Application of geophysical methods to dam safety assessment in Korea

Sung Keun LIM
Korea Rural Community Corporation(KRC)
5 Munye-Ro,Seo-Gu, Daejeon, Korea
sungkeun@ekr.or.kr

Ki Yeon PARK
Office of Environmental Geology, KRC
98 Anyangpankyo-Ro, Euiwang, Korea
kypark@ekr.or.kr

Young Soo SONG
Chonbuk National University professor
567 Baekje-daero, deokjin-gu, Jeonju, Korea
geosys@moak.chonbuk.ac.kr

Sung Ho SONG
Rural Research Institute, KRC
870 Haean-Ro,Sangrok-Gu, Ansan, Korea
shsong@ekr.or.kr

Chi Ho AHN
Technical Engineering Office, KRC
5 Munye-Ro,Seo-Gu, Daejeon, Korea
ngan@ekr.or.kr

SUMMARY

Electrical resistivity methods were applied to delineate leakage pathways and to investigate the condition of core material in earth fill dams. In other to evaluate the engineering geological properties of the soil deposits, two boreholes a dam were drilled to the bedrock that exceeds the height of the dam. A large set of field tests including standard penetration test(SPT) and in-situ permeability tests were carried out along the boreholes.
A series of laboratory tests were also conducted on the undisturbed soil samples obtained using the split-spoon sampler and thin wall tube sampler to determine their engineering characters. The resistivity values which were estimated from the previous inversion result for each depth were compared with the N values from SPT for each borehole. It could be classified in two groups where were not showed in general trend and most of the sites had some seepage problem and decrepit facilities need to be improved.
We have also measured resistivity values of undisturbed soil samples obtained from boreholes at 311 different dam sites. We confirmed low resistivity values of soil in core material were distributed at the Gyeongsang basin and some regions in Korean peninsula. As a result of these studies, it was possible to get more quantitative interpretation of seepage problem.

Key words: resistivity, leakage, earth fill dam, SPT, N value

INTRODUCTION

The water seepage is common problem in most of the earth fill dams in Korea. In addition, most of them are worried about the safety due to the deterioration and seepage because the many reservoirs and embankments were built more than half a hundred years ago. Recently, the structural vulnerability on the agricultural dams due to climate changes over the world and natural disasters is increased sharply.
Geophysical survey methods have been widely adopted as a key element to investigate the condition of core material, to identify the regions where leakage occurs and to ascertain preferred pathways for leakage(Panthulu et al., 2001). In Korea, application of geophysical methods to precise safety assessment for reservoir dams and embankments started in the late 1990's(Song et al., 1999). According to the previous reported results, seepage patterns in most of dam sites can be classified into seepage through the abutment, the dam wall itself, and its foundation(Song et al., 2005, Park et al., 2005). The ground conditions and the geological features of the dam site greatly influence the amount of seepage and its relevant effects. Internal erosion is a major cause of failure of the reservoir wall. Methods for seepage monitoring and internal erosion detection are therefore essential for the safety assessment of earth fill dams and embankments(Johansson, 1994). Experiences from all over the world indicate that the use of existing methods is not perfect, and that a lot of dams need improved surveillance.
We have performed the electrical resistivity method to delineate leakage pathways through earth fill dams. And a large set of field tests including SPT and in-situ permeability tests were carried out along the boreholes. Also, a series of laboratory tests were conducted on the undisturbed soil samples obtained using the split-spoon sampler and thin wall tube sampler to determine their engineering characters.

DAM SAFETY ASSESSMENT OF AGRICULTURAL INFRASTRUCTURES

There are 68,000 agricultural-based facilities and 19,590 locations need to be maintained periodically in Korea. First class facility to conduct regular safety assessment every five years is 1,016 locations and second class facility to conduct safety assessment if necessary is 18,574 locations. Reservoirs are accounted for 90.5 percent of the whole target assessment facilities. Recently, due to the continued adverse weather and earthquake events of countries adjacent to the Korean peninsula, the many lives and untold property damage were occurred and then the Government strengthen the safety management regulations of facilities for measures against damage from storm and flood.
Accordingly, the Ministry of food, agriculture, Forestry and Fisheries established the comprehensive details of the practice schedule for the reservoir to accomplish second class facilities in accordance with the guidelines for conducting the safety assessment of first class facilities. Figure 1 shows the number of annual precision safety assessment from 1995 to 2010. The annual target facilities have increased drastically since 2007.

