Monitoring method for the aging slope by geophysical explorations

Tatsuru Yamamoto [1], Harushige Kusumi [2] Tsuyoshi Yamamoto [3] and Makoto Nakamura [4]

[1] Graduate school of Kansai University
E-mail : k095797@ipcku.kansai-u.ac.jp
[2] Dept. of Civil and Engineering, Kansai University
E-mail : kusumi@ipcku.kansai-u.ac.jp
[3] Ministry of Land, infrastructure, Transport and Tourism
[4] Newjec Inc.
E-mail : nakamuramk@newjec.co.jp

ABSTRACT: This research is monitoring the ground condition inside the aging slope. The purpose of this research is to consider the value of a monitoring method with the ground evaluating system to estimate the soundness in the aging slope. In Japan, at the high economic growth period after the 1960's, a great number of slopes were formed to construct many roads and most slope protection methods were to cover with shotcrete on the slope. Now, those slopes are aging. Therefore, there is a possibility that the slope failures occur due to the weather and natural disaster such as climate variations, heavy rainfall and earthquake. It is important to establish the method monitoring the ground condition inside the slope to estimate the soundness in the aging slope and to effectually maintain slopes. In this research, firstly, by using elastic wave exploration and electric detection, we examined the ground condition in situs. Secondly, we changed each measured results of geophysical explorations into the porosity and the saturation with the ground evaluating system. This system uses seismic velocity – the porosity and the saturation relational expression (Wyllie 1956) and the resistivity – the porosity and the saturation relational expression (Archie 1941).

1. INTRODUCTION

In Japan, roads were rapidly built during the high economic growth in 1960'. A great number of slopes were formed to construct many roads and most slope protection methods were to cover shotcrete on the slopes. Now, those slopes with shotcrete are aging, and it is important to understand efficiently, and to evaluate stability and durability of the aging slopes.

The stability on the slope with shotcrete is greatly influenced by the weathering and the change of the back ground mountains and grounds. To make underground visible, the geophysical exploration is adopted. Two or more geophysical explorations are conducted in recent years, and the case where the geological structure is evaluated overall has been increasing as well. However, there are not still a lot of cases where these geophysical exploration results are quantitatively evaluated. Therefore, the establishment of the technique for quantitatively evaluating two or more geophysical explorations is needed, and the accumulation of the application example is also important.

The purpose of this research is to evaluate the ground more accurately by using the system [1) 2)] that converts seismic velocity distribution and electric resistivity distribution obtained in situ into the porosity distribution and the saturation distribution, and to verify the validity of the monitoring methodology by the conversion analysis to evaluate the soundness in the aging slope.

2. GEOLOGICAL CONDITIONS IN THE RESEARCH SITE

An analytical object in this research is a cutting ground slope along the national road No.9 in Omi district in Fukuchiyama City in Kyoto. Figure.1~3 shows the points for the investigation, and it is near to the south of the national road, and comparatively large-scale slope of about 200m in length and about 50m in height. A large-scale slope with shotcrete (district A) is distributed in the eastern part of the slope, and a small-scale cutting ground slope (district B) is distributed in the western part of it. These two points of the slope with shotcrete and the cutting ground slope are analyzed. As for the surface on the slope with shotcrete (district A), there are a lot of cracks due to aging, and a lot of vegetation from the crack and the swell are seen. The cutting ground slope (district B) is a naked ground slope, and there is hardly a big transformation that can be seen.

Geological features are in Tanba strata at Triassic in the Mesozoic-Jurassic Period, and are chiefly composed of a part of sandstone layer, a sandstone shale alternation of strata, and a basalt lava layer. In the boring investigation result in the research site, the stratum is distributed in the form of lens, and various cracks formed when the stratum is formed develop. Neither the thrust nor the slide surface is seen.

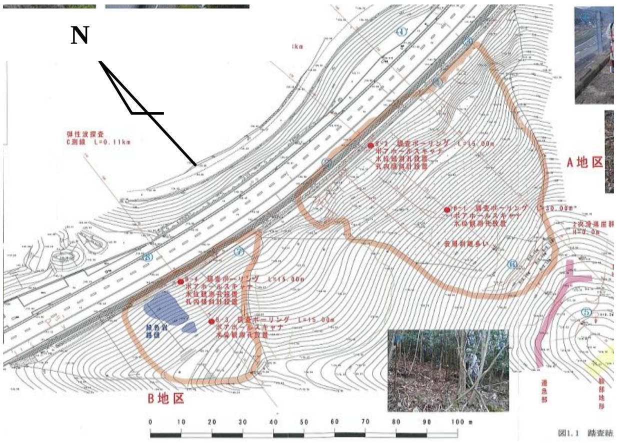

Figure.1 The investigation point (a cutting ground slope along the national road No.9 in Omi district in Fukuchiyama City in Kyoto.).

