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GEOTECHNICAL PROPERTIES OF LANDSLIDE DAMS INDUCED BY THE IWATE-MIYAGI NAIRIKI EARTHQUAKE IN 2008

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ABSTRACT

The 2008 Iwate-Miyagi Nairiku earthquake caused severe geotechnical damages such as rock falls, landslides and debris flows. More than 50 landslide dams made of the collapsed soils and rocks appeared after the earthquake. In this paper the geotechnical properties of a landslide dam are investigated. The in-situ tests are carried out at Yunokura landslide dam which is one of the largest landslide dams along the Hasama River. In addition the laboratory tests with the disturbed samples obtained at Yunokura are performed. The tests results show that the shallow part to the depth of about 8 m contains mainly soils with lower N values and lower elastic wave velocities than that of the deeper part. The in-situ permeability coefficient measured at the bore hole is two orders larger than that obtained by the laboratory permeability tests with disturbed samples.

Keywords: Landslide dam, SPT, PS logging, surface wave exploration, permeability test

INTRODUCTION

The disastrous earthquake hit the southwestern area of Iwate Prefecture and the northwestern area of Miyagi Prefecture at 8:43, local time, on 14 June, 2008. The National Research Institute for Earth Science and Disaster Prevention (NIED, 2008) assigned a moment magnitude (Mw) of 7.0 to this earthquake, with focal depth of about 8 km. The largest acceleration ever recorded was observed at a KiK-net site (maintained by NIED) 2.6 km distant from the epicenter. The maximum acceleration combined with three components was over 4,000 cm/s^2.

The earthquake caused severe geotechnical damages such as rock falls, landslides and debris flows. The earthquake claimed 17 lives, left 6 missing people mainly due to the geotechnical hazards. The surface soil in damaged areas consisted mainly of volcanic and pyroclastic sediments such as a dacite, pumice tuff, and welded tuff. Aerial surveys detected over 2,200 slope failures. Major patterns of the slope failures were surface failures of weathered rock, rock falls along columnar joints, and landslides along a bedding plane. Collapsed soil and rock formations buried some major roadways and rivers. Some natural slope failures along rivers produced landslide dams and quake lakes. More than 50 landslide dams produced from the collapsed soil and rock were observed after the earthquake. Immediately after the earthquake, countermeasure work began to prevent overtopping-induced erosion at landslide dam sites.

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In this paper the geotechnical properties of a landslide dam are investigated in order to discuss the stability of a landslide dam against seepage and overtopping. In-situ tests are carried out at Yunokura landslide dam which is one of the largest landslide dams along the Hasama River. In addition the laboratory tests are performed for the disturbed samples obtained at Yunokura.

OVERVIEW OF LANDSLIDE DAMS AND QUAKE LAKES

Figure 1 shows the locations of major 15 landslide dams in Iwate and Miyagi Prefectures (MLIT, 2008). More than 50 landslide dams including small ones were observed in the damaged area. The locations are identified with field reconnaissance, aerial survey with helicopter, aerial photos (GSI, 2008; TCA, 2008) and reports of Prefectures (Miyagi, Iwate and Akita Prefectures, 2008). The surface soil in the area consists mainly of volcanic and pyroclastic sediments such as andesite, pumice tuff and welded tuff due to past eruptions of the Kurikoma Volcano on the border between Iwate and Miyagi Prefectures. Most natural slope failures occurred on these volcanic sediments. The failure patterns of the natural slope failures are classified to surface failure of weathered rock, rock falls along columnar joint and landslide along potential bedding plane. The epicenter of the earthquake also is shown in Figure 1. Most major landslide dams are located in southern area from the epicenter. It is possible that this tendency is due to the geological conditions and the directivity of earthquake source fault. Some source inversion analyses (e.g. NIED, 2008) shows that the fault slip propagated toward south from the hypocenter and the asperity is located on the border between Iwate and Miyagi Prefectures. Moreover, some slope failures are located at the usual landslide landforms. Multifaceted and detailed investigations are necessary to identify the real damage factor for each site in the future.

