View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Missouri University of Science and Technology (Missouri S&T): Scholars' Mine

Missouri University of Science and Technology
Scholars' Mine

International Conference on Case Histories in Geotechnical Engineering

(1998) - Fourth International Conference on Case Histories in Geotechnical Engineering

10 Mar 1998, 2:30 pm - 5:30 pm

Survey of Seepage Through Heightened Earthfill Dam With High-density Electrical Prospecting Method

Yoshikazu Yamaguchi
Public Works Research Institute, Tsukuba, Japan

Hitoshi Yoshida
Public Works Research Institute, Tsukuba, Japan

Yutaka Imabayashi
Public Works Research Institute, Tsukuba, Japan

Tadahiko Sakamoto
Japan Dam Engineering Center, Tokyo, Japan

Follow this and additional works at: https://scholarsmine.mst.edu/icchge

Part of the Geotechnical Engineering Commons

Recommended Citation

Yamaguchi, Yoshikazu; Yoshida, Hitoshi; Imabayashi, Yutaka; and Sakamoto, Tadahiko, "Survey of Seepage Through Heightened Earthfill Dam With High-density Electrical Prospecting Method" (1998). *International Conference on Case Histories in Geotechnical Engineering*. 27.
https://scholarsmine.mst.edu/icchge/4icchge/4icchge-session02/27

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conference on Case Histories in Geotechnical Engineering by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

Proceedings: Fourth International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, March 9–12, 1998.

SURVEY OF SEEPAGE THROUGH HEIGHTENED EARTHFILL DAM WITH HIGH-DENSITY ELECTRICAL PROSPECTING METHOD

Paper No. 2. 11

Yoshikazu Yamaguchi
Public Works Research Institute, Tsukuba, Japan

Yutaka Imabayashi
Public Works Research Institute, Tsukuba, Japan

Hitoshi Yoshida
Public Works Research Institute, Tsukuba, Japan

Tadahiko Sakamoto
Japan Dam Engineering Center, Tokyo, Japan

ABSTRACT

High-density electrical prospecting was conducted on a heightened earthfill dam during the first filling of the reservoir to study the possibility of applying this prospecting method to examination of zoned structures inside an embankment dam and monitoring of seepage through the dam body. Visual inspection and measurement with the measuring devices were also conducted to control the safety of the dam. As a result, it was found that zoned structures inside the dam such as a newly built embankment, an existing embankment, and drain are zones each having a different resistivity value. In addition, since the area where the resistivity inside the dam body changed with the impounding almost coincided with the area where pore water pressure changed, the seepage area is an area where the resistivity changed.

KEYWORDS

earthfill dam; electrical prospecting; resistivity; seepage; redevelopment; heightening; safety control

INTRODUCTION

The construction of dams in Japan dates back more than 2,000 years, and there are about 2,500 completed dams with a height of 15 meters or more at present. Almost all early dams were small earthfill dams for irrigation. Although most of them still exist as old structures and function well, some of them have problems concerning safety, such as internal erosion, slope erosion, concentrated leakage through the dam body or its foundation, inadequate drainage systems, large settlement and inadequate spillway capacity. After World War II, the construction of large dams was started mainly for flood control, water resources development, power generation and so on, and is in the most active period now. However, more than 50 years have passed since the end of World War II, and many dams of this kind are rather old now. Besides, recently in Japan, because of the decrease in suitable sites for dam construction and the advances in dam design and construction technologies, the demand and possibility of redevelopment of dams, such as heightening, reservoir excavation, improvement of intake facilities and redistribution of storage capacity, have been rising (Sakamoto and Yamazumi, 1994).

Taking embankment dams as an example, zoned structures and seepage conditions in dam bodies should be investigated in the case of redevelopment and remedial works. The most effective and precise method for this is drilling to obtain geologic logs, to and conduct laboratory tests using core samples and in-situ tests in drill holes. But to drill many holes in a dam body, particularly in an impervious zone, is a money- and time-consuming procedure, and might reduce the degree of stability. Physical prospecting, with which a wide area can be investigated economically and in a short time, should be combined with a smaller number of drill holes.