Figure.2 A large-scale slope covered shotcrete. (district A)

Figure.3 A small-scale cutting ground slope. (district B)

3. CONVERSION ANALYSIS METHOD

In the analyzed object point, the elastic wave exploration and the electric detection were done. We did the analysis that converted the seismic velocity and the resistivity that had been obtained by the investigation into the porosity and the saturation fraction that were the ground physical properties value. The outline of the converting analysis described as follows.

Though the seismic velocity and the resistivity in the rock mass have different physical values, they can relate the porosity and the saturation fraction of the rock mass as a parameter. About the seismic velocity, the Wyllie's formula [3] shown in expression (1) is generally known, and about the resistivity, the expression Archie's formula [4] shown in expression (2) is generally known.

$$\frac{1}{V_P} = \frac{(1-\varphi)}{V_m} + \frac{\varphi \cdot Sr}{V_f} + \frac{\varphi \cdot (1-Sr)}{V_a} \qquad (1)$$

$$\rho = a \cdot \rho_w \cdot \varphi^{-m} \cdot Sr^{-n} \qquad (2)$$

Here,

V_P: Seismic velocity of the rock masses.
V_m: Seismic velocity of the test piece.
V_f: Seismic velocity of the pore water.
V_a: Seismic velocity of the pore air.
φ: Porosity.
Sr: Saturation.
ρ: Resistivity of the rock masses.
a, m, n: Coefficient by the difference of geological features.

According to the recent research, the formula of Archie is considered not to be very suitable to the rock, though it suits well in the layer of sand. Therefore, our system used the parallel circuit model of the formula of Archie shown in expression (3).

$$\frac{1}{\rho} = \frac{1}{F \cdot \rho_w} + \frac{1}{\rho_c} + \frac{1}{\rho_0} \qquad (3)$$

Here,

F: Stratum resistivity coefficient ($F = a\varphi^{-m}Sr^{-n}$)
ρ_c: Resistivity of the conductive particle in the space with clay etc.
ρ_o: Resistivity of the test piece.

Expression (1) and expression (3) are shown respectively as the following uniting equation about one rock element (cell that divides into a small element) after converting the porosity and the saturation fraction.

$$V_p = f(\varphi, Sr) \tag{4}$$

$$\rho = g(\varphi, Sr) \tag{5}$$

Therefore, if the resistivity and seismic velocity on the natural ground are already-known, an unknown porosity and the saturation fraction can be obtained from expression (4) and expression (5) by the inverse analysis (optimization technique).

In the rock element (cells divided into a small element) shown in Figure.4, if a couple of resistivity and the seismic velocity of each cell are requested, the porosity and the saturation fraction can be calculated by the inverse analysis (optimization technique), whith is called a conversion analysis, because the conversion parameter is set. The system flow to evaluate the geological features by the conversion method is shown in Figure.5.

In the setting of the conversion parameter, it is preferable to calculate from the rock core in the investigation spot, and when obtaining the rock core is difficult, you can use the parameter of the rock type that corresponds from the data base based on the existing test outcome that is called a conversion parameter data base. With the above-mentioned procedure, it is possible to understand the multiple geographical exploration results quantitatively as a necessary ground property for evaluating the soundness in the slope, by uniting the result of the elastic wave exploration and the electric detection evaluated alone and qualitatively.

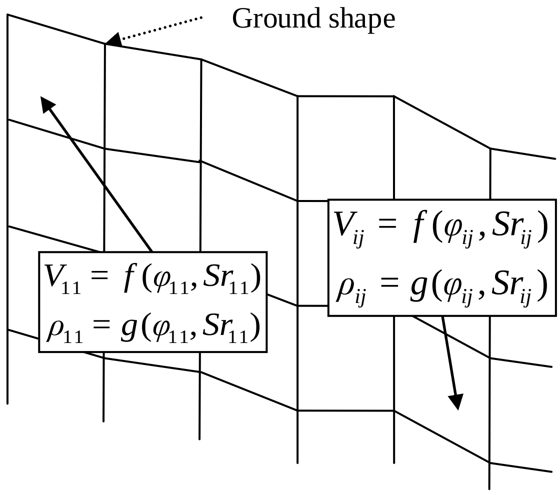

Figure.4 The rock element.