Table 1 summarizes the dimensions of major landslide dams (MILT, 2008). The number in Table 1

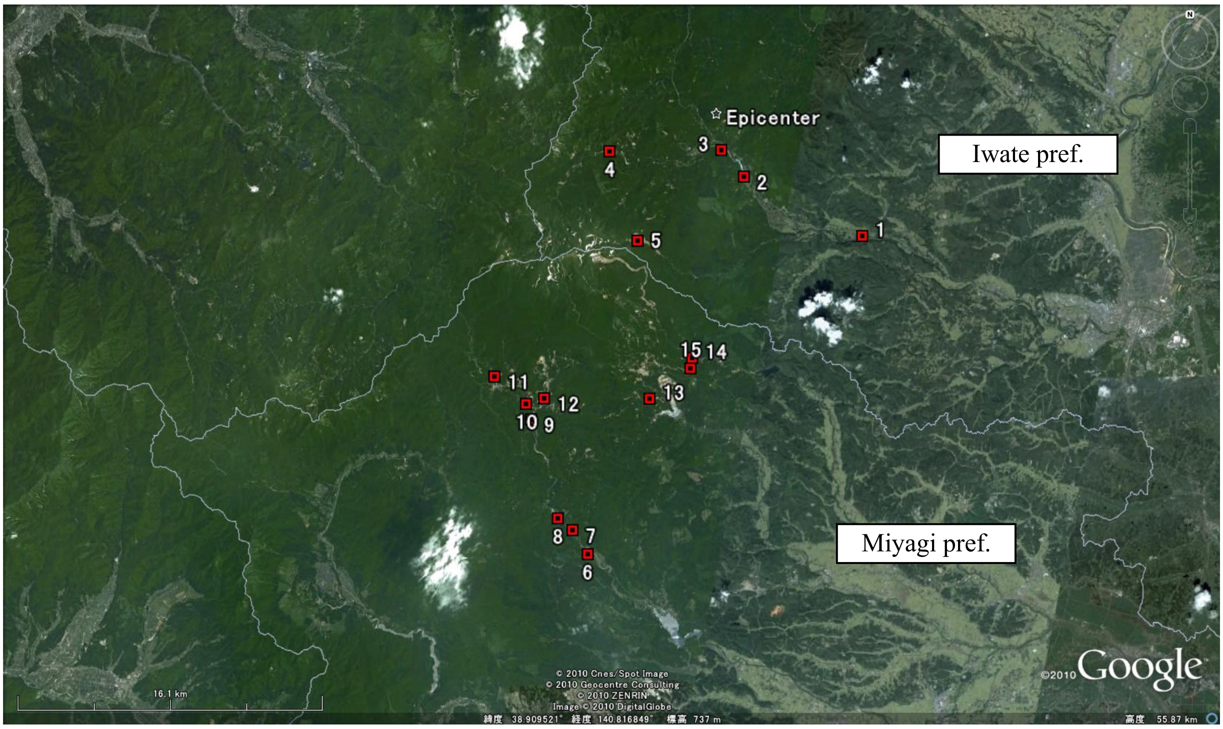


Figure 1. Major landslide dams (MLIT, 2008) in Iwate and Miyagi prefectures

corresponds to the location in Figure 1. At Ichinonobara (No. 2), large amount of collapsed soil dammed up the Iwai River (Photo 1). The collapsed slope was gentler than other most natural slope failures which caused landslide dams, and the potential slide is possible to be triggered by this earthquake. As the Iwai River had no artificial dam with a large capacity at the downstream side of the Ichinonobara quake lake, the countermeasure works against the erosion of landslide dam was started immediately after the main shock. A temporal drain on the left bank was expected to avoid the overtopping on the landslide dam (Photo 1). The volume of collapsed soil at Ubusume (No. 5) was the largest one which made a quake lake. The length of landslide dam was about 260 m along the Ubusume River (Photo 1).