In recent years, geotomography and high-density electrical prospecting (HDEP) have become very attractive for subsurface exploration in civil engineering. This paper presents details of the application of the HDEP to a heightened earthfill dam during the first impounding of the reservoir to survey zoned structures and seepage conditions in a dam body.

OUTLINE OF SAYAMA DAM

Sayama Dam, constructed about 2,000 years ago, is the oldest earthfill dam for irrigation in Japan. This dam has been heightened four times

Fourth International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu

since its completion; the latest redevelopment project was carried out in 1928. However, in recent years, because of the rapid urbanization in the lower reaches of the dam, the dam had to be heightened to increase the flood control capacity of the reservoir and to provide a larger recreational area.

The redevelopment project consists of about 1-m heightening of the existing dam body with a maximum height of 17.4 m as well as about 3-m excavation of the reservoir bed. The height and the crest length of the redeveloped dam (main dam) are 18.4 m and 750 m respectively. Plane and typical cross section (cross section No. 56) of the dam are shown in Figs. 1 and 2 respectively.

For the embankment on the upstream side of the dam body, sandy soil–

Table 1 Design values of existing and newly built dam bodies

Zone	Existing Dam	Type A Material & Earth Blanket	Type B Material	Drain
Wet Density, t/m^3	1.90	1.99	2.06	1.90
Saturated Density, t/m^3	1.95	2.12	2.17	—
Cohesion, kN/m^2	34.3	19.6	9.8	0.0
Internal Friction Angle, °	15.0	27.0	33.0	35.0
Permeability Coefficient, m/s	1×10^{-6}	1×10^{-7}	1×10^{-6}	1×10^{-5}

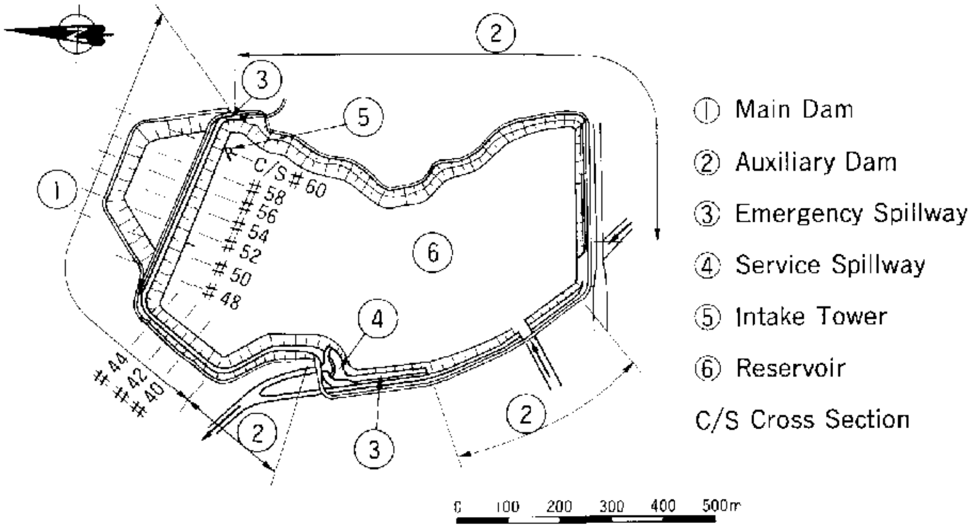
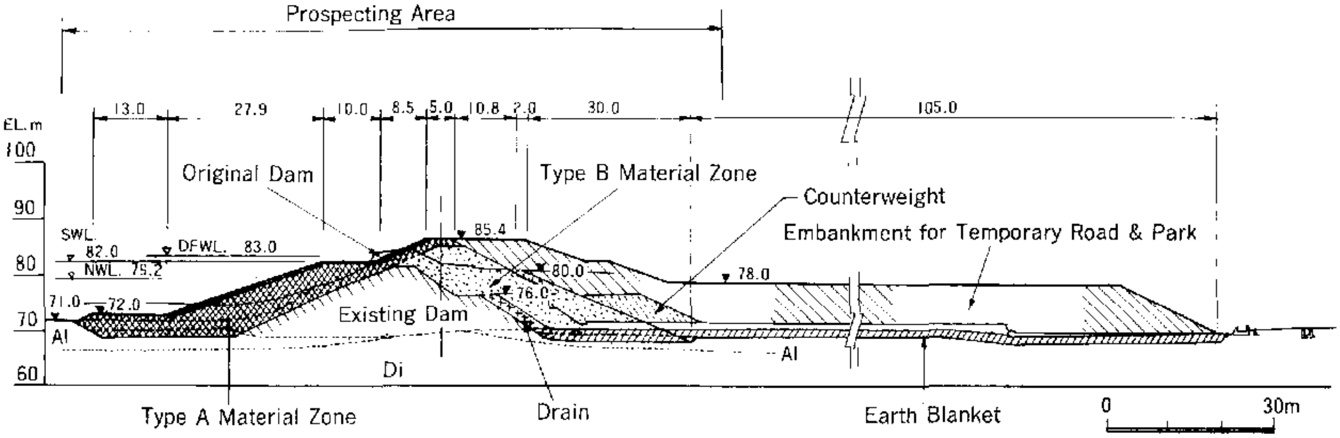


