LANDSLIDE ANALYSIS BY DIFFERENT TIME PHOTOGRAMMETRY

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ABSTRACT

Mass movement of the ground in a landsliding area can be detected by photographs taken at different time. Change of three-dimensional position of objects on the ground is used for analysis of the landslide. Based on the assumption that the deformation of the landsliding mass is very small compared with the slid distance of the mass, mathematic model and analytic procedure are constructed. The 3-dimensional displacement (3DD) vectors of the ground objects are obtained by their positional data measured on the different time photographs. The 3DD vectors projected on a map give the information of slid direction and distance of the mass movement. Inspecting the variation of individual distance between neighbor points on the photographs, the landsliding mass group is distinguished. The 3DD vectors projected on a vertical plane parallel to the main direction of landslide are used to presume the depth and shape of the under-ground slide surface. Complicated solid shape of the slide surface can also be analyzed in this manner.

1. INTRODUCTION

As an applicable study of the symposium, real time imaging and dynamic analysis,the analytic system treating the landslide problems is proposed. Aerial photographs taken at different time flight is valid to detect the displacement of surface points on the ground suffered from the landslide. The following information can be produced by the analysis of the three dimensional positional data procured by measurement of the different time photographs :
1) velocity and direction of the landsliding mass;
2) boundary of destructive and dangerous field;
3) depth & shape of underground slide surface.
To provide rapid and reliable information of these items is very important and necessary for planning the measures of prevention and/or reduction against the landslide disaster. Delay of the information results in enlargemenmt of the disastrous field. It is noted here that without the aerial photogrammetry, we have no rapid, safe and effective means to obtain the above information. In the following chapters, analytic procedure to obtain the landslide information is briefly described. Application of the procedure is shown to a landslide occurred in Japan.

2. ANALYTIC PROCEDURE

2.1 Basic Data Acquisition

2.2.1 Fright on the Landsliding Area : The first flight must immediately be performed if an omen of landslide is discovered. The next flight can be planned after a considerable movement of objects on the sliding ground is confirmed. Because the displacement of an object is detected by variation of its 3 dimensional coordinate values measured on the photographs taken at first and next flights, and the variation must enough be larger than the error of photogrammetry (Yoshizawa, 1991).

2.2.2 Tracking Point : The tracking points are used to obtain the 3DD-vector (three dimensional displacement vector) of the landsliding ground. They are selected and placed on the images of various ground objects, such as corner of house, boundary point of farm, top of outstanding tree, etc., recorded in the photographs. They must be confirmed in all photographs taken at different time. Variation of three dimensional coordinate values detected between two photographs, taken at different time, is treated as numerical component of 3DD vector of the tracking point. Thus basic data for landslide analysis can be prepared.

2.2 Examination of Landslide Characteristics

2.2.1 Behavior on Topographic Map : The 3DD vectors projected on a map is effectively used to observe the landslide behavior related with fractural phenomena such as head scarp, toe bulge, developing fissures etc. (see Fig.9). In this way, we can understand the landslide characteristics with the consideration of extensive topographic, geographic and geologic conditions. This examination is important for subsequent procedure of landslide analysis.

2.2.2 Behavior on Vertical Projection : The 3DD vectors of tracking points are projected on a vertical plane parallel to the main direction of the landslide. The inclination of each vector predicts the slope angle of underground slide surface, i.e., if the deformation of landsliding mass (fissured earth block) is very small compared with the displacement of the mass, the inclination of 3DD vector on the mass is approximately parallel to the slope angle of underground slide surface. Observing the entire vectors on the vertical projection, shape of underground slide surface can also be predicted. That is to say, the landslide is considered as a phenomenon that many fissured earth blocks overlying on the main slide surface move downward, governed by gravity, keeping a condition of consolidated group, and hence, the variational feature of inclination of consecutive vectors predicts the underground geometry of the landslide (Yoshizawa,1992).