Many landslide dams appeared along the Hasama River in Miyagi Prefecture. Although a large artificial dam (Hanayama) is located at the downstream side, immediate countermeasure works began after the main shock because many people live along the river. At Azabu (No. 7) and Kogawara (No. 8) on the plane at the downstream side and at Yunokura (No. 10) (Photo 2) and Yubama (No. 11) (Photo 3) in the mountain area, the large volume of collapsed soil caused large quake lakes. The length of the landslide dam Yubama was about 1 km long; this was the longest one among the landslide dams. Large rock boulders with the diameter of over 1 meter and broken trees were observed on the surface of landslide dams (e.g. right photographs in Photos 2 and 3). Some rocks were welded tuff with columnar joints which

Table 1. Summary of the dimensions of major landslide dams (MILT, 2008)

No. in Fig. 1	Site, City, Prefecture	River	Width of dam (m)	Length of dam (m)	Volume of collapsed soil (1000 m^3)
1	Kogawara, Ichinoseki, Iwate	Iwai	30	60	20
2	Ichinonobara, Ichinoseki, Iwate	Iwai	200	700	1,730
3	Tsukigidaira, Ichinoseki, Iwate	Iwai	60	160	80
4	Sukawa, Ichinoseki, Iwate	Iwai	130	280	390
5	Ubusume, Ichinoseki, Iwate	Ubusume	200	260	12,600
6	Sakanoshita, Kurihara, Miyagi	Hasama	20	80	90
7	Azabu, Kurihara, Miyagi	Hasama	220	220	300
8	Kogawara, Kurihara, Miyagi	Hasama	200	520	490
9	Nuruyu, Kurihara, Miyagi	Hasama	80	580	740
10	Yunokura, Kurihara, Miyagi	Hasama	90	660	810
11	Yubama, Kurihara, Miyagi	Hasama	200	1000	2,160
12	Kawaragoyasawa, Kurihara, Miyagi	Hasama	170	400	210
13	Aratosawa, Kurihara, Miyagi	Nihasama	-	-	-
14	Numakura, Kurihara, Miyagi	Mihasama	120	300	270
15	Numakura-urasawa, Kurihara, Miyagi	Mihasama	160	560	1,190

(a) Ichinonobara (No. 2 in Figure 1)

(b) Ubusume (No. 5 in Figure 1)

Photo 1. Landslide dams in Iwate prefecture (by Motoki Kazama, 28 June)

(a) Overview by Motoki Kazama, 28 June **(b) Surface view by Hiroaki Kabuki, 20 July**
Photo 2. Landslide dams at Yunokura (No. 10 in Figure 1)

(a) Overview by Motoki Kazama, 28 June **(b) Surface view by Ryosuke Uzuoka, 7 September**
Photo 3. Landslide dams at Yubama (No. 11 in Figure 1)

are major surface geologic material around Mt. Kurikoma. In addition, fine surface soils and weathered pumice tuff were also observed in the dam (e.g. right photograph in Photo 2). It is possible that the soil constitutions of the landslide dams varied with the locations and the depth. The constitutions are dependent on the geology, the degree of weathering of the original slope and the failure configuration such as the height of main scarp and flow distance. When the sediment of collapsed soil contains fine particles and the dam is long along the river, the permeability of dam becomes small and the rising rate in the water level of dammed lake becomes large during precipitation. Moreover, the rise in the water level reduces the stability of the dam due to overtopping-induced erosion and piping.