Fig. 1 Plane of Sayama Dam



DFWL=Design Flood Water Level, SWL=Surcharge Water Level,
NWL=Normal Water Level, Al=Alluvium, Di=Diluvium.

Fig. 2 Typical cross section of Sayama Dam clay mixtures (Type A materials) are used to assure watertightness and stability. Sandy soils (Type B materials) are employed for the downstream side to assure stability mainly. All of these construction materials can be obtained through the excavation of the reservoir bed and the foundation for the spillway. A drain is newly provided in the dam body to drain off the percolating water. Design values of existing and new dam bodies are summarized in Table 1.

The foundation of the dam is composed of alternate horizontal layers of sand–gravel mixture and clay, which has a permeability coefficient ranging from 1×10^{-7} to 1×10^{-5} m/s. A downstream earth blanket with a length of about 100 m was placed on the foundation to increase the seepage path, to reduce seepage and to reduce seepage exit gradients. The earth blanket consists of Type A materials.

The embankment work was completed in September 1996, and the first filing of the reservoir was carried out from late in October 1996 to mid-December 1996. During the impounding, monitoring of the behavior of the dam with several kinds of measuring devices and visual inspection, and HDEP were conducted.

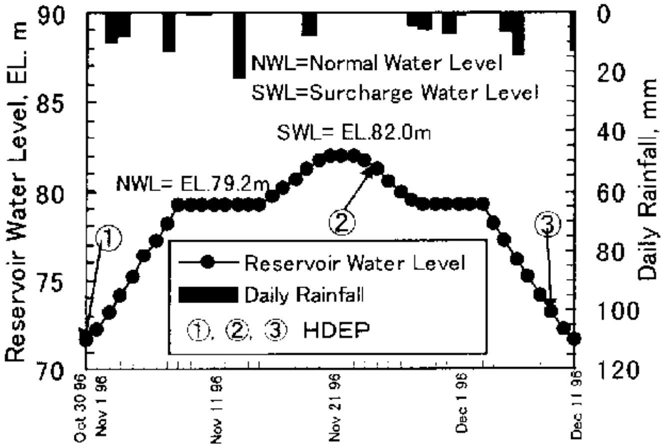


Fig. 3 Reservoir water level and daily rainfall during the first filling

INSTRUMENTATION SYSTEM

The water level fluctuations in the reservoir and the daily rainfall during the first filling of Sayama Dam are illustrated in Fig. 3. For the safety control of the dam and its foundation, visual inspection and measurement with the measuring devices were carried out. The types and frequency of measurements are summarized in Table 2.

Because the HDEPs stated below were conducted along cross section No. 58+10 m, the layout of measuring devices installed along cross section No. 58 was as shown in Fig. 4. This section is almost the same as the typical cross section.

HIGH-DENSITY ELECTRICAL PROSPECTING

The HDEPs were performed along cross section No. 58+10 m three times during the impoundment. As shown in Fig. 3, the first, the second and the third surveys were carried out just before the first filling, at the time when the reservoir water level was nearly equal to the surcharge water level, and immediately before the completion of the first filling, respectively.