Dynamic characteristic of landslide is classified into rotational, translational and complex types of ground movement. Considering the shape of underground slide surface on a vertical projection parallel to main direction of the slide, it can be said that the rotational slide has a shape just like a part of circle, the translational slide has flat curved or polygonal shape, and the complex slide shows combination of various shapes. If the landslide is rotational, the mass is sliding on the circular surface, so that the inclination of vectors changes gradually ; from steep at head region to gentle (sometimes negative) at toe region. The translational slide has almost parallel vectors in majority region of the slide, but in the vicinity of head or toe rigion, rotational behavior appears in several vectors. The colmplex slide shows unconformable inclination of consecutive vectors. In this case, we can treat the slide surface as an aggregate of various curved and plane surfaces. On a vertical projection, the shape of complex slide can be analyzed by combination of various straight and circular line elements.

2.3 Presumption of Underground Slide Surface

The authors have proposed the following analytic methods for presumption of geometric shape and lying position of slide surface beneath the landsliding area (Yoshizawa and Miyazawa,1992).

2-Dimensional Analysis

Method(1) Analytic geometry method by concentric circles
Method(2) Least square method for concentric circles
Method(3) Least square method for polynomial curved line
Method(4) Polygonal curve fitting to arbitrary shape
Method(5) Connection of many kinds of circles or curves

3-Dimensional Analysis

Method(6) Curved surface fitting by polynomial function
Method(7) Combination of various types of curved surface
Method(8) Combination of slide lines in many projections

In the 2-dimensional analysis, the shape of slide surfcace is presumed by curved or polygonal line elements on a vertical projection plane parallel to the main direction of landslide movement. In the 3-dimensional analysis, the shape of slide surface is presumed by curved surface,polyhedron or their combination. Basic concepts of these methods are illustratively described in the figures below, but because of the limitation of paper's volume, many analytic equations are omitted.

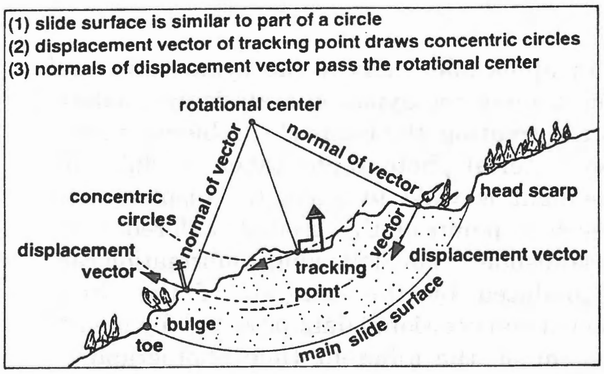


Fig.1 Rotational Slide with Circle [1] (Method 1)

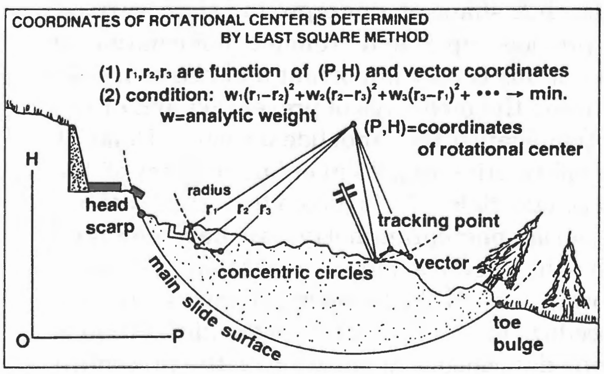
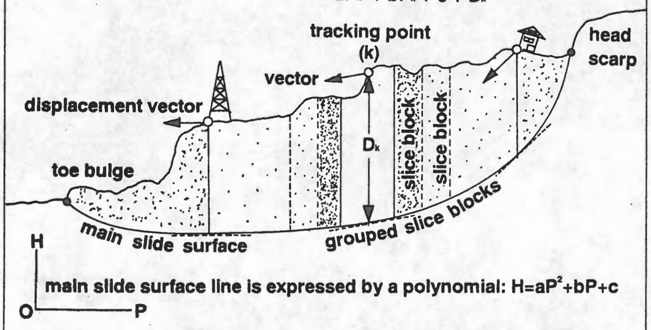


Fig.2 Rotational Slide with Circle [2] (Method 2)