Some landslide dams had natural river channels on the surface due to erosion during the overtopping after precipitation. For example, although an overtopping of landslide dams at Numakur-urasawa (No. 15) occurred on 24 June, the artificial dam lake at the downstream side absorbed the debris flow and there were no social damages. After the overtopping, a natural river channel was formed on the surface of the landslide dam at Numakura-urasawa. The landslide dams at Ubusume and Kawaragoyasawa (No. 12) also had natural river channels on the surface. Although some small landslide dams broke a few weeks after the earthquake, no social damages were reported.

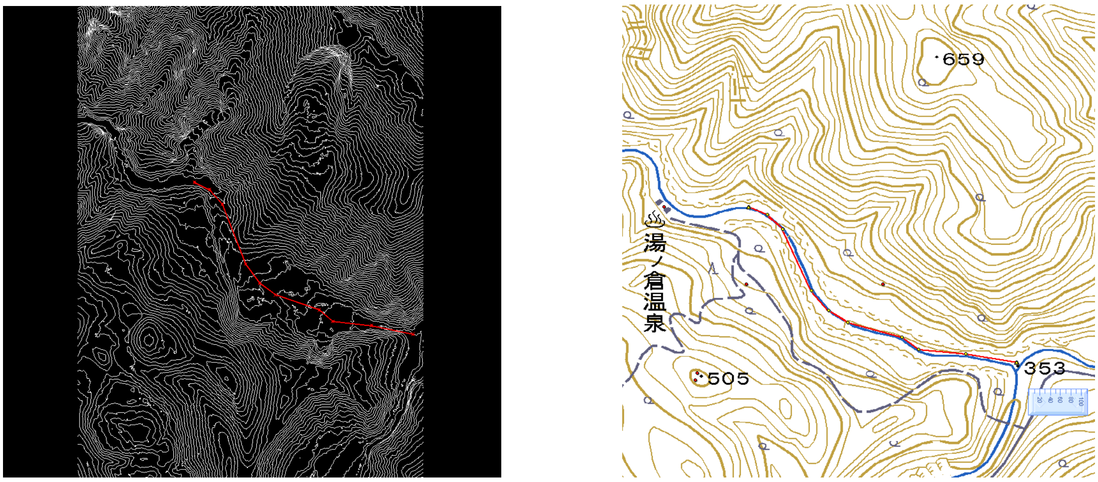
INVESTIGATION AT YUNOKURA LANDSLIDE DAM

Yunokura is one of the largest landslide dams along the Hasama River. First the topography and the geology are introduced. Second the transition of the landslide dam for about one year after the earthquake is reviewed. Third the results of in-situ tests and laboratory tests with disturbed samples from the landslide dam are described. The in-situ tests include SPT, PS logging, surface wave exploration and borehole permeability tests. The laboratory tests include grain size analyses and permeability tests.

Topography and geology at Yunokura

Figure 2 shows the topographical map before and after the earthquake. The topography before the earthquake is 1:25,000 topographical map by Geographical Survey Institute (GSI). The topography after the earthquake was obtained by aerial laser profiler conducted by MLIT. The slope failure occurred from near the top of the mountain at the left bank. Figure 3 shows the cross section of the landslide dam along the river which is obtained by comparing the topography before and after the earthquake in Figure 2. The collapsed soil of about 810,000 m^3 flowed down the left bank slope and deposited on the downstream along the river. The bottom length and the maximum height of landslide dam are about 540 m long and 30 m high.

The original slope consists of welded tuff and pumice tuff which were from the Kurikoma volcano. The large boulders on the surface (Photo 2) were originally from the welded tuff layer on the top of the slope. The geological properties are typical one in the damaged area as mentioned before. The mechanical properties of the original surface rock should be investigated in order to clarify the seismic stability of the