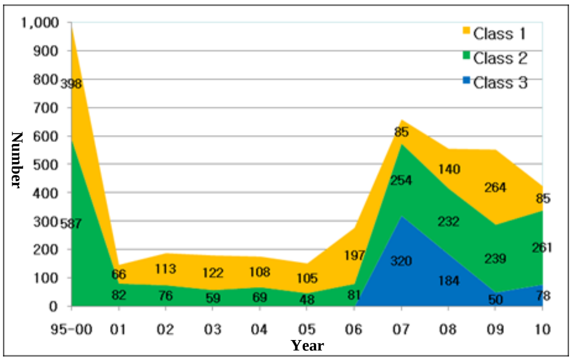

Figure 1. The number of target safety assessment facilities versus year. Class 1 means reservoir facility can accommodate more than 500,000 ton water. Class 2 means reservoir facility can accommodate less than 500,000 ton water. Class 3 is the facility except class 1 and class 2.

ELCTRICAL RESISTIVITY SURVEY AND BOREHOLE DRILLING INVESTIGATION

We conducted electrical resistivity surveys along the crest, each step to delineate leakage pathways and two boreholes a dam were drilled to the bedrock to evaluate the engineering geological properties of the soils at earth fill dams in Korea. Electrical resistivity survey is one of the oldest and most popular geophysical techniques in electrical exploration, due to its ability to produce images of the subsurface efficiently and efficient user friendly inversion software.

By applying electrical resistivity survey to investigate the condition of the core material, we could expect to get information on the variation of the electrical anomaly pattern due to the saturation of the soil. The objective of survey was to delineate the weak zone of the dam wall and estimate the status of core zone.

About 99.8 % of agricultural dams in Korea are an earth fill type covered with soil all over the embankment, so the ground connections of electrode for all dams were very good. Two profiles per target dam were explored as shown in Figure 2; one profile at the crest and the other profile at the downstream slope. Figure 2 also displays the location of the two borehole sites on the crest of a dam.

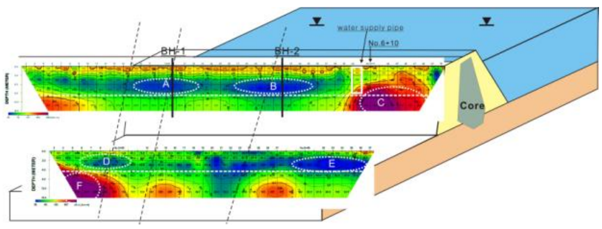

Figure 2. Result of resistivity survey performed on an earth fill dam. Exact location and depth of two borehole sites are denoted as vertical black bars.

Figure 2 shows the result of electrical resistivity survey performed at an earth fill dam located on the Gyeonggi province, Korea. As shown in Figure 3, a major low-resistivity anomaly of less than 40 Ohm-m appeared at the center of the dam to the outside of the crest, and were thought as the vulnerable areas saturated with water leakage. The electrical resistivity sections measured at the downstream slope also show a low-resistivity anomaly at the right side of the dam and this anomaly has a continuity along the right abutment.

CORRELATION BETWEEN ELECTRICAL REESISTIVITY AND N VALUE FROM SPT

The borehole drilling investigation has been known as the most direct and unbiased technique. In general, while the vertical drilling is used for investigation of the earth structures and structural foundations, the SPT was additionally executed to determine the soil conditions and obtain the soil samples. In order to evaluate the engineering geological properties of the soil deposits, two boreholes a dam were drilled to the basement that exceeds the height of the dam. For determining the conditions and characteristics of dam materials, a SPT at 1.0 ~ 3.0 m depth intervals was also conducted during the borehole drilling, and disturbed and undisturbed soil samples were continuously obtained using the single tube core barrel together with the split-spoon sampler of SPT and the thin-wall open-tube sampler, respectively

Here, we would like to present the geotechnical SPT method and regulation for geophysical application and interpretation.

The resistivity and N values from SPT for each borehole were compared in Figure 3 to look into their relation. The resistivity values for 311 sites were estimated from the previous inversion results.

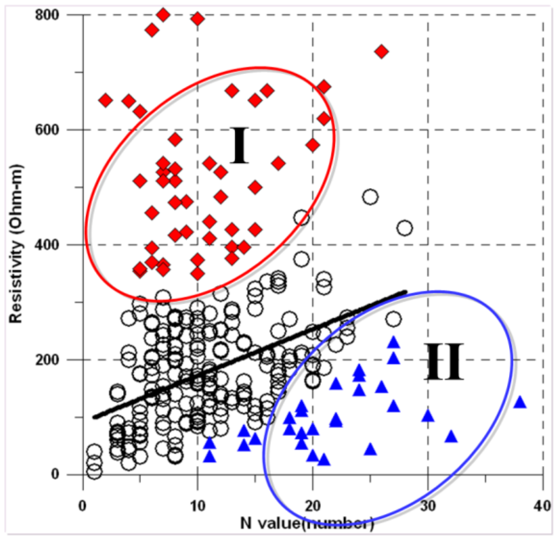

Figure 3. SPT N Value versus Resistivity for each borehole. Group I is the zones where resistivity values were high but N values were low. Group II is the zones where resistivity values were low but N values were high.

