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EMPIRICAL EVALUATION OF SEEPAGE OF FILL-DAMS USING RESERVOIR WATER LEVEL AND RAINFALL*

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SUMMARY

Seepage of fill dams is generally measured by observation equipment installed on the downstream side of the cutoff zone in the dam body and at the toe of the slope. Seepage is an important item measured to evaluate the safety of a dam, but seepage of a dam is impacted by noise such as the rise or fall of the RWL or the rainfall, so safety of a dam is evaluated only during a period when these impacts can be ignored and assuming that seepage has not increased from the past level at the same level. The authors have attempted to evaluate seepage behavior based on the range of past RWLs and seepage quantity at a

* *Évaluation empirique des percolations de barrages en remblai en fonction du niveau de réservoir et des précipitations*

sampled dam that was constructed 30 years ago. This paper presents the range of seepage based on past RWLs and rainfall and proposes an evaluation method based on this range.

Keywords: fill dam, seepage, safety.

RÉSUMÉ

Afin de calculer la quantité d'eau de percolation dans les barrages en remblai, il est habituel d'installer des équipements de contrôle en aval du bâtiment principal, où le contrôle des infiltrations d'eau est effectué, ou encore dans la zone en amont. Cette quantité d'eau infiltrée permet non seulement de juger du niveau de sécurité du barrage, mais aussi d'effectuer des mesures indispensables.

Cependant, la quantité d'eau de percolation d'un barrage est soumise à deux influences majeures : d'une part, l'augmentation et la diminution des eaux dues au niveau changeant dans le réservoir, et d'autre part, les eaux de pluie. Cette évaluation du degré de sécurité d'un barrage ne peut donc se faire que durant les périodes où il est possible de procéder en excluant ces deux facteurs. Ainsi, nous avons évalué le degré de sécurité d'un barrage en procédant à une comparaison effectuée lorsque le niveau de l'eau restait le même dans le réservoir et que la quantité d'eau de percolation n'augmentait ni ne diminuait pas. Les auteurs de cet essai ont pris comme référence un type de barrage dont la construction a été terminée il y a 30 ans, et se sont basés sur le niveau de son réservoir ancien ainsi que sur ses quantités d'eau de percolation dans le passé, pour essayer de cerner comment cette infiltration se produit. Notre essai concerne donc la quantité de percolation évaluée dans ce type de barrage, évaluation basée sur le niveau d'eau du réservoir et les eaux de pluie dans le passé, et propose à travers cette analyse une manière de surveiller la quantité de percolation dans un barrage.

1. INTRODUCTION

The measurement of seepage is one of the most important issues for the safety management of fill dams. At many dams, the seepage is usually monitored by collecting water on the downstream side [1], [2].

Several researches have been carried out for evaluating dam safety on seepage. For example, Nakajima et al. [3] evaluated seepage routes based on water quality. Harita et al. [4] and Mizuno et al. [5] evaluated qualitative trends of the seepage without rainfalls. Sakamoto [6] analyzed the relationship between the water level of reservoir and the seepage. However, these studies mainly evaluated the seepage qualitatively without the influence of rainfall.

Baba et al. [7], the Tohoku Regional Agricultural Administration Office [8] plotted the seepage and rainfall, then proposed the evaluation of the seepage in considering the influence of rainfall. Mori et al. [9] estimated the seepage using long-term monitoring data with rainfall. These works performed multiple regression analysis under the assumption of linearity.

This paper focuses on long-term monitoring data of seepage with rainfall. Based on the detailed study of the relationship among seepage, reservoir water level, and rainfall, ann empirical formula which includes non-linearity is proposed. A comparison of the proposed empirical formula and actual measurements, confirms the validity of the formula, a simple system for managing the safety of fill dam is discussed.

This paper consists of two parts. The first part describes a method that evaluates seepage when there is no impact of rainfall, and the second part explains a method that eliminates the impact of rainfall.

Chapter 2 evaluates relationship between reservoir water level (RWL) and seepage assuming linearity, then set the number of days and amount of rain for which the impact of past rainfall disappears.

Chapter 3 explains a method that reproduces the impact of rainfall. A function reproduces the period of gradual decrease was used. Next, rainfall that does not impact seepage was defined as ineffective rainfall. Finally, a parameter study was done based on the relationship of the seepage and rainfall hourly.

The results are shown Chapter 4 and some conclusions are presented in Chapter 5 respectively.

2. EVALUATION OF SEEPAGE WITHOUT ANY IMPACT OF RAINFALL

This chapter describes an evaluation method based on the RWL – seepage relationship assuming these linearity, then set the number of days and amount of rain that impact of past rainfall disappears.

