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Study on landslide due to earthquake by using Discontinuous Deformation Analysis

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Keywords: Discontinuous Deformation Analysis (DDA), Landslide, humid tectonic zone, Sanriku-minami earthquake, Japan

ABSTRACT: A large-scale high-speed landslide appeared on hilly area of Tsukidate-cho in the northern part of Miyagi Prefecture in Japan, caused by Sanriku-minami earthquake on May 26, 2003. This landslide movement was strongly controlled by the horizontal acceleration of this seismic, which exceeded 1,000 gal by the place. The rapid landslide is often recognized on slopes in Japanese islands, situated in humid tectonic zone, at the time of the strong earthquake. This study reconstructs this rapid landslide by using Discontinuous Deformation Analysis (DDA), paid attention with the characteristics of landslide movement. DDA method is well suited the rapid landslide.

1 INTRODUCTION

Large number of slope disasters such as landslides and slope failures, due to earthquake or heavy rainfall, occur in every year on slopes in Japanese islands, situated in humid tectonic zone. The prevention for the slope disasters, on the basis of concrete investigation of the landslides and slope failures, therefore, is important to protect the livelihood of regional residents.

The landslide is one of the mass-movement on slopes, called Jisuberi in Japanese, generally continuous and gradual mass movement on slopes. Rapid type of landslide is also known to be often occurred by earthquake in Japanese hilly slopes and embankment slopes (*e.g.* Nishimura et al., 1969; Tamura et al., 1978), however, the mode of the movement on rapid landslide has not been examined on a quantitative basis because observation of the slide is difficult.

A large-scale rapid landslide appeared on the hilly slopes in the northern part of Miyagi Prefecture in Japan, caused by Sanriku-minami earthquake (M7.0) on May 26, 2003. This landslide was rapidly mass-movement (The Japanese Geotechnical Society and Japan Society of Civil Engineers, 2003).

This study aims to reconstruct of the rapid landslide by using Discontinuous Deformation Analysis (DDA; Shi & Goodman, 1984) for the base to clarify the mechanism of rapid landslide.

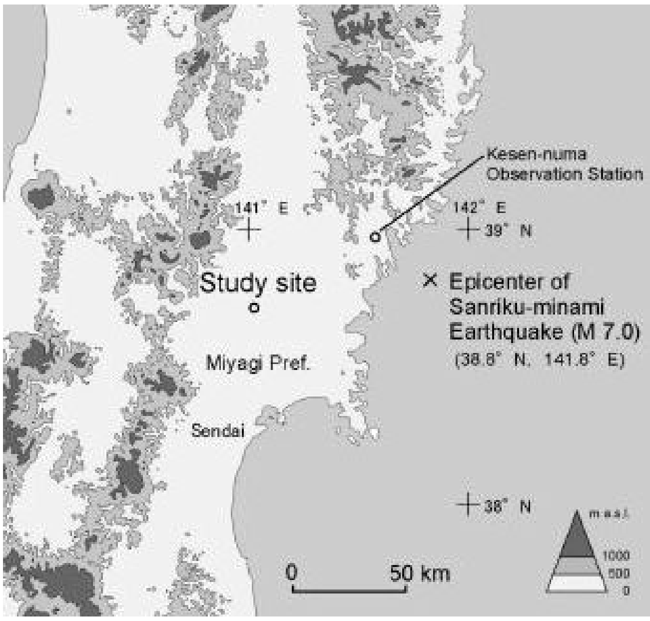

Figure 1. Study site.

2 LANDSLIDE IN STUDY SITE

The epicenter of Sanriku-minami earthquake was situated in off the coast of Miyagi Prefecture in northeastern Japan (Fig. 1; 38.8° N, 141.8° E, 71 km depth). The magnitude of the earthquake was 7.0, and maximum seismic intensity was 6 lower. A maximum horizontal acceleration of the seismic exceeded 1,000 gal at the place.