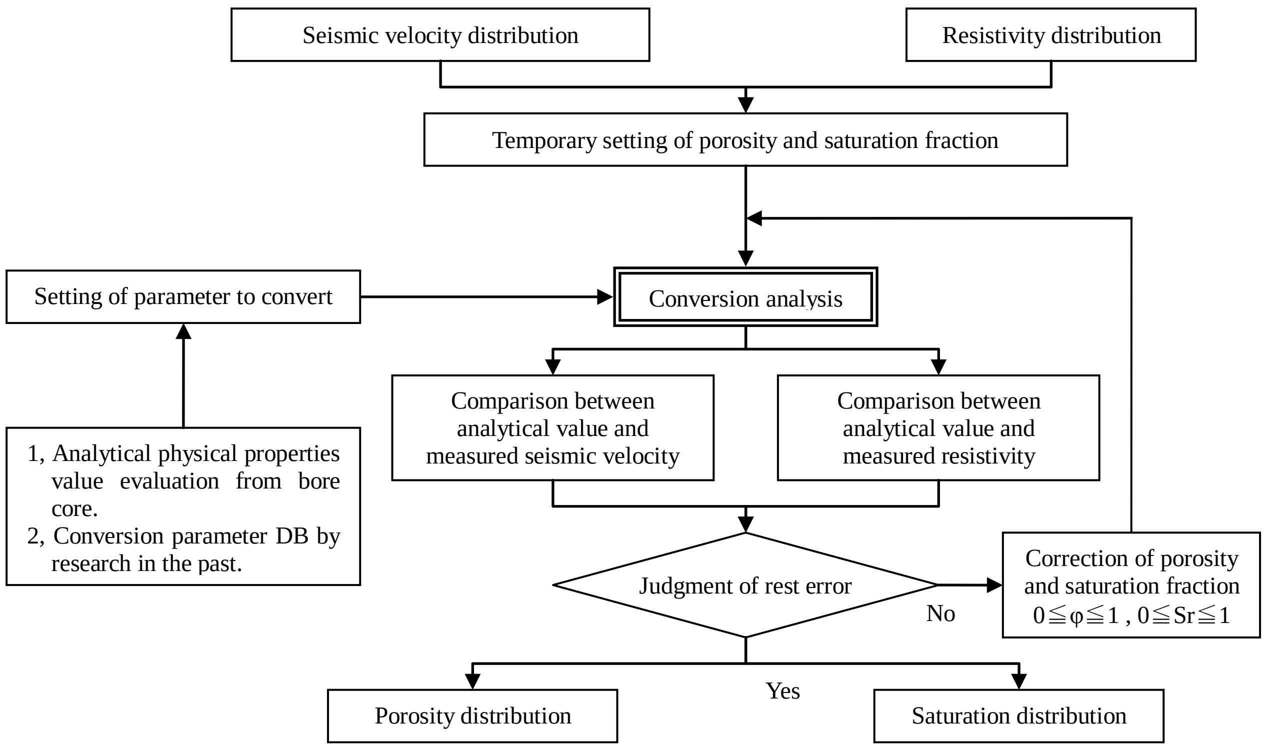

Figure.5 The system flow to evaluate the geological features structure by the conversion method.

The conversion parameter was decided in this research referring to the conversion parameter data base based on the test outcome of the past research though it is normally preferable to evaluate the physical properties value by using the boring core in the locale to set the conversion parameter. Table-1 shows the conversion parameter of the rock type used in this conversion analysis.

Table.1 The conversion parameter of the rock type used by this conversion analysis.