Apparent resistivity of the dam and its foundation was measured by a pole-pole electrode array. The measuring line was 118 m long in plane. Electrodes were placed on the surfaces of the dam body and its foundation at intervals of 2 m. In the case of the second prospecting some electrodes were floated on the water surface in the reservoir. Maximum electrode spacing, i.e. maximum prospecting depth was set at 30 m. 720 to 780 data samples were taken in each survey.

The alpha centers method was used to analyze all the measured data and to obtain the reconstructed resistivity image of the dam and its foundation (Shima, 1990). Topographic compensation was also made with the FEM simulation.

Table 2 Types and frequency of measurements

Type	Number of Measuring Sections	Number of Measuring Points	Frequency	Remarks
Surface Movement	10	20 Crest and D/S Berm in Each Section	once a week	Section # 42, 47, 49, 51 53, 55, 59, 60 & 61
Seepage	5	5	once a day	Section # 51, 52+20 m, 55+5 m, 57+5 m & 59
Pore Water Pressure	4	67	once a day	Section # 42+10 m, 51+10 m, 54+10 m & 58
Phreatic Line	4	4	once a day	Section # 42+15 m, 51+15 m, 54+5 m & 58

Fourth International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu

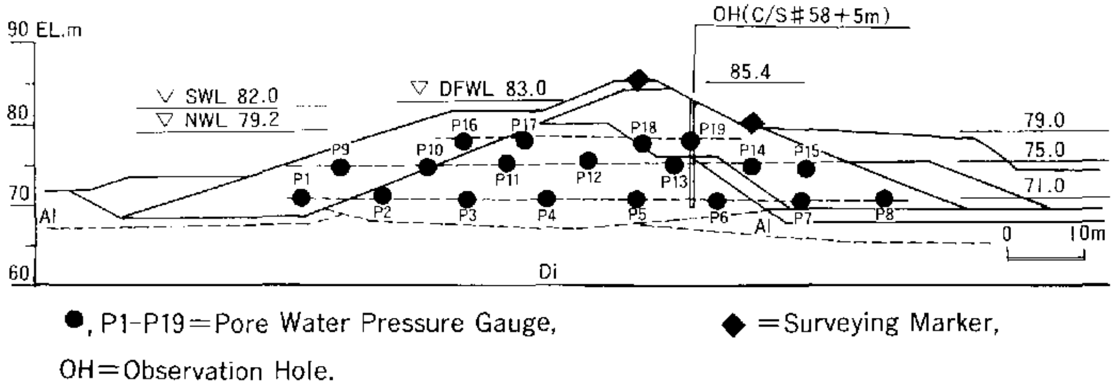


Fig. 4 Layout of measuring devices in cross section No.58

OBSERVED BEHAVIOR DURING FIRST FILLING

The results of measurement and visual inspection during the first filling of the reservoir showed that the dam as a whole exhibited safe behavior. The measured results of the measured results of pore water pressure and water level in the observation hole around cross section No. 58 where the HDEPs were conducted are described in the following paragraphs.

Excess pore water pressure took place as a result of fill placement for the dam at each of the four cross sections where pore water pressure gauges were installed. The value of excess pore water pressure was larger in the newly built embankment than in the existing embankment. However, no distinct difference was recognized between in the Type A material zone and the Type B material zone in the newly built section. At cross section No. 58, fluctuations in the value of pore water pressure head were observed at 3 of the 19 pore water pressure gauges used, namely, P1, P2 and P9. The change in the value of pore water pressure head with the passage of time is shown in Fig. 5 together with fluctuations in the reservoir water levels. This figure shows that after the reservoir water level rose above the elevation at which the pore water pressure gauges were mounted, the value of pore water pressure head measured by P1 and P9 placed in the Type A material zone varied in line with fluctuations of reservoir water levels although there was some time lag. However, the pore water pressure head measured by P2 which was placed at the same elevation as P1 in the existing embankment section near the boundary between the newly built and existing sections responded more slowly to the change in reservoir water level than the pore water pressure head measured by P1. Besides, the range of variation of the P2 value was smaller than that of the P1 value.

The reservoir water level during the first filling, and changes in water levels inside the observation hole provided at cross section No. 58+5 m with the passage of time are shown in Fig. 6. This figure reveals that fluctuations in reservoir water levels cause almost no changes in water levels inside the observation hole.