Seeing the degree of correlation from Figure 3, two groups are different from the general correlation pattern, although most of the values are positively related to each other.

It could be classified in two groups where is not showed in general trend. Group I is the zones where resistivity values were high but N values were low. Group II is the zones where resistivity values were low but N value were high.

According to the previous research, these groups were interpreted that the upper group I was suspected to be in the piping condition and the lower group II was presumed to show low resistivity values due to the core material of an earth fill dam(Oh and Sun, 2008). However, it is not simple that we estimate core material condition of many dams based on these results, equally.

So overcoming the limitation of interpretation for the correlation between resistivity and SPT, we tried to figure out the maintenance properties of dams which belong to Group I and Group II shown in Figure 3 by means of analyzing a bunch of data obtained from the precise dam safety assessment. A large set of field tests including SPT and in-situ permeability tests were carried out along the boreholes. Also, a series of laboratory tests were conducted on the undisturbed soil samples obtained using the split-spoon sampler and thin wall tube sampler to determine their engineering characters. Figure 4 shows an example of grain size distribution analyzed from undisturbed soil sample in RRI(Rural Research Institute) laboratory. Usually, undisturbed soil of 1.0 m length was sampled near the surface and in the deeper zone, respectively. In case of this dam site, the sampling depth started from 3.0 m to 4.0 m and from 9.0 m to 10.0 m. Figure 4 shows clay content of soil is significantly diminished at deeper zone, compared with lower zone. The results of borehole-drilling investigations for the earth fill dams indicated that the core was mainly composed of sand, silt and clay.

Sample Name		BH - 1		Soil Test Results
Depth(m)		3.0~ 4.0	9.0~ 10.0	
Grain Size (%)	Gravel(mm) (> 4.75)	5.0	5.2	
	Sand(mm) (0.075 ~ 4.75)	46.9	49.1	
	Silt(mm) (0.005 ~ 0.075)	28.3	34.1	
	Clay(mm) (<0.005)	19.8	11.6	

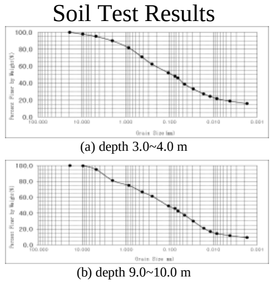

Figure 4. An example of Grain size distribution and index properties of soil sample obtained from a dam site. The soil classes are described according to grain size left the graph; (a) the result in depth 3.0~4.0 m (b) the result in depth 9.0~10.0 m. The grain size distribution curve was obtained from the results of the sieving test accomplished by RRI laboratory.

Figure 5 shows the contour map of clay content distribution obtained from the results of sieving test with undisturbed soil samples of 311 different dam sites. Previously, Group I and Group II on the map are demonstrated in Figure 3. As can be seen from Figure 5, most sites in Group I were located to the low clay content zones, and also had the seepage problems. Based on the previous reports, also, most of the sites in Group I had some seepage problem and decrepit facilities need to be improved.

It may indicate that the deficiency of fine particles like soils may cause an increase of resistivity value, and results in the weakening of the core material, which appeared as low N values. And it may lead to the failure of the reservoir dam due to piping and excessive seepage through the core zone.

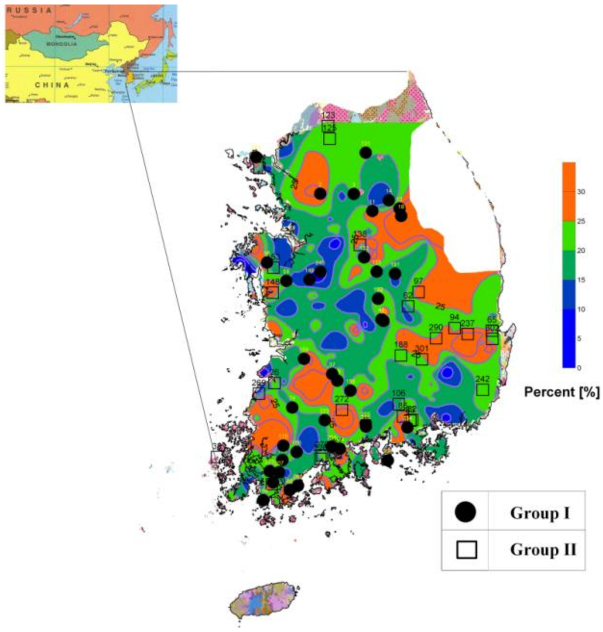

Figure 5. A contour map of clay content distribution analysed from undisturbed soil samples of dam sites. Black circles and open black squares denote the Group I and the Group II interpreted from Figure 3, respectively.