- MAIN SLIDE SURFACE IS PRESUMED BY POLYNOMIAL EXPRESSION
- LEAST SQUARE METHOD GIVES THE PARAMETERS OF POLYNOMIAL AND DEPTH OF SLIDE SURFACE UNDER EACH TRACKING POINTS

$$H_k = aP_k^2 + bP_k + c + D_k$$

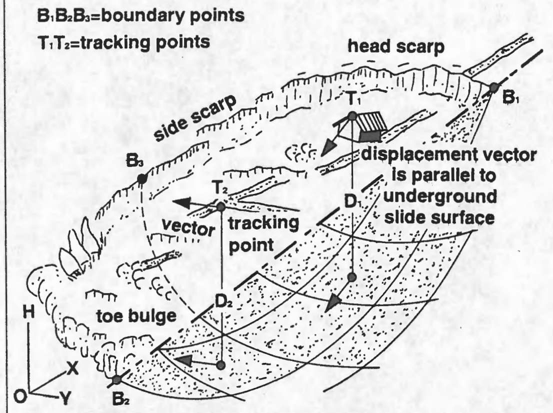


(1) translational movement of many grouped slice blocks is assumed
(2) basic condition: (deformation of a block)<<(movement of the block)
(3) therefore: depth of slide surface under a point (k) is kept constant
(4) elevation of tracking point (k) is given by : $H_k = aP_k^2 + bP_k + c + D_k$
(5) least square method determines the parameters a,b,c,and D_k, D_{k+1},•••

Fig.3 Slide Surface by Polynomial Curve (Method 3)

SLIDE SURFACE IS PRESUMED BY POLYNOMIAL FUNCTION

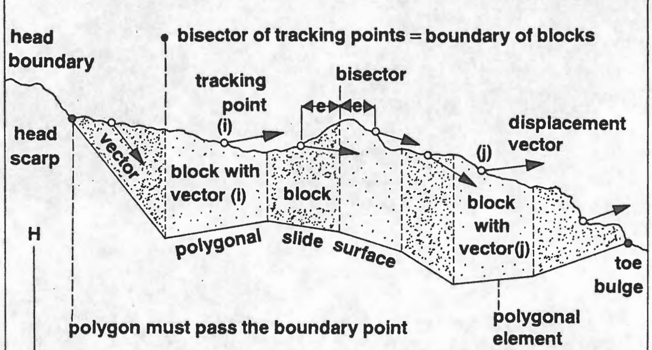
$$H=AX^2+BY^2+CXY+DX+EY+F$$



- A,B,C,D,E,F and D_1,D_2 are determined by least square method
- data for analysis are positions of B_1,B_2,B_3 and vectors of T_1,T_2

Fig.6 Surface by Polynomial (Method 6)

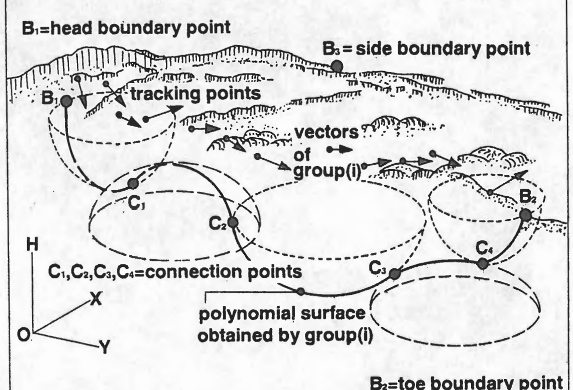
- SHAPE OF MAIN SLIDE SURFACE IS APPROXIMATED BY POLYGON
- IRREGULAR OR DISCONTINUOUS SLIDE SURFACE CAN BE SHOWN



(1) bisector of distance of adjoining tracking points bounds the blocks
(2) displacement vector shows movement of the block on slide surface
(3) shape of underground slide surface is represented by polygon
(4) inclination of polygonal element is parallel to the ground vector
(5) shape of polygon is adjusted by boundary conditions

Fig.4 Slide Surface by Polygonal Shape (Method 4)