The landslide due to the earthquake appeared on the hilly area of Tsukidate-cho, approx. 80 km from the epicenter, in the northern part of Miyagi Prefecture. The hilly area, landslide occurred, is less than 60 m in altitude, where the pyroclastic materials cover on the slops. The landslide took place in the south-facing valley-shaped gentle slope where was embanked by pyroclastic materials. The maximum angle of the slope is about 10°, and the average angle of it is 6-7°. Debris, caused by landslide, moved downward along the valley-shaped gentle slope, and it spread out like a fan in the accumulation area.

The scale of the landslide was 180 m long, 27 m height. The thickness of the debris in the accumulation area was about 5 m (Fig. 2). The average velocity of the debris-flow is estimated to be 1.2-1.8 m/sec., and the maximum of it is estimated to reach 6-7 m/sec., by the eyewitness account (The Japanese Geotechnical Society and Japan Society of Civil Engineers, 2003). This landslide is regarded as a high-speed slide viewed from the relations the velocity of the debris-flow and the slope angle.

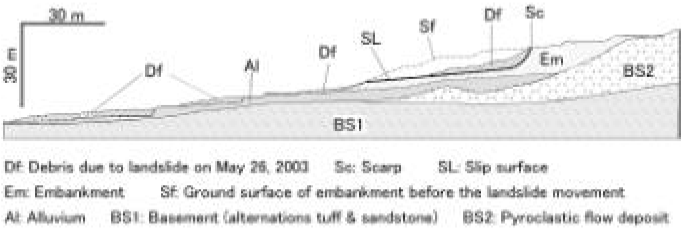

Figure 2. Cross section of landslide which occurred on May 26, 2003.

3 MODELING

3.1 *Approach for reconstruction of the landslide*

Two targets for the reconstruction of the landslide movement are shown in Table 1. One is the extent of debris, especially the position of debris end, which is confirmed by slid debris surface morphology. The other target is the velocity of landslide movement, which is estimated by the eyewitness account on landslide occurrence.

DDA simulation will be repeatedly carried out with converting the parameters, when the DDA results and the targets will be in agreement (Fig. 3).

Table 1. Targets for reconstruction of the landslide movement.

Velocity of landslide movement	Average 1-2 m/sec.
	Maximum 6-7 m/sec.
Debris extent (Position of debris end)	180 m from the Scarp

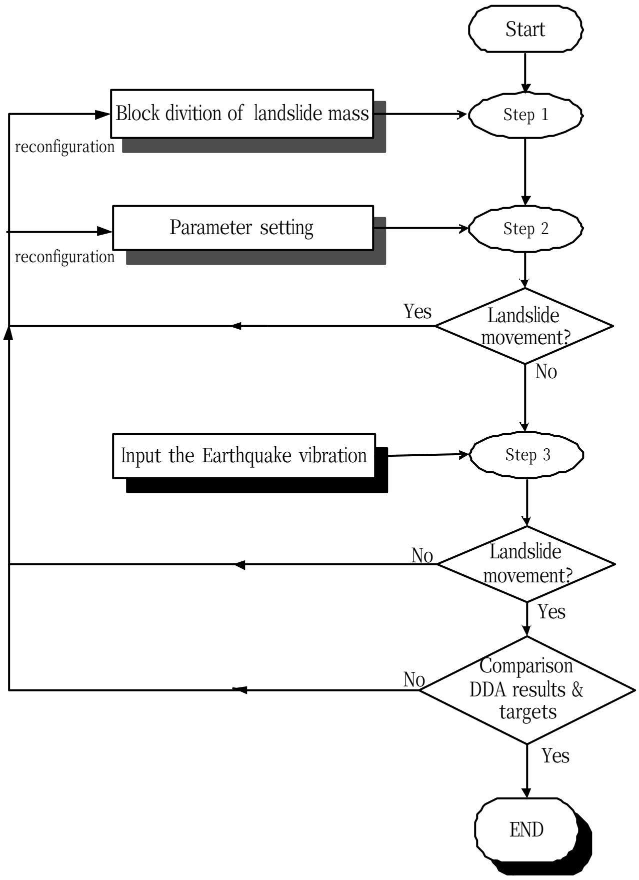

Figure 3. Flow of the simulation.