SOIL RESISTIVITY MEASUREMENT

To get more quantitative interpretation of seepage problem, We have measured resistivity values of undisturbed soil samples obtained from boreholes at 311 different dam sites. SAS1000 instrument(by ABEM Co.) is used to measure electrical resistivity during the indoor experiments. Electrical resistivity studies have developed and been employed to study electrical properties of rock and soil materials in the subsurface. The electric current is commonly conducted through rocks and sediments by the pore fluids, clay minerals, and metallic minerals in the rocks and sediments (Reynolds, 1997).

Electrical resistivity obtained from the results of the survey is a physical quantity associated to the electrical properties of the ground and can vary from locations to locations. Mostly it is affected by grain size, porosity, permeability and clay mineral contents of ground. Therefore it is very important to examine the properties of the soil of dam sites for safety assessment. So we have the measured resistivity values of undisturbed soil samples which were obtained using the single tube core barrel together with the split-spoon sampler of SPT.

Figure 6 shows resistivity distribution measured from undisturbed soil samples at 311 different dam sites in Korea. The low resistivity values of soil in core material were showed at the areas of the Gyeongsang province(black rectangular areas on the contour map shown in Figure 6), south-west coast line and the vicinities of Gongju and Okcheon. In general, Clay minerals of illite group such as montmorillonite make soil and rock resistivity lower(Park, 2004). According to previous research, the Cretaceous sedimentary rocks are located at many part of Gyeongsang province, in the vicinities of Eumsung, Gongju, Youngdong, Jinan, Haenam and Neungju in Korea(Reeman and Chun, 2002).

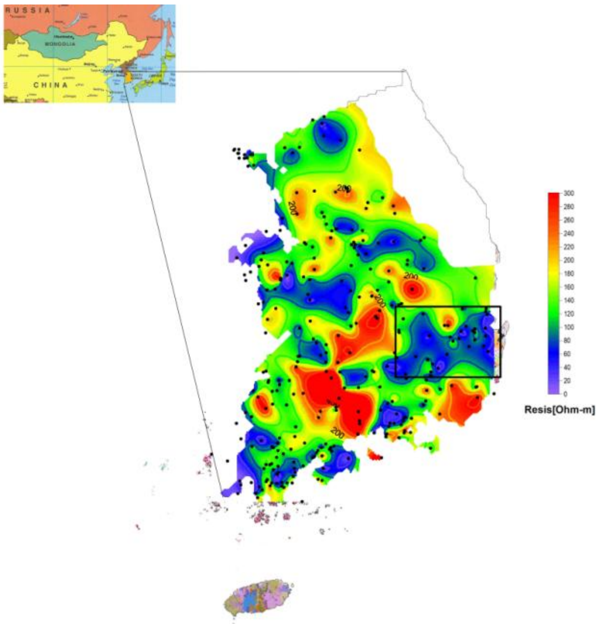

Figure 6. A contour map of resistivity distribution measured from undisturbed soil samples of dam sites. Dam sites for precise safety assessment are denoted as black circle dots.

The low resistivity zones shown in Figure 6 were well matched with the area overlaid with Cretaceous sedimentary rocks. From this analysis, we could say that the soils of these areas contain much clay minerals which are connected to volcano activities from in the end of Cretaceous to in the early part of the Tertiary. If the nationwide clay distributions of the soils in earth fill dams are obviously known through continuing these studies in near future, we can expect the accuracy and quality of resistivity survey be improved.

CONCLUSIONS

The results of resistivity survey and borehole test were interpreted together to infer the condition of the core material of an earth dam against the piping or leakage condition, and to understand the relation between the two properties. It was compared between the resistivity values which were estimated from the previous inversion results of 311 dam sites and N values from SPT for each borehole. It could be classified in two groups where was not showed in general trend, and most of the dam sites were located to the low clay content zones. Based on the previous reports, these dam sites also had some seepage problem and decrepit facilities need to be improved. Low resistivity values of soil in core material were distributed at the Gyeongsang basin and some regions, where were well matched with the area overlaid with Cretaceous sedimentary rocks. It is assumed that the soils of these areas contain much clay minerals which are connected to volcano activities from in the end of Cretaceous to in the early part of the Tertiary.

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