Application of discontinuous deformation analysis in prediction analysis of natural dam formation by landslide

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The movement of the landslide was simulated in DDA, and the rock property was estimated when the debris of the landslide form the natural dam in the valley. It is confirmed that the landslide is considered to begin to move when value of the cohesion of the block joint is under 10 KPa and value of the frictional angle of the joint is less than 20 degree. These calculated properties of the joint agree with the general value of the joint of the landslide on this site. In addition, the velocity and the mode of movement of the landslide are examined. As a result, it is caught that the movement of the landslide began from the lower block and spread to the upper block gradually. DDA is useful to examine the sensitivity analysis of the landslide movement.

Keywords: DDA; Landslide; Natural dam; Sanbagawa metamorphic belt; Japan

1. Introduction

When a landslide, situated on a valley side slope, slides downward, the valley is filled up with the debris. As a result, the lake which is created by the natural dam appears in the upper area of the dam. If the natural dam collapses, a debris flow occurs in the downstream and damages the downstream area. Therefore, the countermeasure to the landslide along a river is very important in order to maintain a river system. Although detailed investigation of the landslide are needed to draw up the countermeasure to the landslide, the numerical analysis about the activity conditions of the landslide is significant to draw up the plan of the countermeasure to the landslide (Takeuchi and Hamasaki, 2001). From the above view points, we tried sensitivity analysis by using Discontinuous Deformation Analysis (DDA) (Shi and Goodman 1984) in order to examine the factors which lead to the formation of the natural dam by landslide. There are few examples which solved a landslide problem in DDA (Hamasaki and Sasaki 2004).

2. Study site

Study site is located in Sanbagawa metamorphic belt, which is composed of green-schist and black-schist of Mesozoic, on Shikoku Island in Japan. Many landslides occur in Sanbagawa metamorphic belt because the surface rock of this area is deep weathered (e.g., Terado, 1986). In recent years, these landslides are sliding at heavy rain.

The target slope is located in the valley side slope where many landslides are found. We select a section of the slope for this study because the section of the slope has not been slid yet. The surface part of the rock has been sheared due to intense crushing and subsequent deep weathering. The average angle of the slope is 19°. The scale of the landslide is considered to be 550 m long, 200 m height, if the slope collapses. Slip surface of this landslide is thought to exist about 50m depth from surface of the slope (Fig. 1).

The difference in elevation from the valley bottom to the road is 15 m. The town exists downstream from the spot where the natural dam formation is expected.

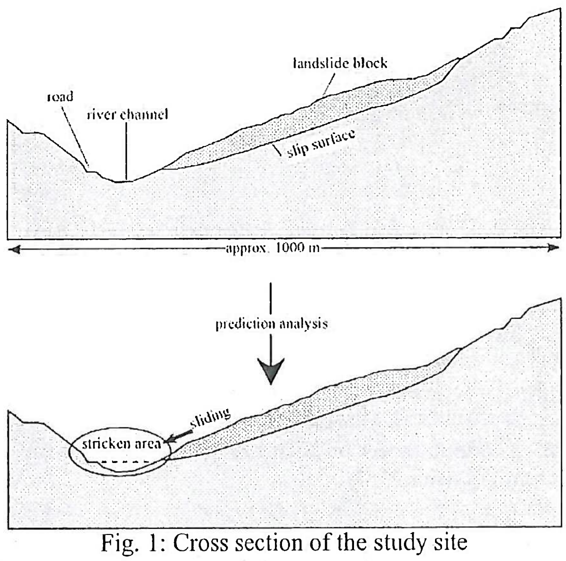

Fig. 1: Cross section of the study site

3. Modeling

3.1 Simulation of formation of the natural dam by landslide

If the landslide occurs on the valley side slope, a lot of debris will bury the valley bottom. The goal of this simulation is to clarify the parameters of the rock property of when the landslide debris fills the valley to the height of the road on the opposite side of the slope. Therefore, DDA simulation will be repeatedly carried out with converting the parameters until the DDA results will be agree with the qualification.

3.2 Block Model of the landslide mass -Voronoi division-

In this case which the DDA model is built up, model of the landslide mass should be divided into fragments with irregular shape because the rocks of the slope is intense crushing and deep weathering as previously described. Thus, we try to divide into construct the block model using the Voronoi division (Fig. 2). As a result, the landslide mass is divided into the 266 fragments (Fig.3).