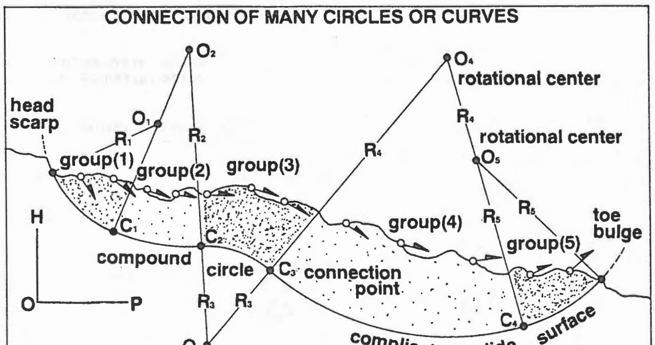
COMBINATION OF CURVED SURFACES BY GROUPED POINTS



(1) tracking points are grouped by degree of their connection
(2) surface by polynomial function of each group is obtained
(3) all surfaces are partly combined by boundary conditions

Fig.7 Combination of Surfaces (Method 7)

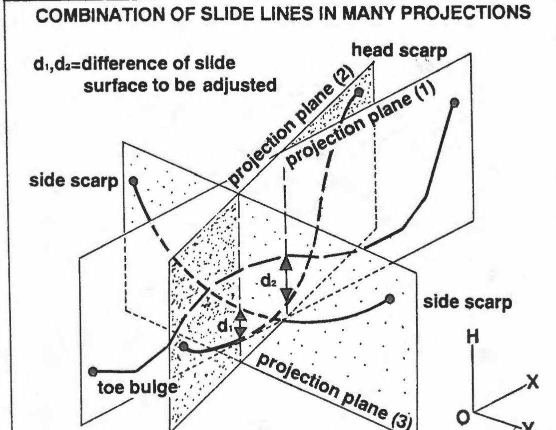
CONNECTION OF MANY CIRCLES OR CURVES



(1) tracking points are grouped by degree of mass movement
(2) rotational center of each group is obtained (see Fig.1 or Fig.2)
(3) circle elements are connected considering boundary conditions

Fig.5 Connection of Circles or Curves (Method 5)

COMBINATION OF SLIDE LINES IN MANY PROJECTIONS



(1) projection planes are set in many directions of slide area
(2) slide line on each projection is obtained by Fig.1,2,3,4,or 5
(3) depth of slide is determined at crossing point of slide lines
(4) weighted least square method is used to this determination

Fig.8 Combination of Slide Lines (Method 8)