2.1. IMPACT OF RAINFALL

This section describes an approximation of RWL and seepage amount are studied assuming the exponential relation to clarify the rain characteristics such as the number of days, the amount of rain, where the impact of past rainfall disappears.

It is generally known under the high RWL, increment of seepage to the RWL increases. In this section, exponential approximation was used as a simple method to express the increment. Comparison of the fitting was made by a coefficient of determination. It is thought that if the impact of rainfall added, the decision coefficient will decrease to the one without effect of rainfall at the same RWL.

Table 1 shows the decision coefficient for the combination of various number of days and rainfall. The latest rainfall was categorized as “One-day Rainfall” and “2-day rainfall” to “10-day rainfall”. The rainfalls were categorized as “0 mm”, “10 mm”, “30 mm”, and “50 mm” in these amounts.

In cases where more days with lower rainfalls were selected, the decision coefficient will show higher value. Since rainfall data of less duration days result in lower decision coefficients, data of more than certain days is necessary to eliminate the impact of rainfall. On the other hand, longer duration days brings to less available data and also less representativeness. The colored cells in the Table 1 illustrates that less than 50% of total data seems eligible.

Table 1
Comparison of coefficients of determination of various periods

1992-1997	One-day rainfall	2-day rainfall	3-day rainfall	5-day rainfall	7-day rainfall	10-day rainfall
<50mm	0.47870	0.50827	0.53023	0.56176	0.57485	0.58648
<30mm	0.47050	0.50220	0.53275	0.57472	0.59450	0.64105
<10mm	0.47042	0.51113	0.55218	0.59815	0.62425	0.69105
0mm	0.48805	0.52523	0.57301	0.62326	0.66474	0.77352
1997-2002						
<50mm	0.45833	0.62329	0.65818	0.69719	0.71307	0.72179
<30mm	0.45852	0.62282	0.66091	0.71077	0.72886	0.71554
<10mm	0.43608	0.62907	0.67394	0.66276	0.65154	0.58836
0mm	0.60660	0.65732	0.67752	0.62434	0.40780	0.22044
2002-2007						
k<50mm	0.44120	0.49751	0.52374	0.54803	0.55052	0.53853
<30mm	0.46477	0.50474	0.52346	0.53282	0.53553	0.54346
<10mm	0.46965	0.50159	0.51199	0.52078	0.47872	0.39844
0mm	0.48594	0.49949	0.48433	0.48421	0.49061	0.60008
2007-2012						
<50mm	0.40200	0.45845	0.49472	0.52658	0.52827	0.53327
<30mm	0.40690	0.47956	0.51463	0.53646	0.53673	0.53367
<10mm	0.43645	0.47399	0.50650	0.50708	0.47773	0.47086
0mm	0.43121	0.46239	0.48139	0.46386	0.48777	0.66133

* Shaded cells are less than 50% of the total number of days.

In this case, combination of number of days and rainfall which has over 50% of total numbers of data and highest coefficient was selected. As a result, data showing “7-day rainfall less than 50mm” were selected.

Since, the decision coefficient is small, it is impossible to evaluate safety of a dam based only on an exponential function type RWL – seepage relationship. Therefore, in 2.2, a detailed evaluation of the RWL - seepage relationship is done to check the suitability of “7-day rainfall less than 50mm”

2.2. Detailed evaluation of the reservoir water level – seepage relationship

Fig. 1 shows the most recent state of “7-day rainfall less than 50mm”, which was treated as, “state in which the impact of rainfall is thought to be small” in the previous section. Fig. 1 shows the RWL – seepage relationship for a period of 12 years from 2001 to 2012, which was more than 25 years after completion, but the average seepage of 50L/min shows a scatter of about ±10L/min.

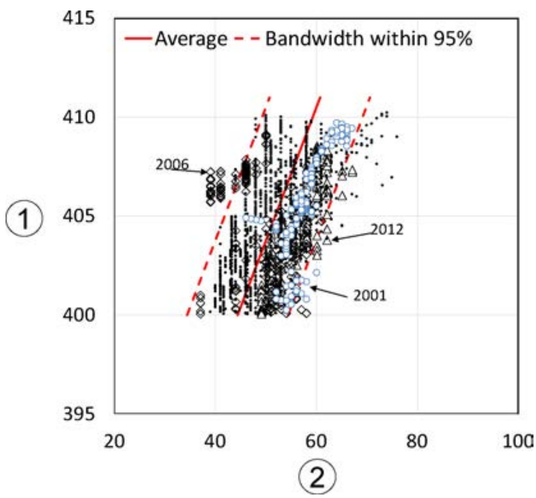

Fig. 1
Reservoir water level – seepage correlation chart
(7-day rainfall less than 50mm)
Diagramme de corrélation entre le niveau d’eau du réservoir et la quantité d’eau de percolation (moins de 50mm en 7 jours)