3.2 *Block Model of the landslide mass*

In the case which the DDA model is built up, model of the landslide mass should be divided into smallest blocks possible because observed debris due to slide break into small fragments. The blocks are divided into smaller ones, however, DDA solution is more complex. Here, we try on two cases of the block model (Fig. 4)

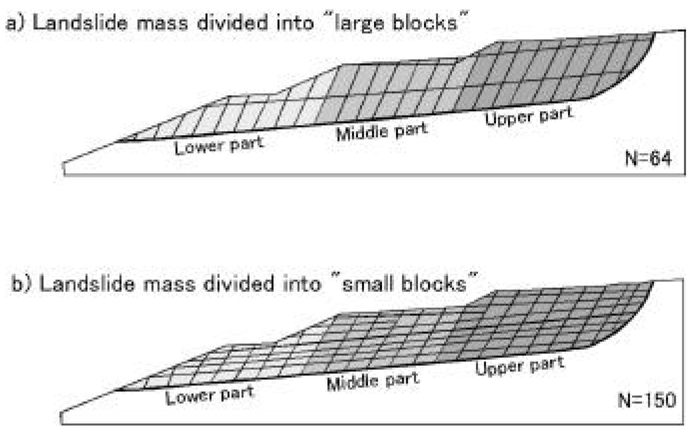

Figure 4. Block model of the landslide mass. Two types of block model are prepared. Each block model is divided into the three sections (upper, middle, and lower parts).

3.3 *Parameters for the landslide*

The parameters using in the simulation are shown in Table 2. Unit weight of block, frictional angle, and cohesion are decided on the field data, obtained from the slope at shortly after the landslide occurrence. Poisson ratio and coefficient of attenuation are established from the empirical data of soil test. Young's module of block is varied from 50 to 400 MPa.

Table 2. Parameters for the landslide.

	Item	Value
Analysis parameters	Displacement Allow Ratio	0.001
	Total Steps (maximum)	15,000
	Maximum Time Step (sec.)	0.1
Block	Unit Weight (KN/m^3)	18.0
	Young's Modules (MPa)	50-400
	Poisson Ratio	0.35
Slope (no displacement)	Unit Weight (KN/m^3)	18000.0
	Young's Modules (GPa)	1,000
	Poisson Ratio	0.35
	Coefficient of Attenuation	0.15
Discontinuity	Frictional Angle (degree)	10
	Cohesion (MPa)	0.01
	Tensile Strength (MPa)	0.0

3.4 *Input of the horizontal acceleration of the seismic*

The data, horizontal acceleration of seismic, is obtained from the "F-Net" which is Broadband Seismograph Network of National Research Institute for Earth Science and Disaster Prevention (NIED). The observation station of the data nearby the landslide site is located in Kesen-numa (Fig.1; 38.97°N, 141.53°E). The data is shown in Figure 5.

The methods and manner of input the data, which is the horizontal acceleration of seismic, are according to the report of Sasaki et al. (2004).

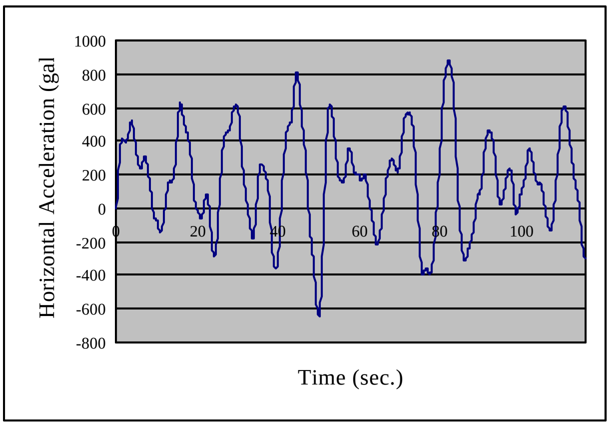

Figure 5. Seismic Horizontal acceleration data of "F-Net" in Kesen-numa observation station.