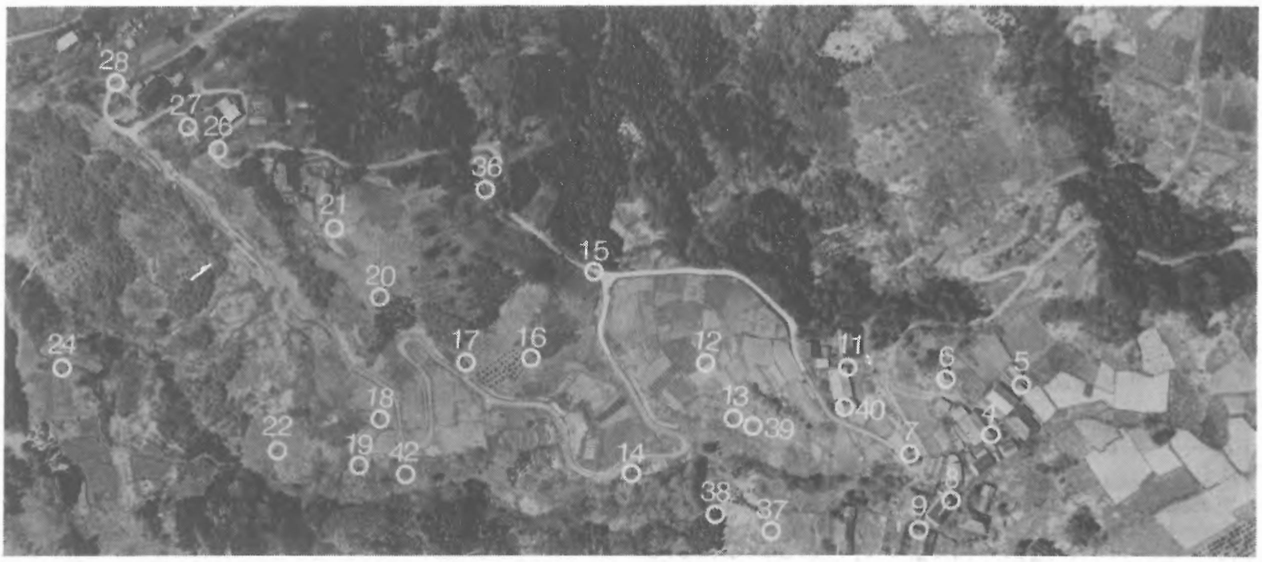


Photo 1 Before Landslide Occurrence (Narao area,Nagano Prefecture,Japan / Photo:Apr.26,1975)

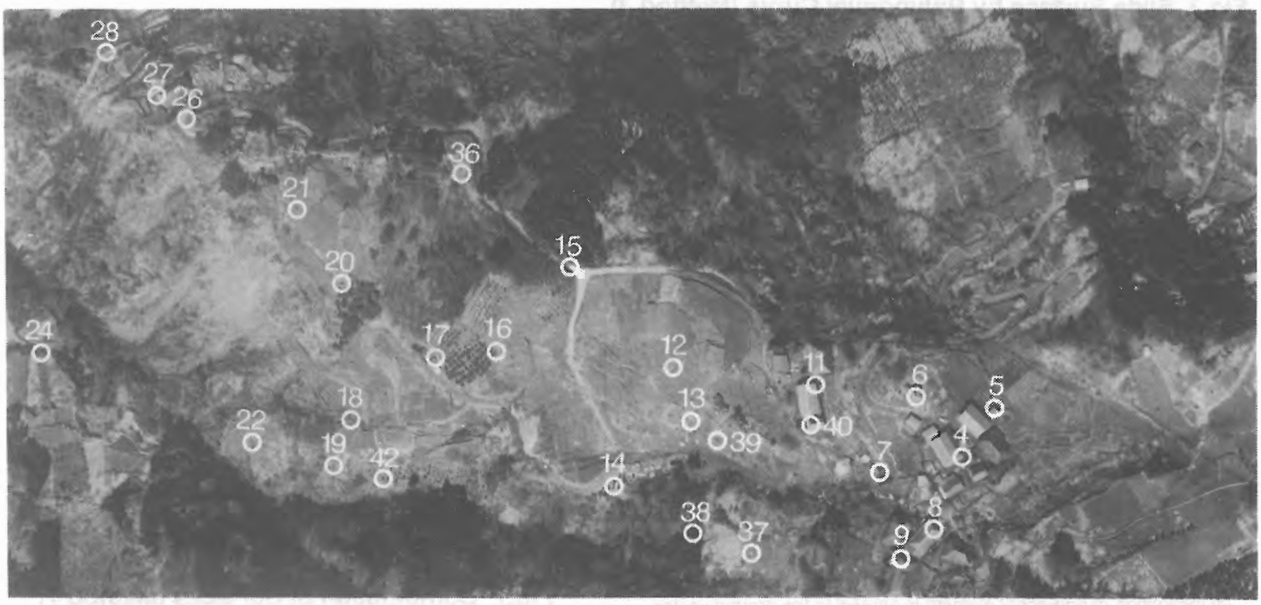


Photo 2 Ground Feature of Landsliding (occurrence of landslide:Oct.6,1976 / photo:Mar.29,1977)