① RWL (EL.m)	① *Niveau de l’eau (EL.m)*
② Seepage (L/min.)	② *Infiltration (L/min)*

The data in 2001, 2006 and 2012, corresponding to the first, midterm and last years, are represented by the marks of ○, ◇ and △ respectively. There was little change in quantitative relationship in 2001 and in 2012. It is thought the seepage reduction due to clogging effects etc, is not large during these years. In addition, a constant RWL – seepage relationship is not necessarily established even in the first year.

To confirm the cause of these types of scattering, the impact of rainfall on the RWL – seepage relationship was similarly examined for "7-day rainfall less than 0mm", "7-day rainfall from 0 to 10mm", and "7-day rainfall from 40 to 50mm". The average gradient and the dispersion of the data or the various RWLs were compared. The results are shown in Table 2.

As shown in Table 2, each 7-day rainfall is similarly scattered. Therefore, the cause of the scattering is difficult to analyze based on available information and which cannot be removed, but is not the "impact of the scale of rainfall".

Table 2
Inclination and dispersion of each object rainfall

7-DAY RAINFALL (MM)	NUMBER OF DATA	INCLINATION (L/MIN/M)	DISPERSION (L/MIN)
0	230	1.79	21.84
0-10	504	1.43	19.23
10-20	412	1.34	18.13
20-40	582	1.36	21.50
40-50	226	1.40	22.73

2.3. Setting basic values of the seepage for a sampled dam

The following are the results of the study described in 2.1 and 2.2.

1) The 7-day rainfall with less than 50mm is selected based on the correlation with the exponential approximation for which the impact of rainfall is considered to be small.

2) Even when there was less than 50mm of rainfall in 7-day, scattering occurred that was not considered to be an impact of rainfall. This scattering is not small, even under lighter rainfall.

As a result of the above, Fig. 2 and Table 3 show typical values used to judge the dam safety. All data of the 7-day rainfall with less than 50mm are plotted to show the impact of during 12 years from 2000 to 2012. At RWL above EL. 400m, there are many data showing the different increment of the seepage.

Table 3
Standard values at the sampled dam

RWL (EL.M)	INCLINATION (L/MIN/M)	AVERAGE	MAX.	MIN.	DISPERSION
		(L/MIN)			
411	1.66	61.85	78.91	44.80	34.11
405		51.88	68.94	34.83	34.11
405	1.31	51.81	68.18	35.44	32.74
400		45.24	61.61	28.87	32.74
400	0.38	46.95	61.95	31.95	30.00
380		39.28	54.28	24.28	30.00

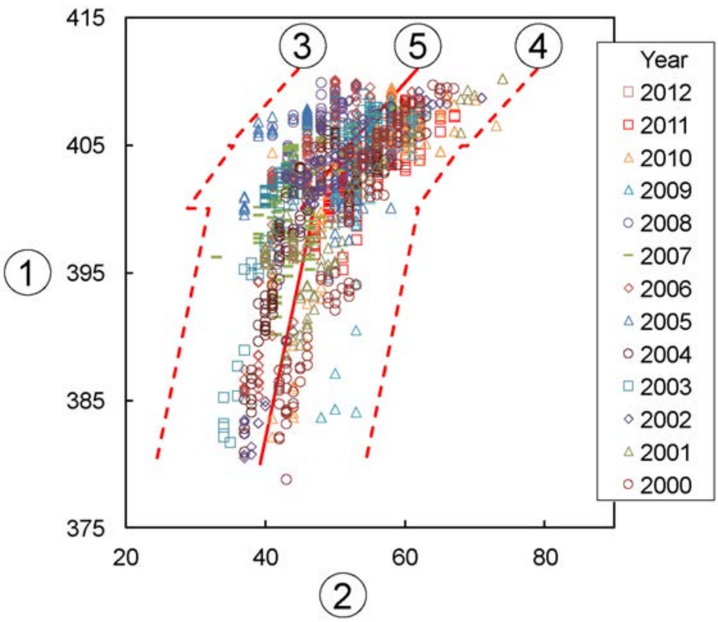

Fig. 2
Standard values at the sampled dam
Valeur de référence dans le barrage pris comme modèle

①	RWL (EL.m)	①	*Niveau de l'eau (EL.m)*
②	Seepage (L/min.)	②	*Valeur infiltration (L/min)*
③	Lower limit	③	*Limite minimale*
④	Upper limit	④	*Limite maximale*
⑤	Average	⑤	*Moyenn*

3. METHOD OF ELIMINATING IMPACTS OF RAINFALL FROM SEEPAGE

3.1. OVERVIEW

In chapter 2, an evaluating method of impact RWL was presented. In Chapter 3, a method of eliminating the impact of rainfall is examined.