4 SIMULATION EXAMPLE

4.1 *Case of the "Large blocks"*

The case of the "Small blocks", the former landslide mass moved downward with displacement itself. The debris was widely extended between closely in the scarp and the lower part of slope (Fig. 6), but it did not reach the target point where is the distance 180 m from the scarp (Fig. 2). In addition, the solution of DDA did not clear up when the value of Young's module was less than 200 MPa and more than 250 MPa (Table 3).

Table 3. Results of simulations

	Young's module (MPa)	Result: Position of debris end	Result: Velocity
Run 04	150	unsolved	
Run 05	200	not reached	not filled
Run 06	250	not reached	not filled
Run 07	300	unsolved	
Run 08	400	unsolved	

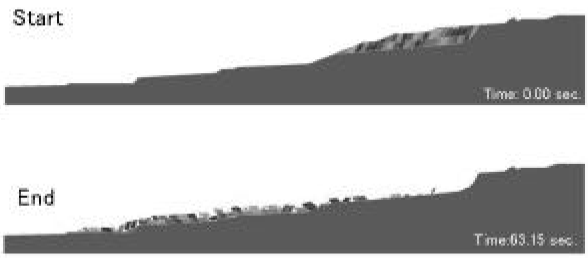

Figure 6. Result of the Run 05 in DDA (divided into the large blocks).

The former landslide mass is divided into three sections, upper, middle, and lower parts (Fig.4). The maximum and average velocities of the slide in the Run 05 were verified (Fig.7).

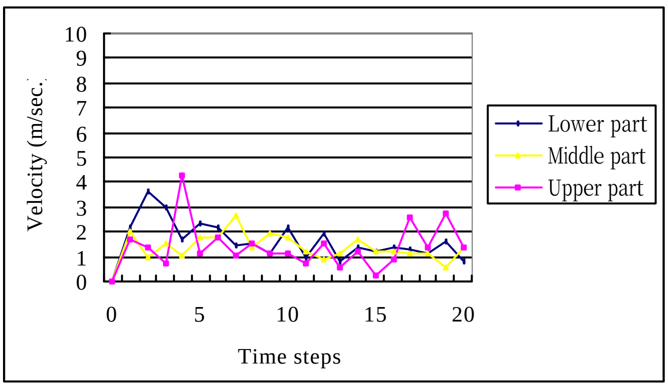

Figure 7. Velocity of the landslide movement in the Run 05 (divided into the large blocks). 20th step is proper for about 63 sec. after earthquake occurring.

The maximum velocities of each section were 4.3 m/sec. (upper part), 3.7 m/sec. (lower part), and 2.7 m/sec. (middle part). The average speed of each section was 1.6 m/sec. (lower part), 1.4 m/sec. (middle part), and 1.4 m/sec. (upper part).

4.2 *Case of the "Small blocks"*

The case of the "Small blocks", the former landslide mass also moved downward with displacement itself. The debris was widely extended between closely in the scarp and the lower part of slope. Its end reached the target point, at the time of about 64 seconds after earthquake occurring (Fig. 8).

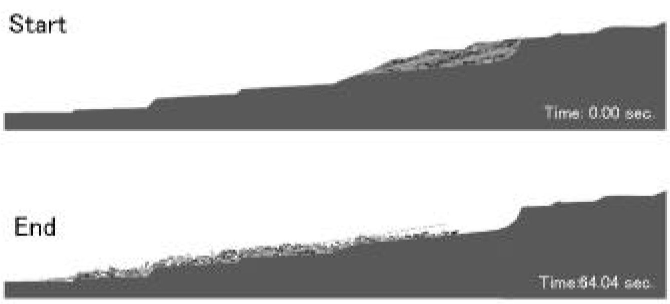

Figure 8. Result of the DDA (divided into the small blocks).

The maximum and average velocities of the each section were verified (Fig.9). The maximum velocities of each section were 6.8 m/sec. (middle part), 6.7 m/sec. (upper part), and 4.6 m/sec. (lower part). The maximum velocity was recorded in step 1 to 2 (3.2 to 6.1 seconds after earthquake occurring) regardless of the sections, and it was gradually attenuated the speed until the stop. The average speed of each section was 2.1 m/sec. (middle part), 1.9 m/sec. (lower part), and 1.7 m/sec. (upper part).

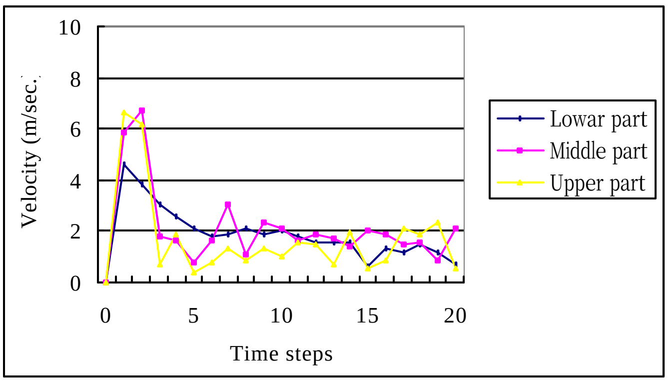

Figure 9. Velocity of the landslide movement (divided into the small blocks). 20th step is proper for about 64 sec. after earthquake occurring.

In consequence, the value of Young's module of block is decided as 70 MPa and Coefficient of Penalty is 300,000. When the value of Young's module was more than 70 MPa, velocity of the landslide movement exceeds the targets of 1-2 m/sec. in average and 6-7 m/sec. in maximum.

5 CONCLUTION

The case which is divided former landslide mass into "Large blocks", the results of simulation do not reconstruct the landslide movement in the point which the maximum velocity is slowly than real one. Slope angle of 6-7 ° is seemed to determine the attenuation on energy of movement.

On the other hand, the case which is divided former landslide mass into "Small blocks", the targets of simulation are filled with the result of DDA. The simulation shows that the landslide movement is reproduced very well (Figs. 8 & 9).

Discontinuous deformation analysis methods with earthquake response model can be applied to landslide movement. The displacement process of inner structure of the landslide mass is, however, necessary to examine the block model.

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INDICES

Numerical Analysis of Discontinuous Rock Masses

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Third Asian Rock Mechanics Symposium, Kyoto, Japan, November 30 - December 2, 2004

CONTRIBUTION OF ROCK MECHANICS TO THE NEW CENTURY

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Study on landslide due to earthquake by using Discontinuous Deformation Analysis

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Purpose and background of this study

The landslide is one of the mass-movement on slopes, called "Jisuberi" in Japanese, generally continuous and gradual mass movement on slopes. Rapid type of landslide is also known to be often occurred by earthquake in Japanese hilly slopes and embankment slopes, however, the mode of the movement on rapid landslide has not been examined on a quantitative basis because observation of the slide is difficult.

A large-scale rapid landslide appeared on hilly area of Tsukidate-cho in the northern part of Miyagi Prefecture in Japan, caused by Sanriku-minami earthquake on May 26, 2003. This landslide movement was strongly controlled by the horizontal acceleration of this seismic, which exceeded 1,000 gal by the place.

This study aims to reconstruct this rapid landslide by using Discontinuous Deformation Analysis for the base to clarify the mechanism of rapid landslide.

Fig.1 Study site

The epicenter of Sanriku-minami earthquake was situated in off the coast of Miyagi Prefecture in northeastern Japan (38.8° N, 141.8° E, 71 km depth). The magnitude of the earthquake was 7.0, and maximum seismic intensity was 6 lower. A maximum horizontal acceleration of this seismic exceeded 1,000 gal by the place.

The landslide due to the earthquake appeared on the hilly area of Tsukidate-cho, approx. 80 km from the epicenter, in the northern part of Miyagi Prefecture.

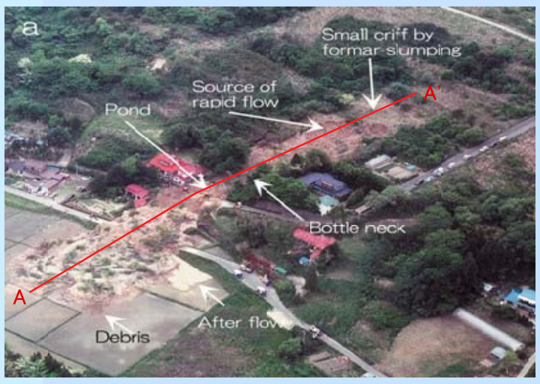
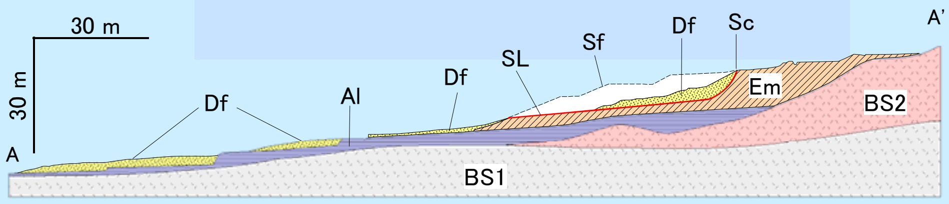


Fig.2 The landslide caused by Sanriku-minami earthquake on May 26, 2003

The hilly area, landslide occurred, is less than 60 m in altitude, where the pyroclastic materials cover the slops. The landslide took place in the south-facing valley-shaped gentle slope where was embanked by pyroclastic materials. The maximum angle of the slope is about 10°, and the average angle of it is 6-7°. Debris, caused by landslide, moved downward along the valley-shaped gentle slope, and it spread out like a fan in the accumulation area.

The scale of the landslide was 180 m long, 27 m height. The thickness of the debris in the accumulation area was about 5 m. The average velocity of the debris-flow is estimated to be 1.2-1.8 m/sec., and the maximum of it is estimated to reach 6-7 m/sec., by the eyewitness account. This landslide is regarded as a high-speed slide viewed from the relations the velocity of the debris-flow and the slope angle.



Df: Debris due to landslide on May 26, 2003 Sc: Scarp SL: Slip surface
Em: Embankment Sf: Ground surface of embankment before the landslide movement
Al: Alluvium BS1: Basement (alternations tuff & sandstone) BS2: Pyroclastic flow deposit

Fig.3 Cross section of the landslide

Table 1. Targets for reconstruction of the landslide movement

Velocity of landslide movement	Average 1-2 m/sec. Maximum 6-7 m/sec.
Debris extent (Position of debris end)	180 m from the scarp

Two targets for the reconstruction of the landslide movement are shown in Table 1. One is the extent of debris, especially the position of debris end, which is confirmed by slid debris surface morphology. The other target is the velocity of landslide movement, which is estimated by the eyewitness account on landslide occurrence.
DDA simulation will be repeatedly carried out with converting the parameters, when the DDA results and the targets will be in agreement (Fig. 4).