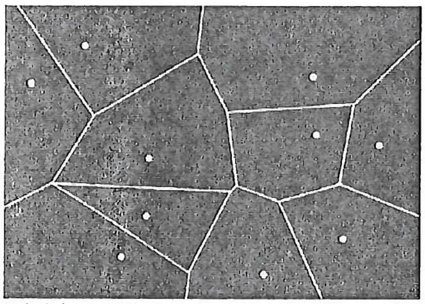

Fig. 2: Division of the block using the Voronoi division.

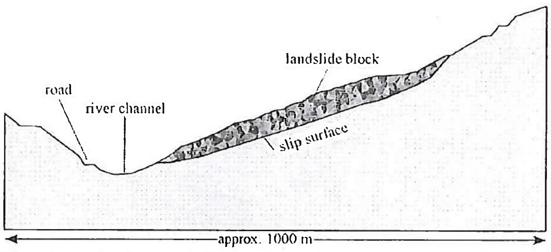

Fig. 3: Block model on this site for DDA using the Voronoi division.

3.3 Parameters for the landslide

The parameters using in the simulation are shown in Table 1. Unit weight of block and Young's module of it are decided from the general data on the landslide in the Sanbagawa metamorphic belt. Poisson ratio and coefficient of attenuation are established from the empirical data of the rock. Frictional angle of joint is varied from 10 to 20 degree. Cohesion of joint is also varied from 5 to 10 KPa.

Table 1. Parameters for the landslide.

Item		Value
Analysis parameters	Displacement Allow Ratio	0.001
	Total Steps	7000
	Maximum Time Step (sec.)	0.1
Block	Unit Weight (KN/m^3)	21.0
	Young's Modules (MPa)	200.0
	Poisson Ratio	0.3
Slope (no displacement)	Unit Weight (KN/m^3)	21.0
	Young's Modules (MPa)	200.0
	Poisson Ratio	0.3
	Coefficient of Attenuation	0.05
Joint	Frictional Angle (degree)	10-20
	Cohesion (KPa)	5.0-10.0
	Tensile Strength (MPa)	0.0

4. Result of the simulation

4.1 Examination of the parameters

First, we tried sensitivity analysis by DDA in order to examine the parameters which are the cohesion of the block joint and the frictional angle of the joint, when the valley is buried up to the height of a road on the opposite side of slope. We confirmed that the landslide mass did not move downward, when value of the cohesion of the block joint is over 11 KPa, and value of the frictional angle of the joint is over 20 degree.

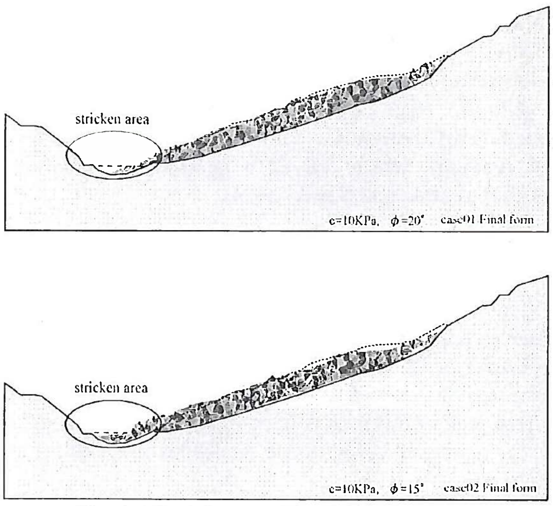

Fig. 4: Final forms of landslide by DDA
(c=10 KPa, ϕ=20-15°)

Subsequently, we inputted 10 KPa as the cohesion of the block joint, and inputted 20 degree as the frictional angle of the joint (Fig.4; case 01). In this case, the landslide mass moved downward. Although, the tip of the debris reached at river channel, it did not come to bury the valley bottom.

When the cohesion of the joint is 10 KPa, and the frictional angle of the joint is 15 degree, the landslide mass moved downward (Fig.4; case 02). The debris buried the valley bottom, however, the tip of the debris did not reach the height of the road.

In the case that the cohesion of the joint is 5 KPa, and the frictional angle of the joint is 15 degree, the landslide mass moved downward and the top of the debris reached the height of the road (Fig.5; case 03).