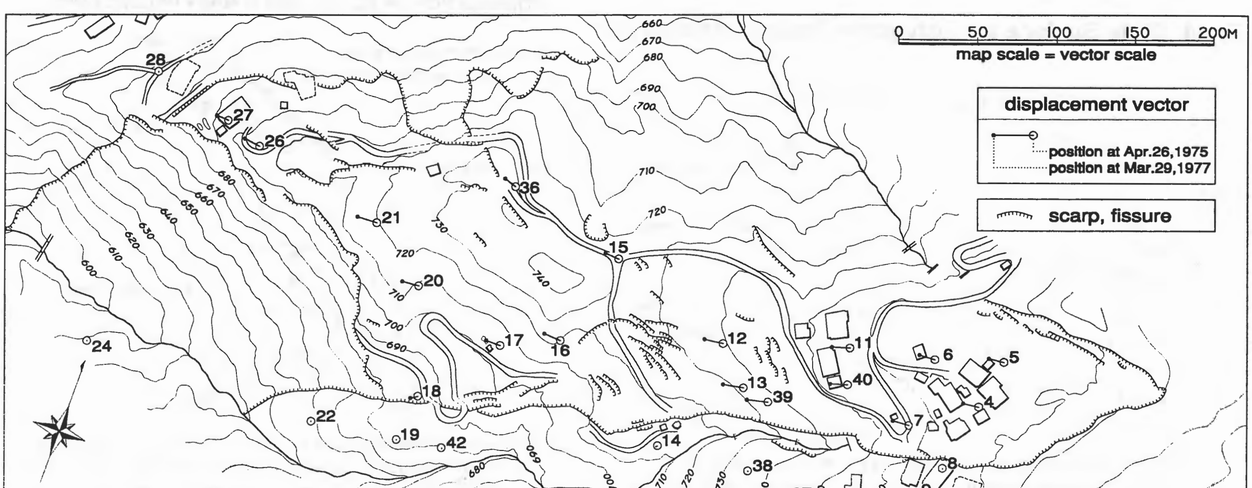


Fig.9 Topographic Map / Displacement Vectors of Tracking Points / Ground Fissures and Scarps

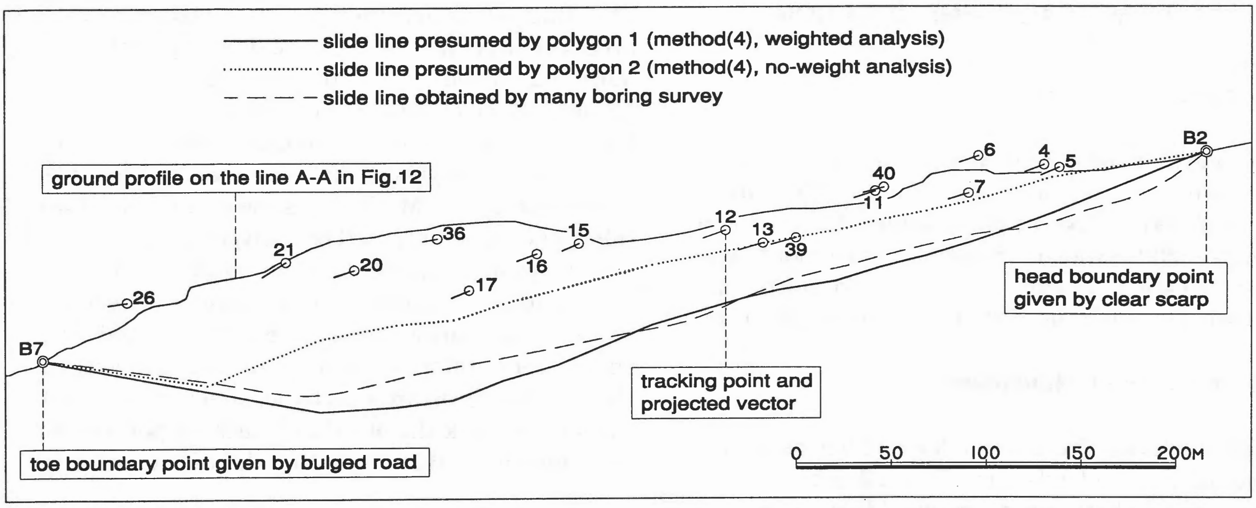
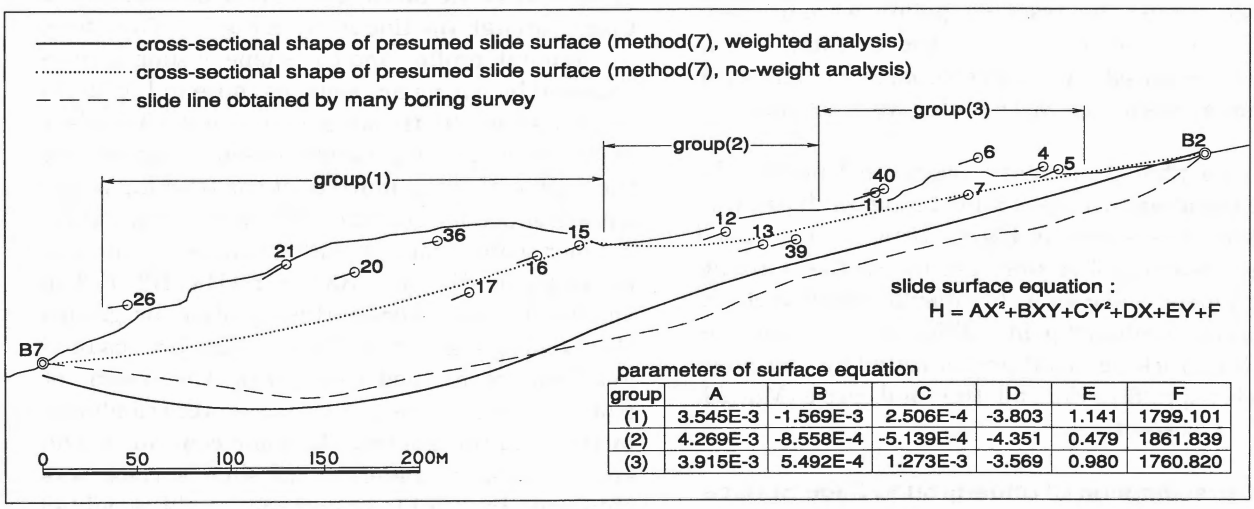