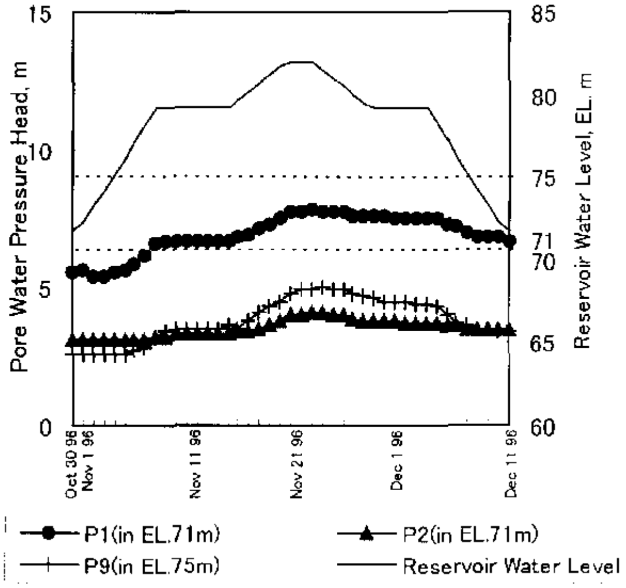


Fig. 5 Pore water pressure head in the dam body

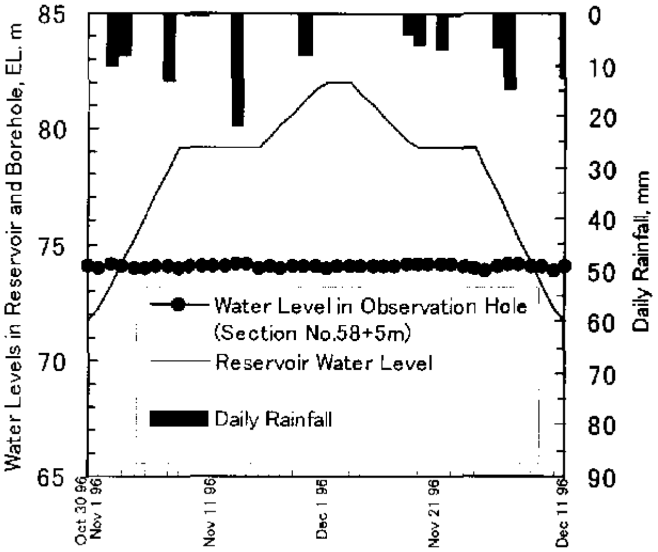


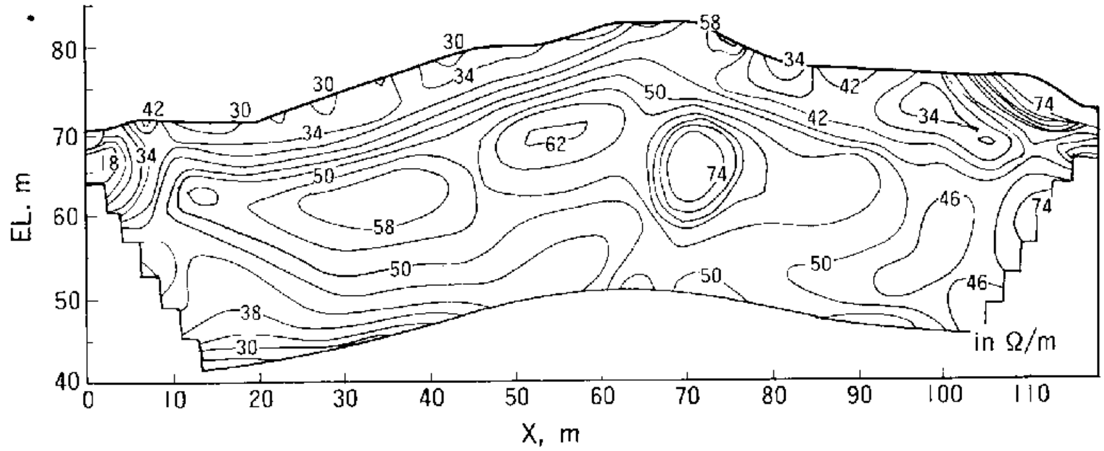
Fig. 6 Water level in the observation hole