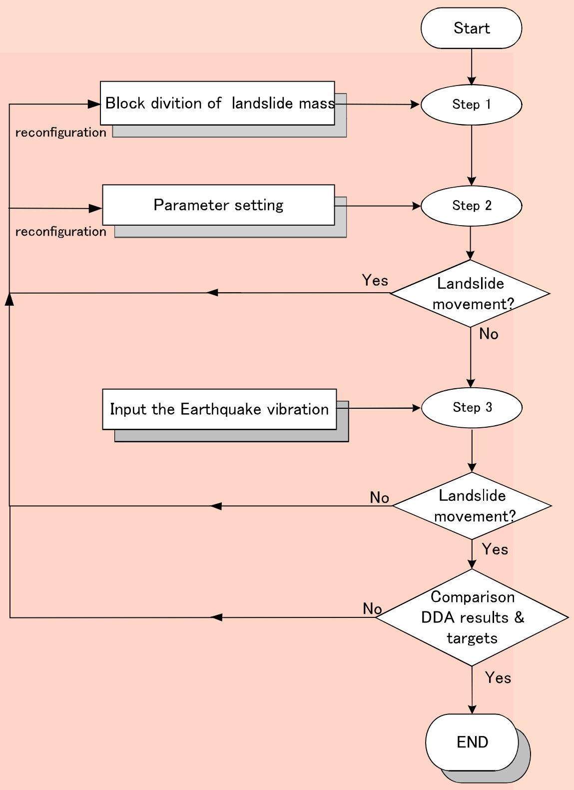


Fig.4 Flow of the simulation

Parameters using in the simulation

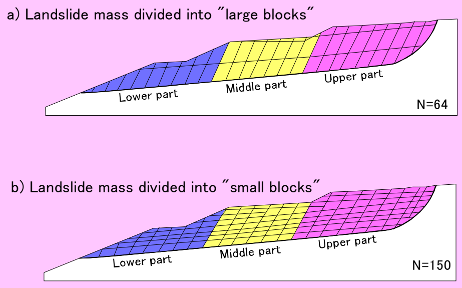


Fig.5 Block model of the landslide mass

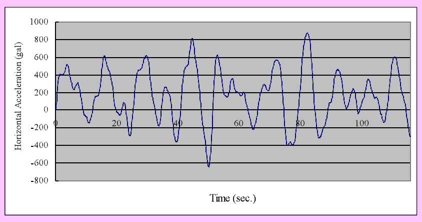
Two types of block model are prepared. The model of the landslide mass should be divided into smallest blocks possible because observed debris due to slide break into small fragments (Fig.2&3). However, when the blocks are divided into smaller ones, DDA solution is more complex.

Here, we try on two cases of the block model (Fig. 5) to judge the validity of cutting size and form of the blocks in DDA. Each block model is divided into the three sections (upper, middle, and lower parts) .

Table 2. Parameters for the landslide

Item		Value
Analysis parameters	Displacement Allow Ratio	0.001
	Total Steps	15,000
	Maximum Time Step (sec.)	0.1
Block	Unit Weight (KN/m^3)	18.0
	Young's Modules (MPa)	70
	Poisson Ratio	0.35
Slope (no displacement)	Unit Weight (KN/m^3)	18000.0
	Young's Modules (GPa)	1,000
	Poisson Ratio	0.35
	Coefficient of Attenuation	0.15
Discontinuity	Frictional Angle (degree)	10
	Cohesion (MPa)	0.01
	Tensile Strength (MPa)	0.0

The parameters using in the simulation are shown in Table 2. Unit weight of block, frictional angle, and cohesion are decided on the field data, obtained from the slope at shortly after the landslide occurrence. Poisson ratio and coefficient of attenuation are established from the empirical data of soil test. Young's module of block is varied from 50 to 400 MPa.



The data of horizontal acceleration of the seismic, is obtained from the "F-Net" which is Broadband Seismograph Network of NIED. The observation station of the data nearby the landslide site is located in Kesen-numa (Fig.1; 38.97° N, 141.53° E).

Fig.6 Seismic Horizontal acceleration data of "F-Net" in Kesen-numa observation station.

Conclusion

●In the case which is divided former landslide mass into "Small blocks", the targets of simulation are filled with the result of DDA. The simulation shows that the landslide movement is reproduced very well (Figs. 9 & 10).

●In the case which is divided former landslide mass into "Large blocks", the results of simulation could not reconstruct the landslide movement in the point which the maximum velocity is slowly than real one. Slope angle of 6-7° is seemed to determine the attenuation on energy of movement.