Fig.10 Shape of Underground Slide Surface Analyzed by Polygonal Curve Fitting (Method 4)



parameters of surface equation

group	A	B	C	D	E	F
(1)	3.545E-3	-1.569E-3	2.506E-4	-3.803	1.141	1799.101
(2)	4.269E-3	-8.558E-4	-5.139E-4	-4.351	0.479	1861.839
(3)	3.915E-3	5.492E-4	1.273E-3	-3.569	0.980	1760.820

Fig.11 Cross-section of 3D Slide Surface Obtained by Combination of Many Surfaces (Method 7)

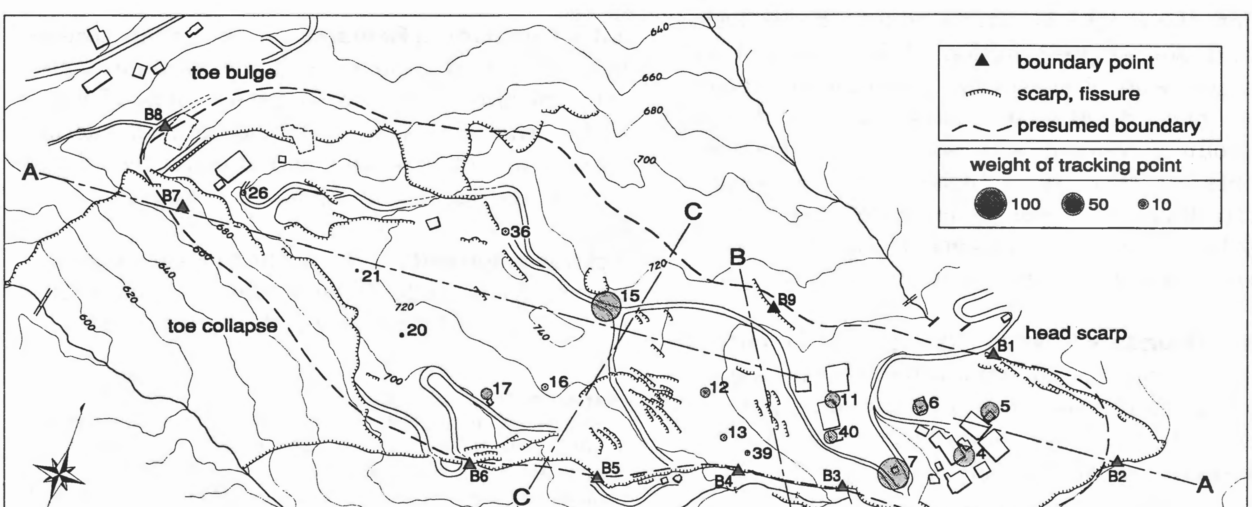


Fig.12 Weight of Tracking Points Used in Analysis / Presumption of Landslide Boundary Line