(a) Before the earthquake **(b) After the earthquake**

Figure 2. Topography before and after the earthquake at Yunokura

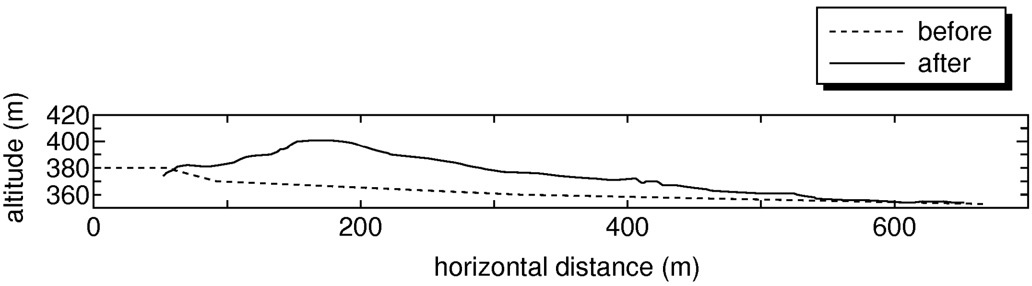


Figure 3. Sectional view along the old river channel (red line in Figure 2)

steep slope.

Transition of the landslide dam at Yunokura

Overtopping often occurred at Yunokura landslide dam. Figure 4 shows the time history of the water elevation of the dammed lake. The water elevation data before June 30 is estimated from the pictures taken by media and the data after June 30 is provided by MLIT. The water elevation have attained to the top elevation (395.4 m) of the landslide dam five times until November 2008.

Photo 4 shows the transition views of the landslide dam for about one half year after the earthquake. The restoration works could not be started immediately after the earthquake because there were no access roads enough to carry the vehicles and materials to the site. On July 5 the drainage with a few pumps was started (blue lines in Photo 4(a)). On July 9 the number of pumps became sixteen and the water elevation began to decline. After the achievement of access road on August 10, a temporal drainage channel on the right bank began to work. Moreover the second channel with larger section was planned (Photo 4(b)); however, large erosion occurred on October 24 (Photo 4(c)). The accumulation rainfall was about 106 mm from 2:00 to 21:00 on October 24, which is the largest continuous rainfall since the earthquake. The erosion due to the overtopping began from the downstream side of the landslide dam at about 14:40 on October 24 and moved toward the upstream side after about two hours (Photo 4(c)). The failure type of the landside dam was a progressive failure with erosion. It is possible that the restoration works on the dam surface reduced the stability by removing large boulders. The dimensions of erosion were about 40 m wide, 15 m deep and 250 m long, and the volume was about 100,000 m^3 (Photo 4(d)) Due to the erosion, the water elevation of the dammed lake declined about 10 m for an hour from 16:40 to 17:40, and the capacity of the lake decreased from 462,000 m^3 to 127,000 m^3 (MLIT, 2008). About one year later the eroded channel kept the configuration although snow melted water flowed in the spring (Photo 4(e)). The river bed at the downstream side was reinforced against further erosion (Photo 4(f)).

In-situ tests at Yunokura

Figure 5 shows the locations of boring and surface wave exploration in October 2009. The testing site is located on the left bank and is near above the old river channel. Figure 6 shows the depth distributions of the N values by SPT, the rock core ratio and elastic wave velocities. The rock core ratio is defined as a ratio of rock core length cut out from a boulder for the unit core with one meter long. The thickness of the collapsed soil at the site is about 22 m which is smaller than the maximum height of the landslide dam in Figure 3. The maximum diameter of cut-out boulder is about 60 cm and the nature is tuff, not welded tuff