Rock type	Sandstone	Basalt	Sandstone shale alternation of strata
a : Coefficient of stratum resistivity coefficient F	0.13	0.43	0.23
m : Index of porosity φ of stratum resistivity coefficient F	0.68	0.78	0.98
n : Index of saturation Sr of stratum resistivity coefficient F	0.8	1.1	2.1
V_m (m/sec) : Seismic velocity of the test piece	6000	6000	6000
V_f (m/sec) : Seismic velocity of the pore water	1500	1500	1500
V_a (m/sec) : Seismic velocity of the pore air	330	330	330
ρ_o (Ωm) : Resistivity of the test piece	8000	8000	5000
ρ_w (Ωm) : Resistivity of the pore water	50	50	50
ρ_c (Ωm) : Resistivity of conductive particle	2000	2000	1500

4. ANALYSIS RESULT

In the porosity distribution obtained by the analysis, the validity of the analytical result is evaluated by comparing the porosity distribution with the rock class division because the drilling survey shows the rock class division. Moreover, in the saturation distribution obtained by the analysis, the validity of the analytical result is evaluated by comparing the groundwater level presumed by the water meter in the boring hole with the saturation distribution. The result of the conversion analysis in each investigation spot is described as follows.

(1) DICTRICT A

Figure.6-1 and Figure.6-2 show the porosity distribution in August and December 2008. The range EL.175-166m of Figure.6-1 shows high porosity because the electric detection became inaccurate influenced by the metal lath under the shotcrete. However, we obtained the result that is roughly corresponding compared with result of the rock class division investigated by the boring result except the area of the high porosity. Figure.7-1 and Figure.7-2 show the saturation distribution in August and December 2008. As well as Figure.6-1, the range EL.172-166m of Figure-7.1 shows a high saturation because the electric detection became inaccurate influenced by the metal lath under the shotcrete. When comparing it with the groundwater level presumed from the water meter in the hole, the position of underground water was able to be perceived to be a roughly corresponding to the area of a high saturation fraction in Figure-7.1, but it was not possible to compare it in Figure-7.2 because the groundwater level was located below the analyzed range.

(2) DICTRICT B

Figure-8.1 and Figure-8.2 show the porosity distribution in August and December, 2008, and Figure-8.3 shows the distribution of the change rate of the porosity in August and December. Compared to the result of the porosity distribution around the boring, we obtained nearly the same result with the rock class division investigated by the borimg. Moreover, we could understand a change with the lapse of time from August to December, and proved the possibility that the weathering progress was able to be expected.

Figure-9.1 and Figure-9.2 show the saturation distribution in August and December, 2008, and Figure-9.3 shows the distribution of the change rate of the saturation fraction in August and December. Comparing the saturation distribution with the groundwater level presumed from the water meter in the hole, in both Figure-9.1 and Figure-9.2, the position of underground water was able to be perceived to be a roughly corresponding to the boundary region that changed from a low area of saturation fractions into a high area, and the validity of the analytical result was proved.

From the above-mentioned result, the analytical result in district B was good compared to district A, and the profit of the monitoring methodology by the conversion analysis was proved.

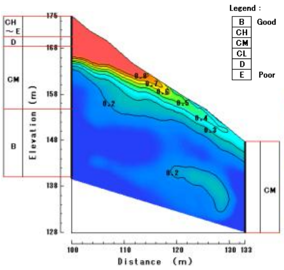

Figure.6-1
Porosity distribution (Aug/2008)

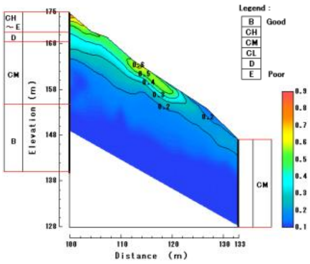

Figure.6-2
Porosity distribution (Dec/2008)

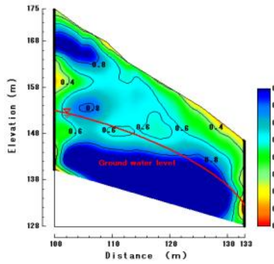

Figure.7-1
Saturation distribution (Aug/2008)

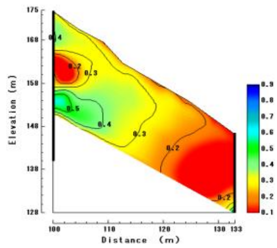

Figure.7-2
Saturation distribution (Dec/2008)