3. PRACTICAL EXEMPLIFICATION

3.1 Narao Landslide

A large landslide suddenly occurred at Narao, northwestern area in Nagano prefecture, Japan, on Oct.6,1976. Extent of the landslide was 800m (length)×200m(width). Seasonal movement was repeated about 7 years. The ground movement exceeded horizontally 20m and vertically 15m.

3.2 Detection of Movement

Photo 1 shows the ground feature before occurrence of the landslide, and Photo 2 after the occurrence. In both photographs, identical ground objects were stereoscopically detected as shown in the numbered white circles. In the center of white circles, the tracking points were pricked. 3-dimensional abscissas of the tracking points were measured by stereocomparator. Thus, the components of the 3DD vector were obtained.

By the photogrammetry taken on Mar.29,1977, the topographic map of landsliding condition was obtained as shown in Fig.9. Long scarp,grouped fissures,and broken road are noticeable. Ground movement is shown by the displacement vectors. At each numbered point, different time positions of the tracking point are indicated by the open circle (Apr.26,1975), and the solid circle (Mar.29, 1977), respectively.

3.3 Presumption of Underground Slide Surface

3.3.1 Weight of Tracking Point : To consider the reliability of positional data of the tracking point, the weight is introduced into the analysis of slide surface presumption. It is evaluated by the precision of surveying, deviation of vector from main direction of mass movement, degree of group movement with surrounding tracking points, etc. Discussing these items, the weight of tracking point was determined as shown in Fig.12. The weight of each tracking point is shown by area of the circle.

3.3.2 Boundary Point : The ground boundary between moving and immovable parts is judged by field reconnaissance or precise photograph. In Fig.12, the boundary points used in this analysis are shown by dark triangle marks.

3.3.3 2-Dimensional Analysis : Fig.10 shows a vertical projection parallel to main direction of the landslide. The ground profile is drawn along the line A-A in Fig.12. The shape of underground slide surface has been precisely surveyed by many field boring continued more than 5 years. The broken line in Fig.10 is a reliable shape of slide line obtained by the boring. Using the 16 vectors of tracking points shown in this figure, analysis of slide line presumption was attempted by the Method(4) shown in Fig.4. Two solutions were obtained by polygon 1 (solid line) and polygon 2 (dotted line) as shown in Fig.10. The solid line shows good coincidence with the broken line (boring survey). But the dotted line shows very different shape. In the analysis of slide surface presumption by least square method the former took the weight of tracking points into consideration. But the latter did not consider it.

3.3.4 3-Dimensional Analysis : Fig.11 is a cross sectional shape of three dimensional slide surface presumed by the Method(7). The cross-section is taken through the line A-A in Fig.12. Therefore, the ground profile and the shape of slide surface obtained by boring are same as those in Fig.10. In this analysis, 16 tracking points and 9 boundary points shown in Fig.12 were used. Considering the degree of group movement,the tracking points were grouped by the line B-B and C-C in Fig.12. 3 dimensional shape of each group was obtained by the form : $H = AX^2+BXY+CY^2+DX+EY+F$. The values of parameters in this equation for groups (1),(2)&(3) are shown in Fig.11. They are result of least square method considering the weight of tracking points. These 3 surfaces were combined by the conditions of boundary and continuity, and entire shape of underground slide surface was obtained. In Fig.11, importance of the weight of tracking point is clearly demonstrated just like the case of Fig.10.

3.3.5 Concluding Remarks : As an applicable field to the real-time imaging and dynamic analysis, the analytic system for presumption of slide surface was proposed. The different time aerial photogrammetry is safe and effective technique for monitoring and analysis of the landslide.

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