●DDA methods with earthquake response model can be applied to landslide movement.

Results

Table 3. Results of simulations (Large blocks)

	Young's module (MPa)	Result: Position of debris end	Result: Velocity
Run 01	50	unsolved	
Run 02	70	unsolved	
Run 03	100	unsolved	
Run 04	150	unsolved	
Run 05	200	not reaced	not filled
Run 06	250	not reaced	not filled
Run 07	300	unsolved	
Run 08	400	unsolved	

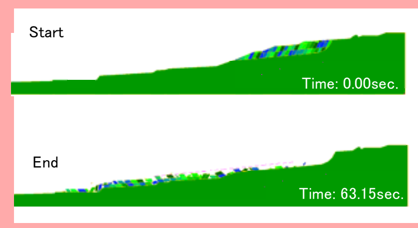


Fig. 7 Result of the DDA (Run05; the large blocks).

In the case of the "Large blocks", the former landslide mass moved downward with displacement itself. The debris was widely extended between closely in the scarp and the lower part of slope (Fig. 7), but it did not reach the target point (the distance 180 m from the scarp; Fig. 2).

In addition, the solution of DDA did not clear up when the value of Young's module was less than 200 MPa and more than 250 MPa (Table 3).

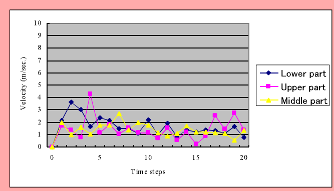


Fig. 8 Velocity of the landslide movement in the Run 05 (divided into the large blocks). 20th step is proper for about 63 sec. after earthquake occurring.

The maximum and average velocities of the slide in the Run 05 were verified (Fig.8).

The maximum velocities of each section were 4.3 m/sec. (upper part), 3.7 m/sec. (lower part), and 2.7 m/sec. (middle part).

The average speed of each section was 1.6 m/sec. (lower part), 1.4 m/sec. (middle part), and 1.4 m/sec. (upper part).

The maximum and average velocities of each section were not consistent with the target.

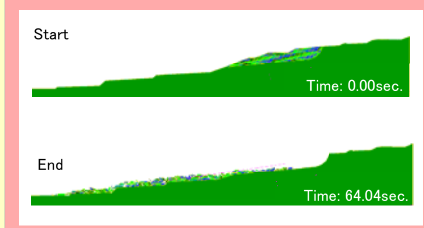


Fig. 9 Result of the DDA (the small blocks).

In the case of the "Small blocks", the former landslide mass also moved downward with displacement itself.

The debris was widely extended between closely in the scarp and the lower part of slope. Its end reached the target point, at the time of about 64 seconds after earth-quake occurring (Fig. 9).

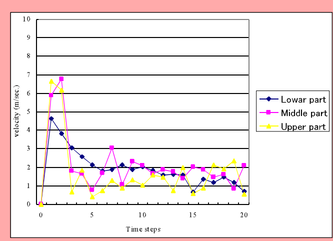


Fig. 10 Velocity of the landslide movement in the "small blocks"
20th step is proper for about 64 sec. after earth-quake occurring.

The maximum velocities of each section were 6.8 m/sec. (middle part), 6.7 m/sec. (upper part), and 4.6 m/sec. (lower part). The maximum velocity was recorded in step 1 to 2 (3.2 to 6.1 seconds after earthquake occurring) regardless of the sections, and it was gradually attenuated the speed until the stop. The average speed of each section was 2.1 m/sec. (middle part), 1.9 m/sec. (lower part), and 1.7 m/sec. (upper part). In consequence, the value of Young's module of block is decided as 70 MPa and Coefficient of Penalty is 300,000. When the value of Young's module was more than 70 MPa, velocity of the landslide movement exceeds the targets of 1-2 m/sec. in aver-age and 6-7 m/sec. in maximum.