Finally, in the case that the cohesion of the joint is 5 KPa, and the frictional angle of the joint is 10 degree, the debris buried the valley completely (Fig.5; case 04).

The above result was arranged in Table 2.

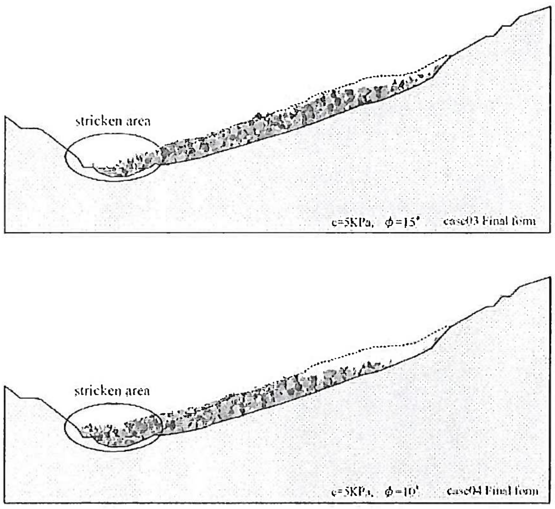

Fig. 5: Final forms of landslide by DDA
(c=5 KPa, ϕ=15-10°)

Table 2. Results of simulations

	cohesion (KPa)	frictional angle (°)	result
case01	10.0	20	no
case02	10.0	15	no
case03	5.0	15	fill
case04	5.0	10	fill

4.2 Velocity of the landslide movement

After parameters of the rock property were determined as case 03, the velocity of landslide movement is estimated.

The landslide mass is divided into 3 parts as follows: no. 2-80 blocks as a lower block, no.81-170 blocks as a middle block, no.171-266 blocks as a upper block (Fig.6). The velocity of the sections is calculated using the average speed of the all blocks of the each section (Fig 7).

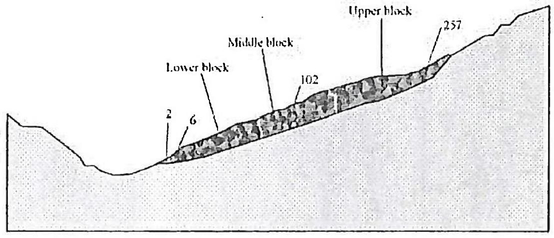

Fig. 6: Final forms of landslide by DDA

Variation of the average movement velocity of the landslide mass is as follows: the peak of movement speed of the lower and middle blocks are recorded at step 11th, and in the upper block, it is recorded at step 6th. It is caught clearly that movement of the landslide have an impact from the lower block to the upper block. The velocity of the lower block picked up gradually until it reached the maximum velocity, and speed is conversely reduced gradually after the maximum velocity. Such variation of the velocity indicates the changes in the mode of movement of landslide. In the early stage, the mode of movement is tension. After maximum velocity recorded, the mode of it changes from tension to compression.

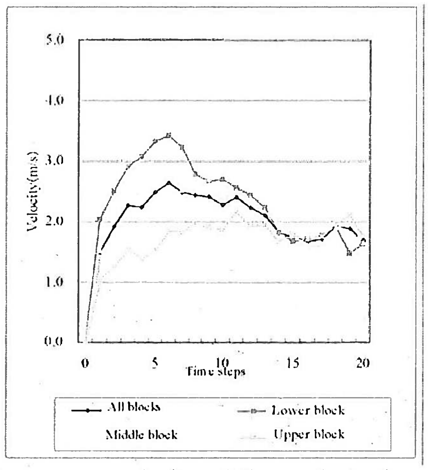

Fig. 7: Average velocity of the each section of the landslide at the case03.

On the other hand, in the middle and upper blocks, the velocity of the blocks fluctuated until it reached the maximum velocity, and subsequently the velocity is decreased gradually. Such variation of the velocity shows that the tension and the compression are repeated in the middle and upper blocks from the early stages of movement to the end. This mode of movement is considered to agree with the actual landslide movement.