The sampled dam reservoir was filled in 1976, and 26 floods from 2006 to 2014, which occurred more than 30 years after the dam was completed, were studied. The seepage, rainfall etc. were analyzed using time data, and a formula to predict the impact of rainfall on seepage in real time was studied. The method considered the effective rainfall [10], delay time from the occurrence of rainfall until it affects seepage, and ineffective rainfall that has no impact on seepage. Based on the above, an empirical prediction method using measurement of seepage is proposed.

3.2. METHODS OF SETTING CONSTANTS

Fig. 3 shows a typical time history of the seepage caused by rainfall at the sampled dam. The red dotted line “a” shows the cumulative rainfall of 50mm or less for which there has been almost no impact on the seepage. “b” shows the ”period of increase” with a clear peak of seepage due to the impact of rainfall, and the “period of decline” when the seepage returns to its original level after the peak. The green dotted line “c” indicates that the seepage peaked after the rainfall peaked.

Precautions when formulating the impacts of rainfall include the following.

1) Quantity of rainfall that is not effective, such as rainfall that is absorbed by underground pores.
2) Delay time until rainfall impacts seepage.
3) Coefficient for outflow between rainfall and seepage.
4) Decline of impact of rainfall over time.

3.3. DECLINE OF IMPACTS OF RAINFALL OVER TIME

A model of the reduction of the impact of rainfall over time was studied based on hourly records. The X-axis in Fig. 4 shows elapsed time since the peak of seepage caused by rainfall and the Y-axis shows the increase of seepage from the level before the rainfall. Fig. 4 shows that the logarithm of the increase of the seepage declined linearly as time passed after the peak. Accordingly,

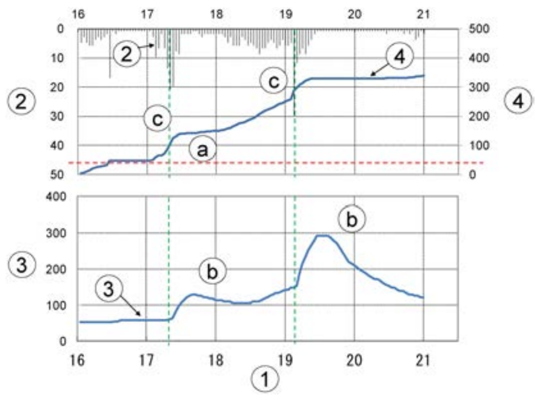

Fig. 3
Relationship of rainfall with accompanying increase of seepage
Relation entre les eaux de pluie et l'augmentation de la quantité d'eau de percolation entraînée par celles-là

①	Days	①	*Jour*
②	Rainfall (mm)	②	*Quantité de précipitations (mm)*
③	Measured seepage (L/min)	③	*Valeur calculée de la infiltration (L/min)*
④	Cumulative rainfall	④	*Quantité de pluie accumulée (mm)*

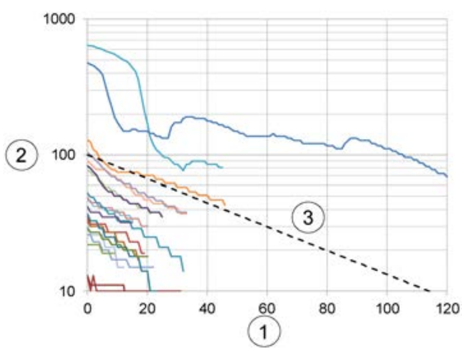

Fig. 4
State of decline of seepage caused by rainfall
Situation lorsque l'influence des précipitations est moins grande

①	Time after the peak (h)	①	*Temps écoulé depuis la période avec la valeur la plus grande (h)*
②	Increase of measured seepage (L/min)	②	*Quantité supplémentaire de la valeur calculée de la infiltration (L/min)*
③	Reduction rate 0.98	③	*Pourcentage de diminution 0.98*

itis considered possible to represent the impact on seepage after rainfall by an exponential function, and so the concept of effective rainfall that is used to estimate underground water levels as part of landslide observations, for example, was introduced.