Fourth International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu

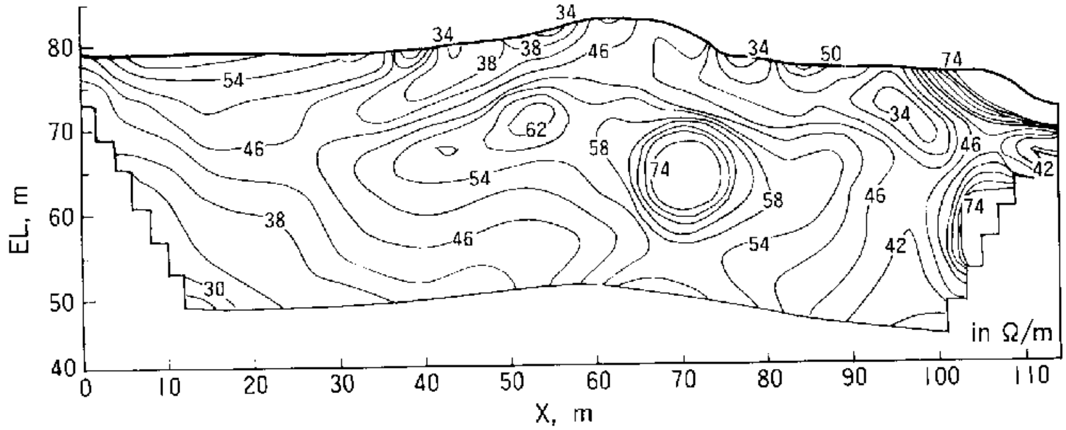
From the measured results mentioned above, it is assumed that percolating water from the reservoir to the inside of the dam remained almost entirely within the Type A material zone that forms the outermost zone in the upstream side of the dam. The short period of less than two months required for this first filing of the reservoir is the reason for it.

ELECTRICAL PROSPECTING RESULTS

The distribution of resistivity of the dam and its foundation obtained from the HDEPs is shown in Fig. 7. However, since there is not a significant difference between the distribution of resistivity obtained from the first prospecting and that obtained from the third prospecting, the results of the third prospecting are not shown in the figure. The



(a) First prospecting



(b) Second prospecting

Fig. 7 Reconstructed resistivity image

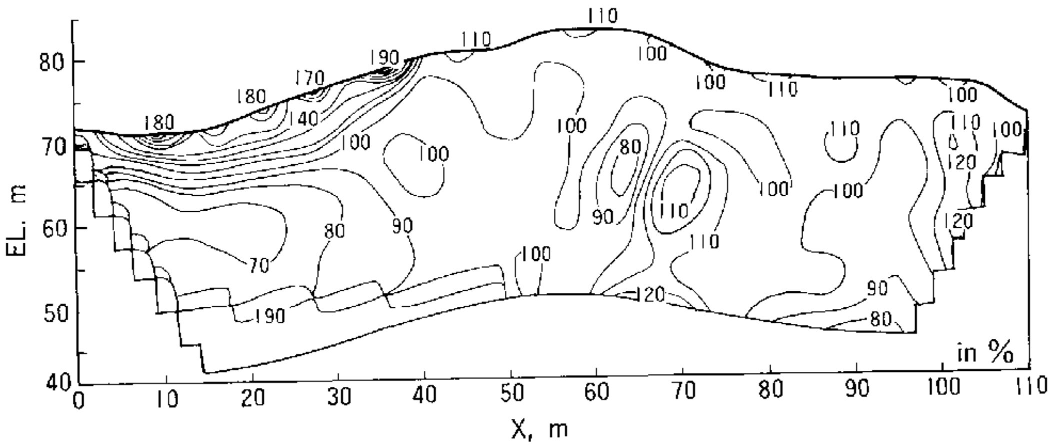


Fig. 8 Comparison of the first and the second prospecting results

results of the first HDEP given in Fig. 7 (a) show that the foundation as well as the zoned structures inside the dam body such as the existing embankment, newly constructed embankment, and drain can be distinguished by the contrast of resistivity. A detailed explanation of resistivity values in each zone is given below.