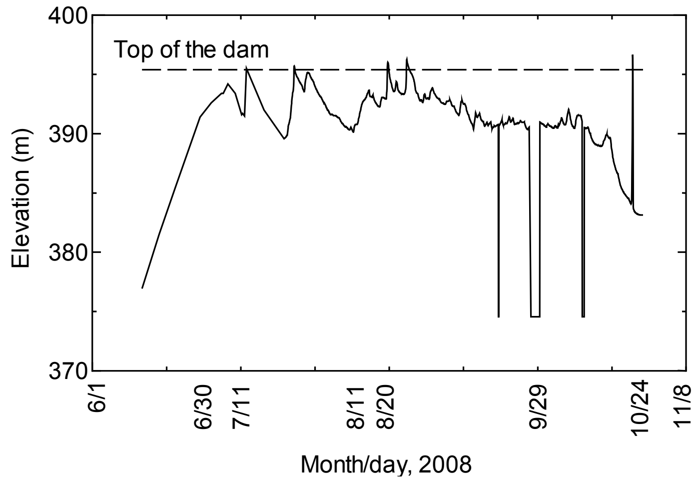


Figure 4. Time history of the water elevation of the dammed lake at Yunokura

(a) 20 July, 2008 by Ryosuke Uzuoka

(b) 7 September, 2008 by Ryosuke Uzuoka

(c) 24 October, 2008 by MLIT

(d) 24 November, 2008 by Ryosuke Uzuoka

(e) 1 July, 2009 by Ryosuke Uzuoka

(f) 31 October, 2009 by Ryosuke Uzuoka

Photo 4. Transition views of the landslide dam from right bank to downstream at Yunokura

on the top of the original slope. Silty sand which might be crushed tuff is filled among gravels and boulders.

The surface soil with the depth of about 2 m might be disturbed by the restoration works; therefore the N values and elastic wave velocities are very low. The N values until 8 m deep are from 10 to 20 which are smaller than the deeper part. In addition, the elastic wave velocities until 10 m deep are smaller than the

