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Maintenance and operation of aged dams

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ABSTRACT: In this paper, our approach for extending the lifetime of the aged dams is described. The main problems of the aged dams are structural deterioration and disappearance of records. The extraction work of the problem was conducted based on the failure mode analysis of the dam for structural deterioration. Consequently, there was no urgent problem connecting with the dam failure. But, it turned out that information such as monitoring records had not been used effectively enough for maintenance of dams. It was reconfirmed that the periodical check and the measurement were the most important for the operation and maintenance of the dam, and various approaches for the improvement of the dam safety have commenced.

1 DAMS OF EPDC

1.1 *History of EPDC*

EPDC (Electric Power Development Co.,Ltd.) was established in 1952 to accomplish the large-scale power generation projects suitable for a rapid increase in the power demand of Japan after World War II. The first large-scale electric power development that EPDC had handled was the Sakuma Dam of the concrete gravity type of 155.5 m in height in 1956. Then the domestic construction standard of a large-scale dam in Japan was not provided. So it was designed by adopting an overseas technology and the standard, and constructed by using imported construction equipments. Afterwards, the Okutadami Dam (concrete gravity type, 157.0 m, 1960) and the Miboro Dam (rock-fill with inclined impervious core, 131.0 m, 1961) which was called "Pyramid in the Orient" at that time were developed. The large-scale hydro power projects have been accomplished in a short term, and now EPDC subsequently owns and operates 48 Dams in Japan. The major EPDC dams show in Table 1, and those locations in Figure 1.

1.2 *Current situations and issues of hydro power plant*

Recently, Japan's economic growth is at low level after the high-growth period had been maintained after World War II, and also the expansion of the power demand has stagnated. The number of domestic new hydro power projects has decreased, and the scale is also smaller than before. However, the hydro power as renewable energy performs the key role in accordance with highlighting the value of global environment. Moreover, Japan's self-sufficiency ratio of the energy resources is the lowest in the advanced countries, and importance of the hydro power that is a pure domestic energy is quite high. Effective use of the existing hydro power is the national proposition in term of energy security.

The history of the hydro power development in Japan is so old that the half number of existing hydro power stations passed 60 years or more after construction, and various repair works, big and small, of the old hydro power plants are increasing in recent years. It is big problem for the electrical power companies in Japan how aged hydro power plants will be operated efficiently for a long time. The 73% of EPDC dams also passes 40 years or more (Fig. 2). The mission of EPDC is changing from the large-scale hydro power development into adequate maintenance to extend its dams' lifetime.

Table 1. Major EPDC dams.

Name	Type	Hight (m)	Crest Length (m)	Storage Capacity (m^3)	Since
Nukabira	Concrete-gravity	76.0	293.00	193,900,000	Jan-1956
Sakuma	Concrete-gravity	155.5	293.50	326,848,000	Apr-1956
Akiha	Concrete-gravity	89.0	273.40	34,703,000	Jan-1958
Kuromatagawa I	Concrete-gravity	91.0	276.00	42,845,220	Feb-1958
Tagokura	Concrete-gravity	145.0	462.00	494,000,000	May-1959
Kazaya	Concrete-gravity	101.0	329.50	130,000,000	Oct-1960
Okutadami	Concrete-gravity	157.0	480.00	601,000,000	Dec-1960
Miboro	Rock-fill	131.0	405.00	370,000,000	Jan-1961
Sakamoto	Arch	103.0	256.30	87,000,000	Apr-1962
Ooshirakawa	Rock-fill	95.0	390.00	14,200,000	Dec-1963
Kuromatagawa II	Arch	82.5	235.21	60,000,000	Jan-1964
Ikehara	Arch	111.0	459.96	338,000,000	Sep-1964
Yanase	Rock-fill	115.0	202.00	104,625,000	Jun-1965
Misakubo	Rock-fill	105.0	258.00	30,000,000	May-1969
Kassa	Rock-fill	90.0	487.00	13,500,000	Jul-1978
Futai	Rock-fill	87.0	280.00	18,300,000	Jul-1978

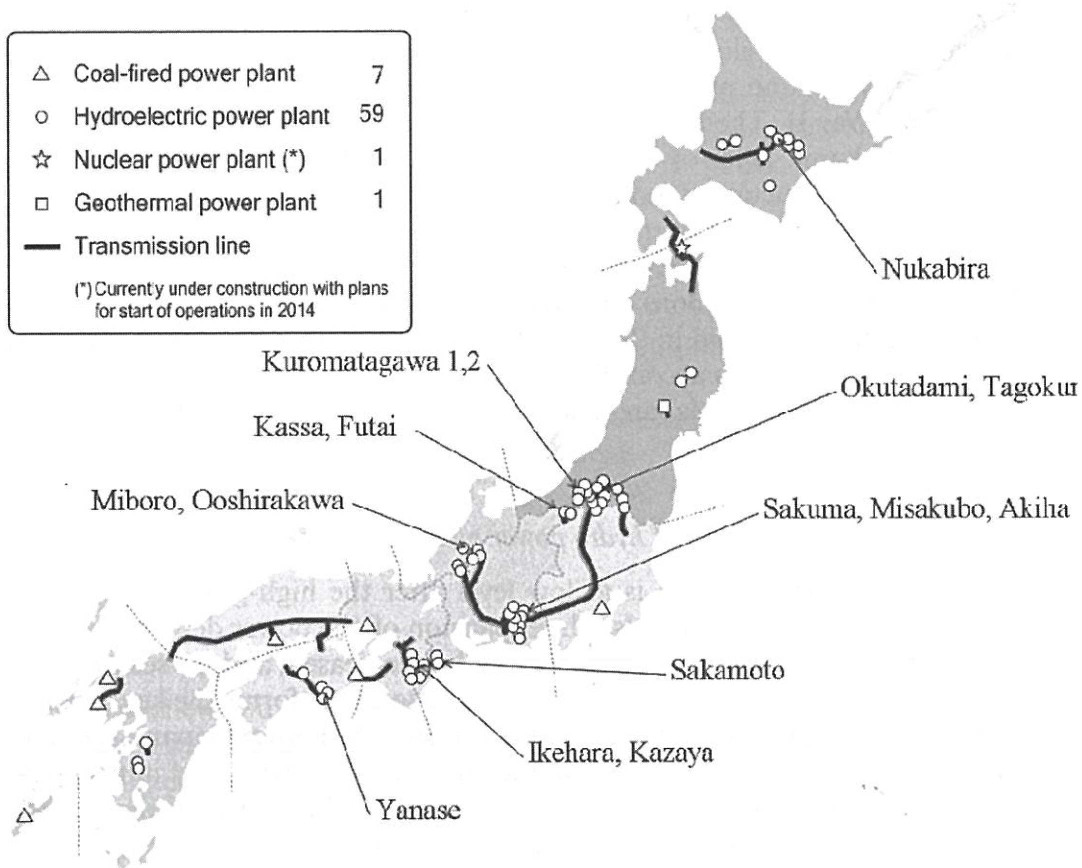

Figure 1. Locations of EPDC dams.

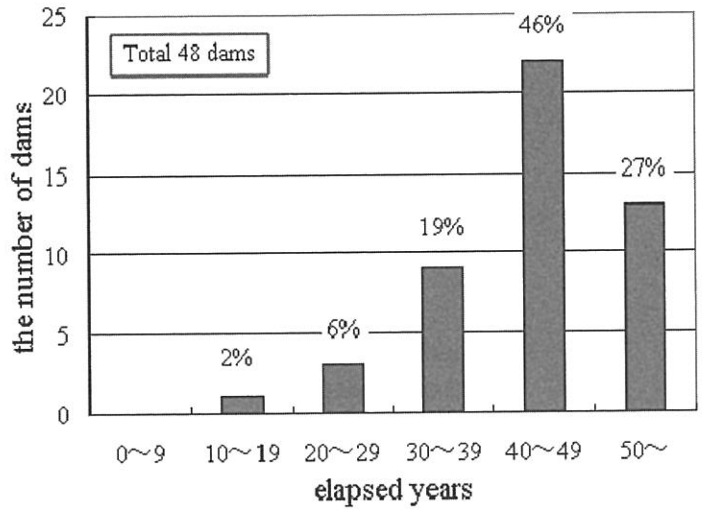

Figure 2. Elapsed years distribution of EPDC dams.

2 THE APPROACH FOR SAFETY MANAGEMENT OF DAM

2.1 *Problems in safety management of dam*

Although structural remarkable damage is not observed, partial deterioration of dams that EPDC manages begins to appear. For example, the water stop in construction joint deteriorated, and the surface materials of rock-fill dam weathered although those phenomena cause neither critical nor dysfunctional damage immediately. The dam has a complicated and organic function to store the river water, to generate the power utilizing the storage water, to supply the water to the industry, the public and for irrigation, and to control the flood. The steel structure such as the gates and the mechanical devises are maintained preventively based on the elapsed time. However, the fixed quantitative evaluation of the degradation phenomenon is difficult, because the dam is composed of various structures. It is necessary to understand that deterioration mechanism is different among each dam and it is important to make an appropriate diagnosis to an individual dam and to maintain it in the most effective way.

Moreover, when dealing with the aged deterioration, the problem is not only structural deterioration but also disappearance of information. The important information such as geological features and technological methods during construction was rarely recorded systematically at that time, and only a part of it was described explicitly in the construction records. A lot of information necessary for dam maintenance is disappearing as time goes by. That is the cause to make the dam safety management difficult.

2.2 *The systematic approach for dam safety evaluation*

The monitoring and the measurement are the most important work for managing the dam safety. The maintenance team at the site office has executed a repair work in a small-scale based on the daily monitoring and the measurement. On the other hand, a large-scale refurbishment has been conducted by the head office. Recently, as the deterioration of the most of dams is proceeding, it becomes more difficult for site office to evaluate the degree of deterioration and the most effective investment cost, which requires a high-level engineering judgment. Considering that situation, we are trying to create the system (Fig. 3) to manage the dam efficiently.

2.2.1 *The risk analysis for dams*

First of all, we tried to understand the current state of the dam, and to extract the risk connecting with the dam failure, then we referred the technique of the dam failure mode analysis used by Federal Energy Regulatory Commission (FERC)[1], after comparing domestic and foreign standards. Secondly, we made the risk scenario (Fig. 4) taking into account the dam

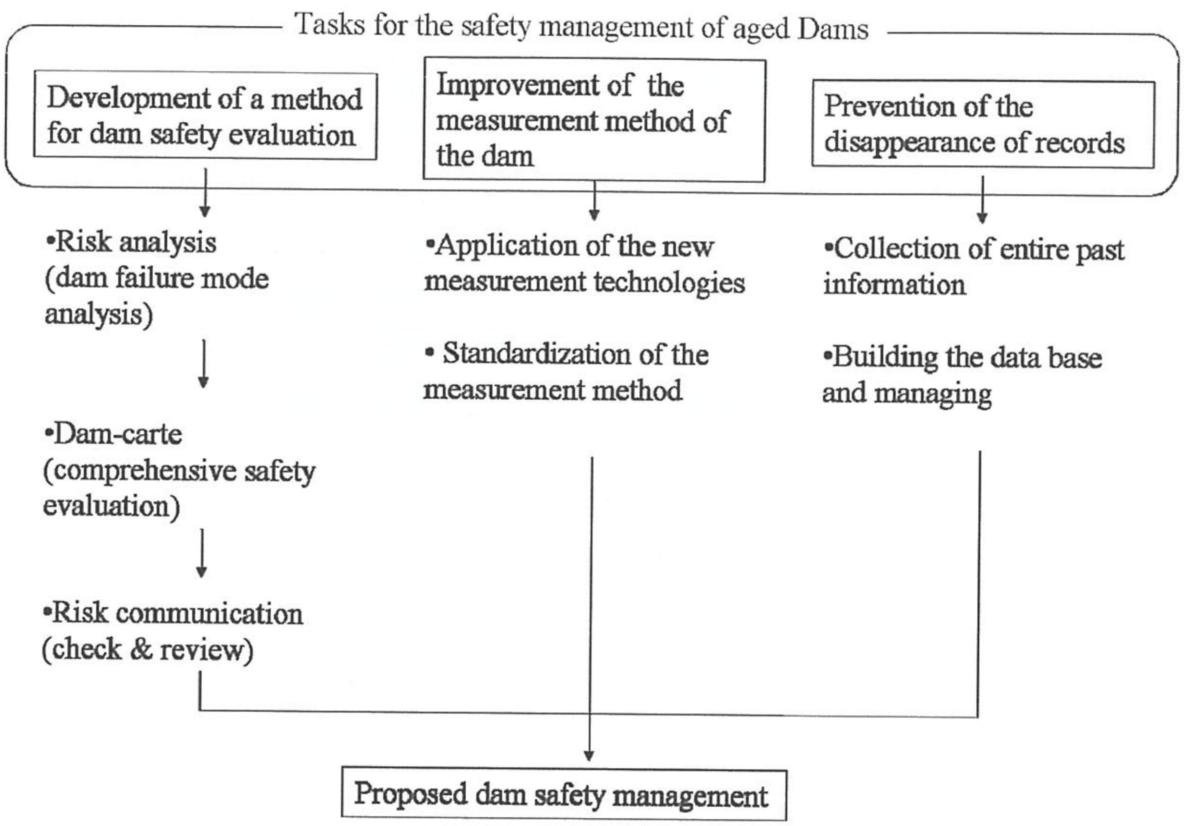

Figure 3. Approach for the safety management of dams.

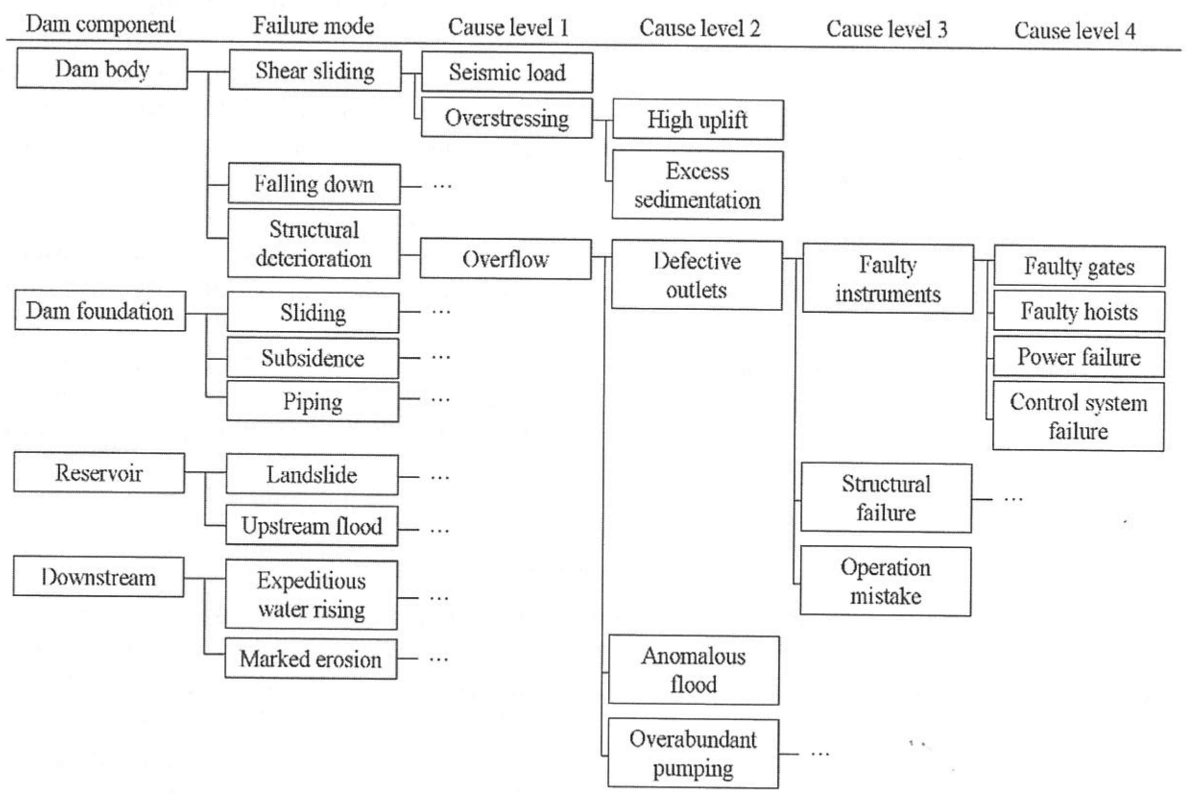

Figure 4. Tree diagram of dam failure mode and cause level.

failure modes and causes by each types of dam. According to the risk scenario, the chief engineer for each dam checks whether there is an event to meet the scenario or not. If there are any items to meet the scenario, they will collect and arrange the evidences, such as the pictures and the monitoring data. They can relate the events occurring in the dam to the dam failure mode, and can improve the knowledge of risk management by doing this analysis.

2.2.2 *The dam-carte (comprehensive safety evaluation)*

The dam-carte is the record of a series of information including the extracted problems by the risk analysis, the countermeasures, the progress, and the verification of the result. In the dam-carte, the extracted problems are prioritized according to the degree of influence and its emergency. And those problems are classified into two categories. One is the small-scale and a short term problem and the other is the large-scale and a mid/long term one. All of the related parties from the chief engineers for each dam to the engineers belonging to the head office have a common view through the dam-carte, and use it as the judging source for the capital investment.

2.2.3 *The risk communication (check & review)*

The risk communication is held to check the propriety of the dam-carte in order to make procedure, and to plan the countermeasures and those priorities. It is organized by the local managers, engineers in the regional offices, and the engineers at the head quarter including the external experts (Fig. 5).

2.3 *Problems and countermeasures led from the result of risk analysis*

2.3.1 *Outline of the risk analysis result*

As a result of the risk analysis done for 48 all dams that EPDC had, there was no critical problem connecting with the dam failure at the moment. However, it turned out that the dam measurement data that was the important information to evaluate the dam condition has not been verified enough so far. For instance, there was the volatility of the data seemed to be the movement of the reference point for the dam measurement, and the loss of the data caused by the plugging of the uplift measurement hole. Thus, there were some cases that the data was not verified regarding the reliability and the measurement method.

On the other hand, the steel structures such as the gate and the electrical control devices etc. were maintained periodically, so there was no problem to keep its quality.

2.3.2 *The problems of the dam measurement*

2.3.2.1 *Seepage from the concrete dam*

The total volume of the seepage from the concrete dam is measured together with the seepage from the joints and from the drain holes. The total amount of the seepage from some old dams over 50 years tended to increase gradually. It was too difficult to point out the reason of the increase when the measurement of the seepage from the joint and the drain holes was not separated. If it was separated as shown in Figure 6, it shows clearly that the seepage from the

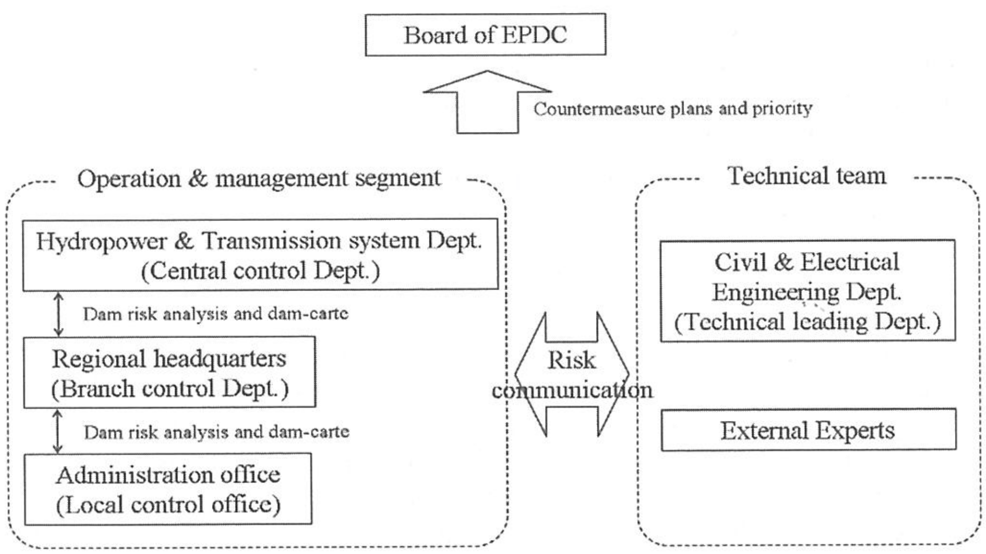

Figure 5. Risk communication in EPDC.

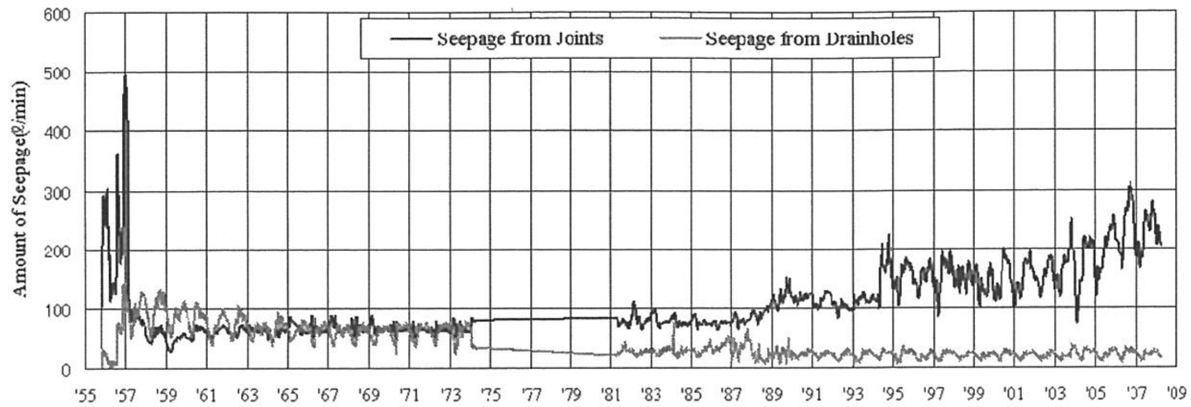

Figure 6. Seepage chart in a concrete-gravity dam.

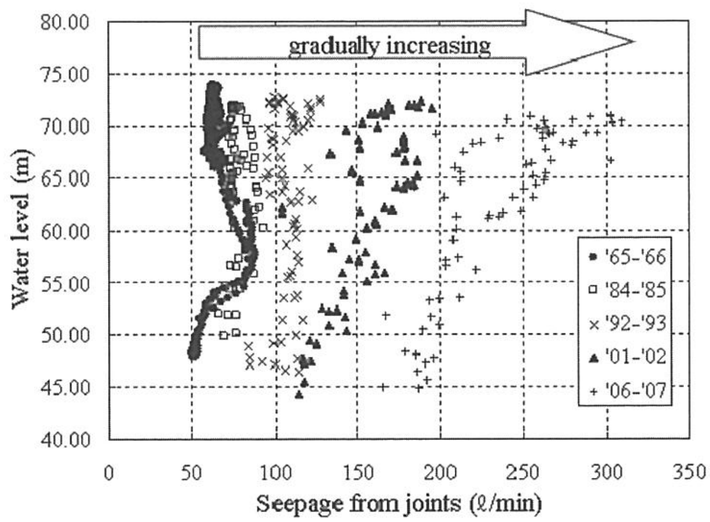

Figure 7. Correlation between seepage from joints and water level.

joints is gradually increasing, and one from the drain holes is decreasing. Figure 8 also shows the linear relation between the seepage from drain holes and the water level recently, so the hydraulic characteristic of the foundation of the dam is thought to be stable.

2.3.2.2 *Uplift measurement*

There were some cases where the uplift of a concrete-gravity dam showed "0". In this case, it is necessary to check the reason why the instrument doesn't react, for example, the break-down of the meter, or the plugging of the drain holes. After the soundness of the devices is confirmed, it will be able to judge whether the uplift shows "0", or the uplift water level doesn't reach the top of the hole. An appropriate uplift measurement can be done only after those confirmation works are done.

2.4 *Improvement of dam measurement*

In case of the measurement of the dam displacement, it is necessary to treat the reference point as fixed point to survey a relative position and the movement of the dam. Several decades have passed since the dam construction, and there are some possibilities that the immobility of the reference point is doubted. Since the reference point is believed to be stable, the main reason of the dam displacement is thought to depend on the measurement error. However, the GPS technology is developed and prevailing, and an absolute position can be specified now. We are attempting to confirm the immobility of the reference point by using the GPS technology.

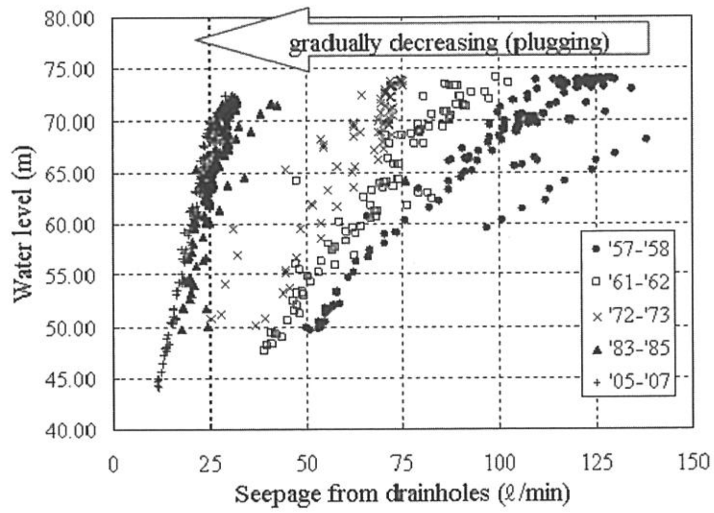

Figure 8. Correlation between seepage from drain holes and water level.

Figure 9. GPS installed on a rock-fill dam of EPDC.

Moreover, an industrial fiberscope can be applied to check the internal condition of the drain holes of the concrete dams, now. When it is plugged by the efflorescence and the function of the drain holes is damaged, measures to recover its function such as cleaning and the re-boring, etc. should be examined.

It is recognized again that it is important to understand that the original purpose of the measurement work is to confirm the stability of the dam, to detect the fault, and to maintain the appropriate environment for the measurement to reflect the dam's condition. And, we are trying to make an in-house standard of the dam measurement that shows the purpose of the dam measurement, the method, and the application of the new technologies.

2.5 *Prevention of the disappearance of records*

The development of the electronic information technology, information processing technology, and the telecommunication technology are improving the handling of the measuring data and the recorded information. Records of the past are uniformly managed and all information is shared among related parties through the data base system. This data base has a probability to make it more convenient to explore the similar events when some troubles are observed at any dams.

3 CONCLUSION

In Japan, after the age of large-scale infrastructure construction, it entered into the age of maintenance, when existing facilities should be maintained adequately for a long time. The dam is the compound and organic structure composed of the foundation, the dam body, and the associated equipment structure, and maintenance methods of dams are different from those of the mechanical and the steel structure. The improvement of the measurement technique makes it possible to specify the dam condition quantitatively and visibly which has not been observed so far. However, the monitoring is one of the most important works for the safety management for the dam. We have to change the consideration about the existing measurement methods, and to examine the new method in order to keep the dam safety. At the same time, we have to prevent the experiences accumulated so far from weathering, and aim to improve the maintenance technology as well as the construction technology.

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