The resistivity of the foundation is almost within the range of 38-58 ohms/m. There are high-resistivity zones in x=20-40m and near x=70m, but it is not clear whether they are related to the geological condition. In particular, the high-resistivity zone near x=70 m is very likely to be a false image caused by the drain, which provides relatively high resistivity. At the upstream end of the measurement line, there is a low-resistivity zone with a resistivity of 18 ohms/m near the boundary between the Type A material zone and the alluvium. This is also attributed to false images peculiar to the area around the end of the measurement line, or to the existence of alluvial clay.

The resistivity of the existing embankment is almost within the range of 38-66 ohms/m. The high-resistivity zone in the mid-part of the embankment coincided with the oldest section of the embankment made up mainly of fine sand originated from the alluvium. The distribution of this zone was revealed by excavation of the old embankment, which was carried out to preserve it (Kanamori *et al.*, 1994).

The resistivity of the Type A material zone is almost within the range of 26-38 ohms/m, and is lower than the resistivity of other zones. This is attributed to the fact that Type A material contains relatively larger amounts of clay than other zones.

The resistivity of the Type B material zone, which is made up of sandy soil, is almost within the range of 34-46 ohms/m. A zone with a low resistivity of 30-38 ohms/m is distributed around the berm near x=80m and in the counterweight near x=100m. Whether the low-resistivity zone near the berm is a reflection of differences in water content or the degree of compaction, or analytical false images due to the topographic undulations is not clear. The reason for the low resistivity in the counterweight is also unknown.

The resistivity of the embankment for the temporary road is almost within the range of 38-66 ohms/m, and is relatively high. This is attributed to the possibility of false images around the end of the measurement line. However, unlike the dam body, this section is not subjected to strict compaction control by density during the construction work, and therefore it is highly likely that the soil has a lower density than that used for the dam body.

Next, we investigate the relation between changes in the distribution of resistivity obtained from the results of each HDEP and the seepage condition inside the dam body. The results of the first prospecting carried out just before the filling were compared with the results of the second prospecting carried out when the reservoir water level was close to the surcharge water level. To clearly indicate the difference in the distribution of resistivity, the distribution of values obtained by dividing resistivity values from the second prospecting by those from the first prospecting and expressed as percentages, is illustrated in Fig. 8.

The resistivity value of the same soil varies depending on porosity and the degree of saturation. The resistivity of pore water among soil particles also affects the resistivity value of the entire soil. In the case of Sayama Dam, since the dam and most of its foundation have a resistivity lower than the resistivity of the reservoir water of about 50 ohms/m, the resistivity of any place into which the reservoir water seeped should increase. From Fig. 8, an increase in resistivity due to a rise in the reservoir water level is limited to the place lower than the surcharge water level in the Type A material zone located in the outermost section in the upstream side of the dam. This coincides with the case where a change in pore water pressure head inside the dam due to a rise in the reservoir water level is almost limited to the Type A material zone. Thus, we can roughly estimate the seepage condition from changes in resistivity inside an earthfill dam.

CONCLUSIONS

We conducted an HDEP on a heightened earthfill dam, and studied the possibility of applying this prospecting method to examination of zoned structures inside the dam and monitoring of seepage through the dam. As a result, we learned that zoned structures inside the dam such as a newly built embankment, an existing embankment, and drain are zones each having a different resistivity value. In addition, since the area where the resistivity inside the dam body changed with the filling almost coincided with the area where pore water pressure head changed, the seepage area inside the dam body is an area where the resistivity changed.

REFERENCES

Kanamori, W. *et al.* [1994]. "Raising of Sayama-ike Dam", Proc. 18th Intern. Congr. Large Dams, Q. 70, R. 32, pp. 503-516.

Sakamoto, T. and A. Yamazumi. [1994]. "Redevelopment projects for multipurpose dams in Japan", 18th Intern. Congr. Large Dams, Q. 70, R. 31, pp. 475-502.

Shima, H. [1990]. "Two-dimensional automatic resistivity inversion technique using alpha centers", Geophysics, Vol. 55, No. 6, pp. 682-694.

Fourth International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu