) and landslide width (W)

Table 1 reproduce the schematic diagram of landslide clod and the relation between the planer feature and depth of a landslide, respectively, compiled by Research Institute of Civil Engineering (2013) based on Ueno (1997), for example. Here are focused onto length (L) and depth (D) (thickness from the earth surface to the surface of rupture). Nevertheless, care should be taken in using these data because the Express Highway Research Foundation (1985, on Table 1) has pointed out a large variance in these values.

A W/D ratio of 3–11 would cover any case, in spite of slight deviation according to references. Nevertheless $W/D < 5$ is regarded as a fairly special example. It is considered that a W/D ratio of 5–10 is reasonable for spontaneous landslides based on the experience of the author, and it practically settles in the range of 5–8 in most cases.

Three-dimensional stability analysis by RBSM revealed that the lateral constraint of a landslide body decreases when W/D is around 8–10 (Fig. 12). This is regarded as a limit when a landslide body does not spread but moves as a whole. This value should not be applied simply as it is at the real scene, but physical properties verified by on-site observation should be regarded together. For example, this value for matters with high stiffness tends

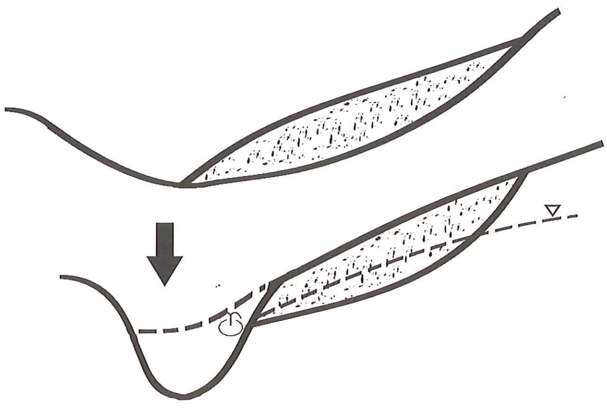


Fig. 11. The schematic cross section of the exposes slip plane at valley side slope according with the river down cutting erosion.

Table 1. The relationship between the morphometric feature of slip plane and the depth in landslide. (After Research Institute of Civil Engineering , 2013)

Reference	Depth & Width (W/D)	Length & Depth (L/D)	Remarks
Highway Research Board, Japan (1985)	5.5–7.0	6.14 (avarage but large SD)	Statistic analysis data based on the landslide disasters by road construction.
Watari & Kohashi (1987)	7–10 (in avarege)	–	Statistic data based on the 100 cases of natural landslide disasters
Ueno (2001)	3.0–10.7	2.8–19.2	Statistic data of natural disasters and disasters at the roar side cutting slopes. There is no large differences by geology. The small figure of L/D: Mainly controlled by geological structures. The large figure of L/L: Mainly the landslide body which consist of claeyey or debri s type materals
Ground Technology Assoc., Hokuriku 8ranch (2004)	4.0 (in approximate) (W=5.377 × D^{0858})	3.0–5.0 (in approximate) (L=1.075 × D^{1381})	Statistic analysis data of 24 cases at the cutting slope in Neogene sedimentary roch. In cases of the weatherd one: the correlation getting poor of W and D.

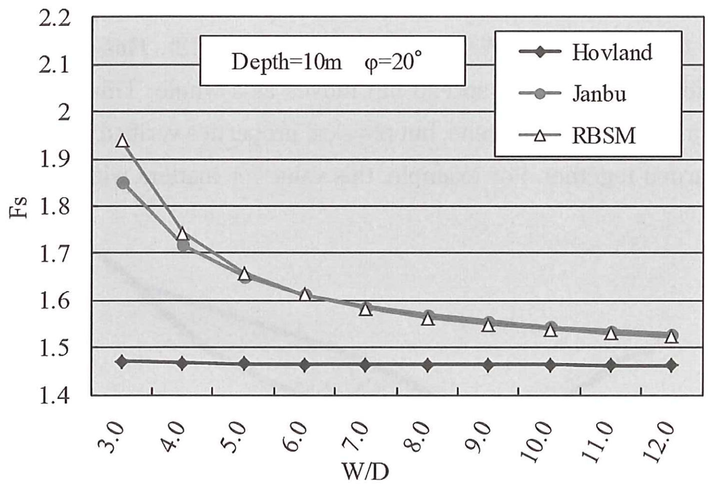


Fig. 12. The relationships between the ratio (w/d) of width (w), the depth (d) and related safety ratio (Fs).

to deviate from the range above because the behavior of such materials depends on the physical properties and structure of geological boundaries (Hamasaki, 2006).

There are unusually great values of W/D in references in Table 1. Although the source of these values is unknown, it is noteworthy that the value of W/D is influenced by the definition of the range of movement of a landslide. For example, a clayey soil slide might exhibit a large width as the whole, although it is an ensemble of small slides.

4. Conclusion and recommendation

4. 1. Summary

The contents of this paper are summarized as follows.

(1) A landslide is a three-dimensional phenomenon. It is therefore important to read aerial photographs and topographic maps, imagining their three-dimensional appearance.

(2) A slip plane is assumed to be present at the landslide body boundary in the landslide topography. This assists deduction of a slip-plane structure to some extent from a landslide body boundary. For example, the contour of a cliff can be understood as the extension of a slip plane.

(3) Various phenomena such as cracks tend to occur at places where relative displacement - relative displacement rate varies, such as at a landslide body boundary. Places where a slip plane lies shallow are candidates for cracks because the relative displacement rate varies easily there.

(4) Various phenomena such as cracks, depressions, and lift ups, are also apt to occur at places where the traveling speed of a slide varies (the uneven part of a slip plane).

4. 2. Remaining issues

This article is concluded with descriptions of two remaining issues.

The first issue is already described in Chapter 1. The present three-dimensional model introduced into this article is applicable only for fresh landslides soon after occurrence, so that all the discussion presented above might not apply to every landslide recognized according to its freshness or stage of evolution: the older a landslide is, micro-landforms get subdued to have roundish edges. Accordingly, the measured cliff surface contour lines of a head or flank tend to give a shallower slip place than the real condition. Careful examination is indispensable in such a case; estimates should be made deeper on the safe side as a whole, while using a depth/width ratio (D/W) as an experiential value. The more aged the landslide to be examined is, the more comprehensive judgment is required, considering the importance of a target, making full use of neighborhood geological surveys, boring explorations, and elastic wave examinations.

Another issue is that a landslide often moves in a configuration that differs from its past movement, or not the whole slide area but only a part of it moves as a process of dividing, even though a landslide is sure to slide again easily. Especially a clayey soil, which slides with weak physical properties, is apt to form a slip plane easily and to move slightly even by a small stress change. Accordingly, a deterministic analysis that assumes a slip plane on the deepest position is not necessarily reasonable. Particularly, the closer to a clayey soil slide and the more fracture of a landslide body progresses, the more non-uniform behavior inside a landslide body becomes, so that displacement difference occurs everywhere. Then distortion appears and various phenomena such as cracks and deformation occur at the places of such displacement difference.

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References

Abe. S., Satou. K., Takahashi. A., Higaki. D.(2002): Slope evolution Processes of Landslides around the Quaternary Volcanoes in the Tohoku district, Japan A. - Case Study in the Surrounding area of the Hijiori caldera, Yamagata Prefecture -: Landslides-Journal of the Japan Landslide Society, **38**, 310-317. *

Fujita, T. (2000) *Outline of landslides for training tool*: The training text for landslide disaster prevention engineer. Vol. 1. **

Hamasaki, E., Takeuchi, N., Ohnishi, Y.(2006) Development of simplified discrete limit analysis for three-dimensional slope stability problem: Landslides-Journal of the Japan Landslide Society, **42**, 389-397 *.

Hamasaki, E., Yamashina, S., Ohno, R., Esaka,F . and Yamasaki, T. (2009) Study on Development of Aratozawa Landslide by Three Dimensional Slope Stable Analysis used by Simplified RBSM: Proceedings of the annual conference of Japan Landslide Society, **48**, 203-209. *

Inokuchi,T. (1988) Landslide Topography of the Sumikawa Landslide: Landslides-Journal of the Japan Landslide Society, **35**, 11-20 *

Japan Landslide Society, Technical committee of terminology in geomorphology and geology of landslide ed. (2004) *Terminology and understanding of the landslide geomorphology and geology*. **

Japan association for applied geology (2000) *Geomorphic engineering of mountain*: Sangaido. **

Japan technical survey association (1984) *Handbook of landslide investigation by aerial photograph* Kashima Publishing Company. **

Miyagi, T.(1991)Risk evaluation of landslide topography by landform classification. Proceedings of "Symposium for the identification of the hazardous landslide area": Japan Landslide Society,

Okinawa. 1–5. **
Miyagi, T., Prasada, G. B., Tanavud, C., Potichan, A. and Hamasaki, E. (2004)Landslide Risk Evaluation and Mapping -Manual of Aerial Photo Interpretation for Landslide Topography and Risk Management-: Report of National Research Inst for Earth Sciences and Disaster Prevention. **66**, 75–137.
Miyagi, T., Hamasaki, E., Hayashi, K. and S. Uchiyama (2005) The linkage of the micro topographic features, the characteristics of movement and the materials in landslides: Proceedings for conference of Japan geographical society. **56**, 99. *
Miyagi, T. and Hamasaki, E. (in press) Risk evaluation of landslides and the micro topography: In *Micro topography in geography*, Kokon Shoin. **
Oyagi, N., Ikeda, I. (1988):Landslide Structure and Regional Perspective on Sumikawa Landslide at Hachimantai Volcanic Area, Northern Honsyu Japan: Landslides-Journal of the Japan Landslide Society, **35**, 1–10 *.
Oyagi, N. (2007) Air-photograph interpretation for analysis on landslide structures: NIED-Library Series **1**, 1–316. *
Research Institute of Civil Engineering (2013) *Presume method of landslides cross profile*: Kashima publishing company. **
Sasaki, I. and Araya, T (2000) A Study on Three-dimensional Shape of Sliding Surface and Movement Feature of Sliding Mass: Journal of Japan Landslide Society, **37**, 32–41 *
Tohoku Regional Office of the Forest Agency (2014) The technical committee report of countermeasure strategy of Douzangawa landslide area, No.1, No.2, No.3. **
Ueno, S. (1997) Prediction of a Landslide by Means of a Topographic Geologic Investigation: Soil mechanics and foundation engineering, **45**, 5–8 *
Watari, M. and Sakai, A. (1975) Logic and the basic field reconnaissance in Landslide disaster prevention: Research report of Civil Engineering Research Institute, Japan, No. 1003. pp.70. **
Watari, M., and Kobashi, T. (1987) *Landslide and Slope failure the forecast and countermeasure*: Sangaido. 41–46 **
Yamabe, K., Marui, H., Yoshimatsu, H., Yamamoto, S. (2010) Landslide dam in Higashitakezawa and Terano area formed by Mid Niigata Prefecture Earthquake: Landslides-Journal of the Japan Landslide Society, **47**, 349–360 *
Yamashina, S., Asano, S., Suzuki, W., Oono, Y.(2004) Slip surface of the Douzangawa landslide occurring in the area of pyroclastic flow plateau: Landslides-Journal of the Japan Landslide Society, **41**, 317–318 *

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