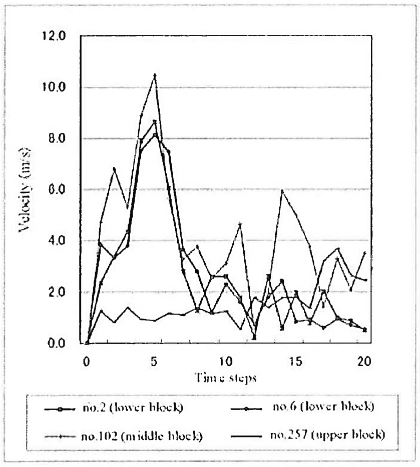

Fig. 8: Velocity of the each block of the landslide at the case03.

Moreover, 4 blocks was extracted from the upper to the lower sections at random, and the velocities of the each block were verified (Fig.8).

The maximum velocities of each block were 10.5 m/sec. (no.102; middle block), 8.6 m/sec. (no.2; lower block), 8.1 m/sec. (no.6; lower block), and 3.7 m/sec. (upper block). The maximum velocity was recorded in step 6th, and it was gradually attenuated the speed until the stop in the lower and middle blocks. On the other hand, in the upper block, the maximum velocity was recorded in step 18th. Such mode of movement shows that the upper block is influenced compression in the early stage of the landslide movement, and the mode of it changes from compression to tension in late stage of the movement.

5. Concluding Remarks

In this study, we carried out the sensitivity analysis by using DDA in order to examine the factors which affect the formation of the natural dam by landslide.

The landslide mass did not move downward, when value of the cohesion of the block joint is over 11 KPa, and value of the frictional angle of the joint is over 20 degree.

The target was filled when the cohesion of the joint is 5 KPa, and the frictional angle of the joint is 15 degree. In that case, the movement of the landslide began from the lower block and spread to the upper block gradually.

DDA methods can be applied to landslide movement. In addition, the displacement process of inner structure of the landslide mass is also in agreement with the actual landslide movement.

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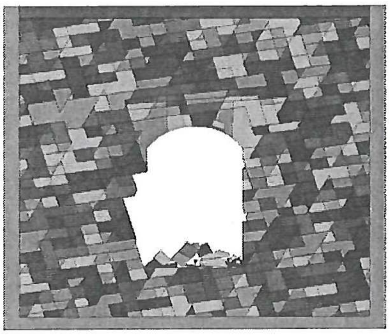

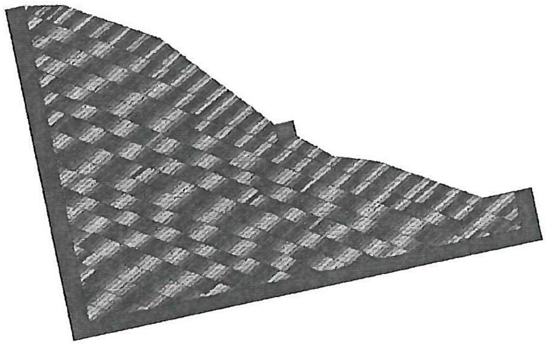

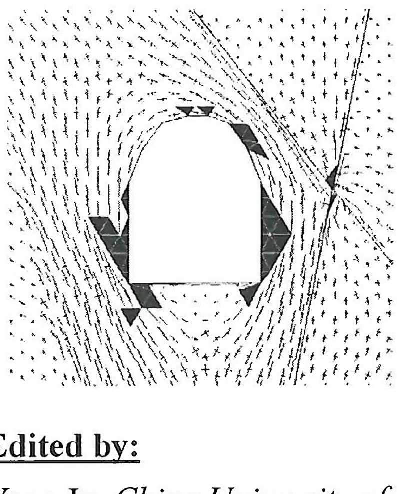

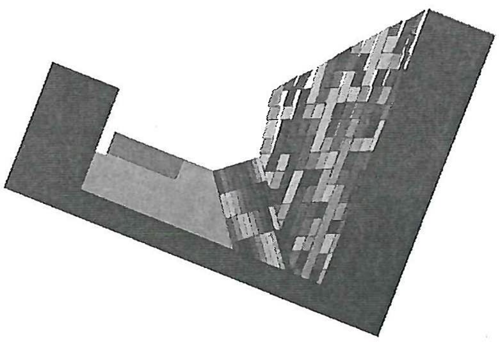

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The figures shown on the front cover may be found in the following papers:
Applications of discontinuous deformation analysis (DDA) to rock stability analysis by Dr. Genhua Shi
Recent insights of analyses using discontinuous methods in rock engineering in Japan by Y. Ohinshi

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