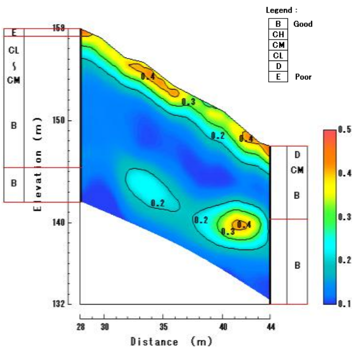

Figure.8-1
Porosity distribution
(Aug/2008)

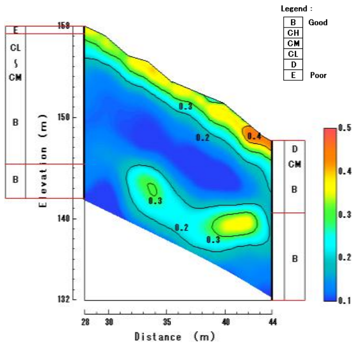

Figure.8-2
Porosity distribution
(Dec/2008)

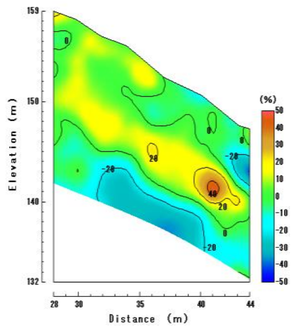

Figure.8-3
Porosity change rate distribution

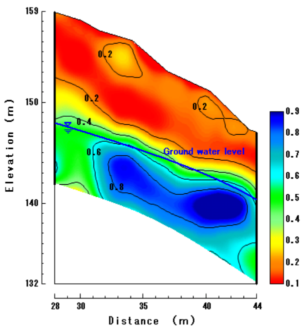

Figure.9-1
Saturation distribution
(Aug/2008)

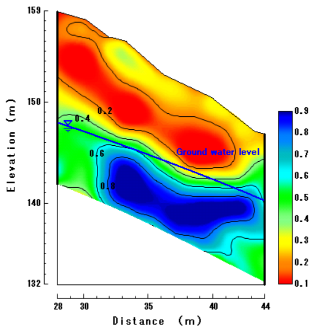

Figure.9-2
Saturation distribution
(Dec/2008)

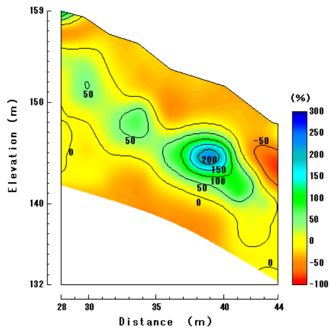

Figure.9-3
Saturation change rate distribution

5. CONCLUSION

In this text, by using the result of the elastic wave exploration and the electric detection, the applicability to the spot of the conversion analysis converting into the porosity and the saturation fraction that can be an effective index to evaluate the soundness in the aging slope was verified. The result of obtaining is shown as follows.

ⅰ) As for the porosity distribution that had been obtained by the conversion analysis, there was a tendency roughly corresponding to the rock class division of the boring result. Moreover, the possibility that the progress of weathering was monitored was proved from a change with the lapse of time of the porosity.

ⅱ) As for the saturation level distribution obtained by the conversion analysis, there was a tendency that the area where the saturation fraction is high is roughly corresponding to the groundwater level of the water meter in the hole, it is thought that the conversion analysis is a profitable technique as one of the monitoring methodologies that can presume the position of the groundwater level.

ⅲ) The result was good in the naked ground slope, but the result in the slope covered with shotcrete was not, because of the influences of shotcrete and metal lath. However, it is thought that the conversion analysis will become more profitable monitoring methodology by considering the applicability of the geophysical exploration matched to the site.

REFERENCES

1) Nakamura, M: Research concerning method of the ground of technological evaluation by inquiry of using together, PhD thesis of Kansai University, 2003.
2) Kusumi H, Takahashi Y and Nakamura M: Rock evaluation method when tunnel is constructed by conversion analysis of resistivity and velocity of elastic wave, JSCE of Journal F, Vol.62, No.4, pp.603-608, 2006.
3) Archie,G.E.: The Electrical Resistivity Log as Aid in Determining Some Reservoir Characteristics,Trans.A.I.M.E., Vol.146 pp54-62, 1942.
4) Wyllie,M.R.,Gregoty,A.R. and Gardner,L.W.: Elastic wave velocities in heterogeneous and porous media.Geophsics,21(1), pp.41-70, 1956.