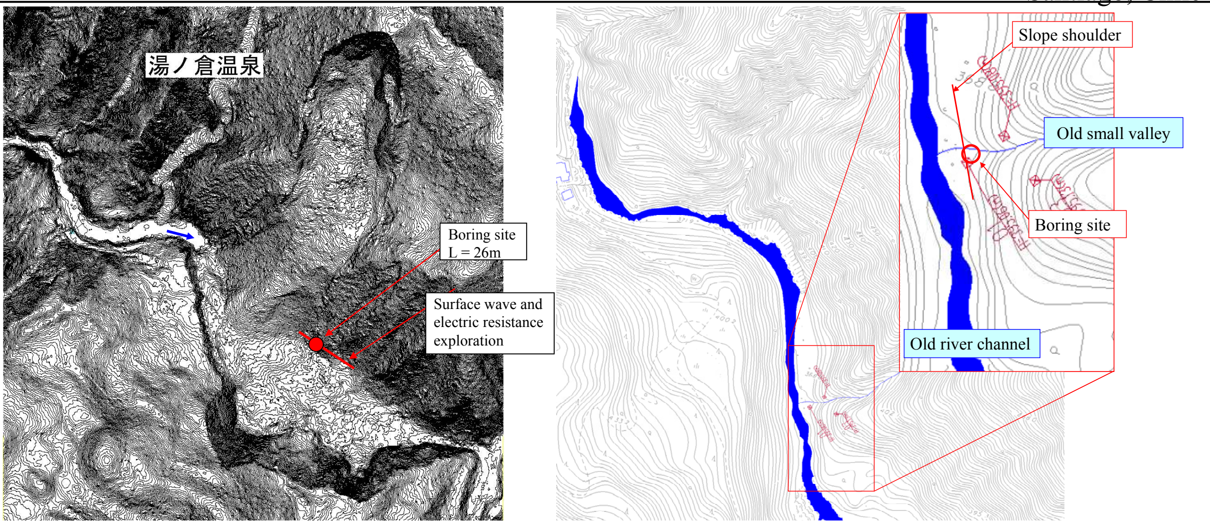


Figure 5. Locations of boring and surface wave exploration at Yunokura

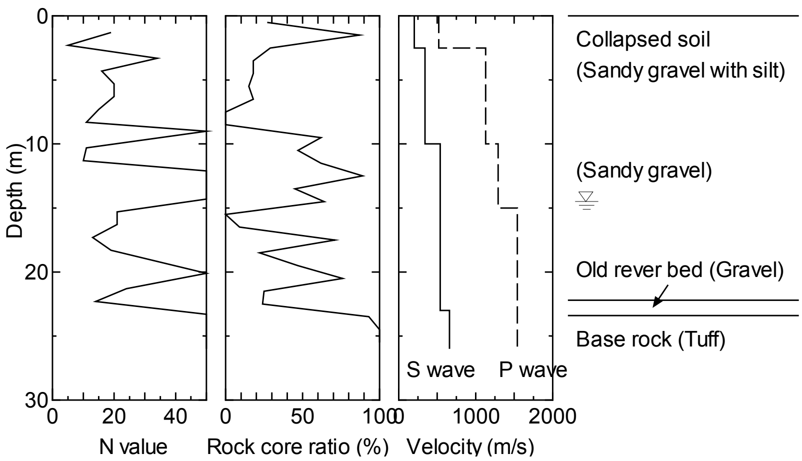


Figure 6. Depth distributions of the N values by SPT, the rock core ratio and P, S wave velocities

deeper part. Although the N values become large at some depths due to rock hitting in the depth of more than 8 m, the N values of the fill among the boulders are less than 20. It is possible that the fill among the boulders is not compacted despite the depth. The depth distribution of the rock core ratio agrees with that of N values. The landslide dam induced by rock slope failure consists of not only rock gravels or boulders but sand or silt. The shallow part to the depth of about 8 m contains mainly soils with lower N values and lower elastic wave velocities.

A borehole permeability test was carried out at about 19 m deep in the borehole. The ground water table was about 15 m deep on October 30, 2009. The permeability coefficients by the water injection method and the water recovery method were 1.0×10^{-2} cm/s and 1.3×10^{-1} cm/s respectively. Although silty sand is filled among gravels and boulders, the permeability is very high.

The surface wave and electrical prospecting were carried out around the borehole. Figure 7 shows the distribution of surface wave velocity and resistivity. The lower resistivity shows the lower permeability and the finer soil. The surface wave velocity and resistivity are relatively low in the shallow depth until

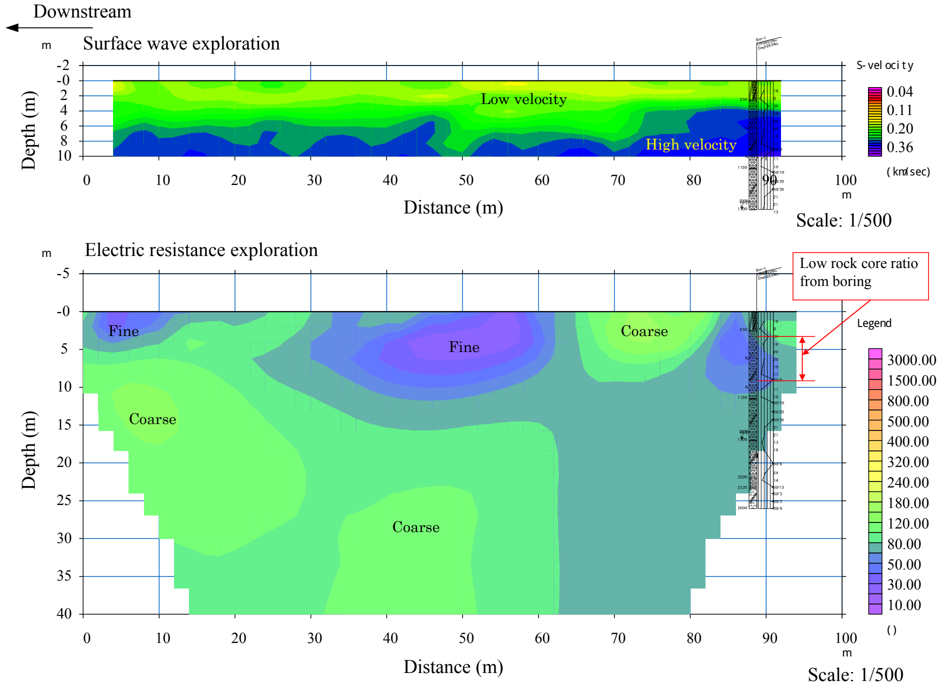


Figure 7. Distribution of surface wave velocity and resistivity

about 10 m. These tendencies agree with the distribution of N values and elastic wave velocities at the boring site. It is noted that the horizontal distributions of surface wave velocity and resistivity are not homogeneous.

The tests results show that the shallow part to the depth of about 8 m contains mainly soils with relatively lower N values and lower elastic wave velocities. On October 24, 2008, the surface of the landslide dam was eroded with the depth of about 15 m. If the elevation at the boring site was not changed since the erosion, not only the soft layer with soils but also the stiff layer with gravels and boulders was eroded.

Laboratory tests with disturbed soil samples at Yunokura

The disturbed samples were taken from the surface or cut-off slope during the restoration works. Table 2 shows the summary of laboratory tests. Figure 8 shows the grain size distribution under 75 mm from sample 2. The Japanese classification of the sample is sandy gravel with silt (GS-F). The permeability coefficients of samples 1 and 2 by laboratory tests were from 7.6×10^{-4} cm/s to 2.3×10^{-6} cm/s about two orders smaller than than by the bore hole permeability tests. These results suggest that there are some water pathways in the landslide dam.

CONCLUTIONS

The geotechnical properties of a landslide dam induced by 2008 Iwate-Miyagi Nairiku earthquake are investigated. The in-situ tests are carried out at Yunokura landslide dam which is one of the largest landslide dams along the Hasama River. In addition the laboratory tests are performed for the disturbed samples obtained at Yunokura. The tests results show that the shallow part to the depth of about 8 m contains mainly soils with lower N values and lower elastic wave velocities than that of the deeper part. On October 24, 2008, not only the soft layer with soils but also the stiff layer with gravels and boulders was eroded. The in-situ permeability coefficient measured at the bore hole is two orders larger than that obtained by the laboratory permeability tests for disturbed samples. These results suggest that there are

Table 2. Summary of laboratory tests

	Sample 1	Sample 2	Sample 3
Density of particle [g/cm^3]		2.70	2.61
Dry density [g/cm^3]			0.92 - 1.08
Water content [%]			50.2
Degree of saturation [%]			90.4
Permeability coefficient [cm/s]	2.3×10^{-6}	7.6×10^{-4}	
Maximum degree of saturation [%]			100
Minimum degree of saturation [%]			35

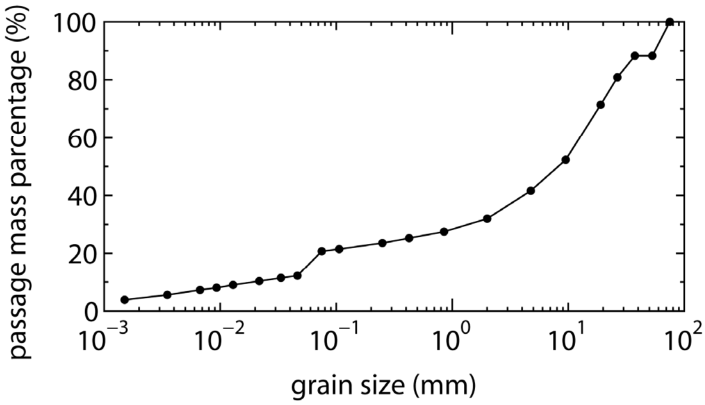


Figure 8. Grain size distribution of disturbed sample 2

some water pathways in the landslide dam. The stability of a landslide dam against seepage and overtopping will be discussed with the data obtained by this research in the future.

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