Effective rainfall is given by Eq. [1].

$$R_e = \sum_{n=1}^{\infty} a^n \cdot r_n \quad [1]$$

Where, "R_e" is effective rainfall, "a" is the reduction rate, and r_n is rainfall of "n" hours earlier.

When the state of decline from the peak of seepage was examined using the past seepage data as shown in Fig. 4, excluding some heavy rainfall and rainfall during the period of decline, a roughly similar incline was found. A constant incline (a=0.95 to 0.99) which reduces the effective rainfall was set so as to confirm the measured seepage. The dashed line in Fig. 5 shows the case where a constant of 0.98 was used. The impact after 5-day (120 hours) in this case is less than 10% of the peak of the increase.

3.4. COEFFICIENTS SUCH AS INEFFECTIVE RAINFALL, RAINFALL, DELAY TIME ETC. WHICH REPRESENT SEEPAGE

Fig. 5 shows the relationship of the increase of effective rainfall and increase of seepage. In some cases, even when effective rainfall occurs, seepage does not increase as shown in "a", the degree of increase of effective rainfall differs from the increase of seepage as shown in "b", and the peak of effective rainfall and peak of seepage are delayed as shown in "c". The range of each parameter is described below.

First ineffective rainfall is explained. In the study of the 26 floods, for cumulative rainfall of less than 50mm, the seepage did not increase. Accordingly, the ineffective rainfall was set as a cumulative rainfall of 0mm to 50mm.

Next, the relationship of effective rainfall and seepage taking these ineffective rainfalls into consideration was obtained based on hourly data. Fig. 6 shows the results. The ineffective rainfall in this diagram is eliminated from the calculation of effective rainfall by treating cumulative rainfall up to 35mm as ineffective rainfall. Although seepage is increased by an increase of effective rainfall, this tendency is not necessarily linear. Considering the fact that the effective rainfall represents the underground water level and that the flow rate of the seepage overflowing the weir is measured, it corresponds to the fact that the flow rate formulae for a sharp-crested weir and a triangular weir are proportional to the upstream water

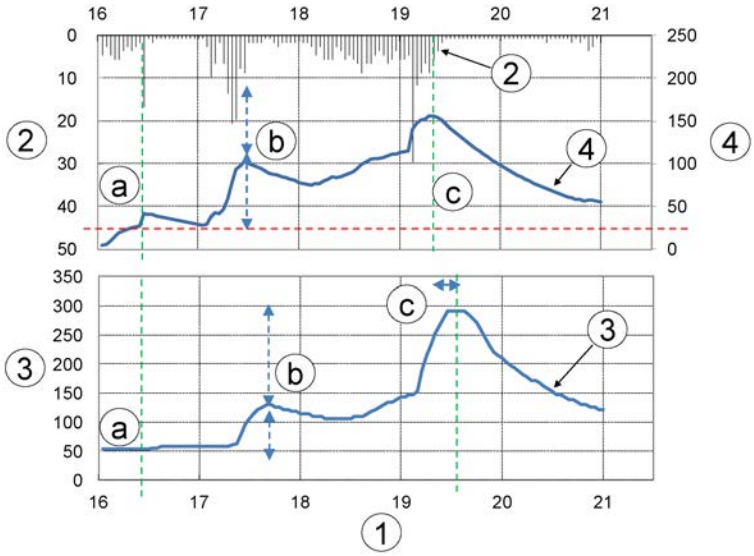

Fig. 5
Relationship of rainfall, effective rainfall and seepage
Relation entre les eaux de pluie, la quantité des eaux de pluie efficaces et la quantité d'eau de percolation

①	Days	①	*Jour*
②	Rainfall (mm)	②	*Quantité de precipitations (mm)*
③	Measured seepage values (L/min)	③	*Quantité de infiltration (L/min)*
④	Effective rainfall (mm)	④	*Quantité de pluie efficace (mm)*

level to the power of 3/2 or 5/2. From the above, the effective rainfall is exponentiated. The power number was set as the range of 1.5 to 2.5.

Finally, the delay period was often 4 hours or less, according to a study of the difference between the times of occurrence of the effective rainfall peak and the seepage peak for the 26 floods. The delay time was set in the range of 0 to 4 hours.

From the above, Eq. [2] was obtained for the increases of effective rainfall and seepage.

$$\Delta Q = b \cdot R_e^{\,d} + c \qquad [2]$$

where, ΔQ is the increase of seepage and *b, c*, and *d* are constants.

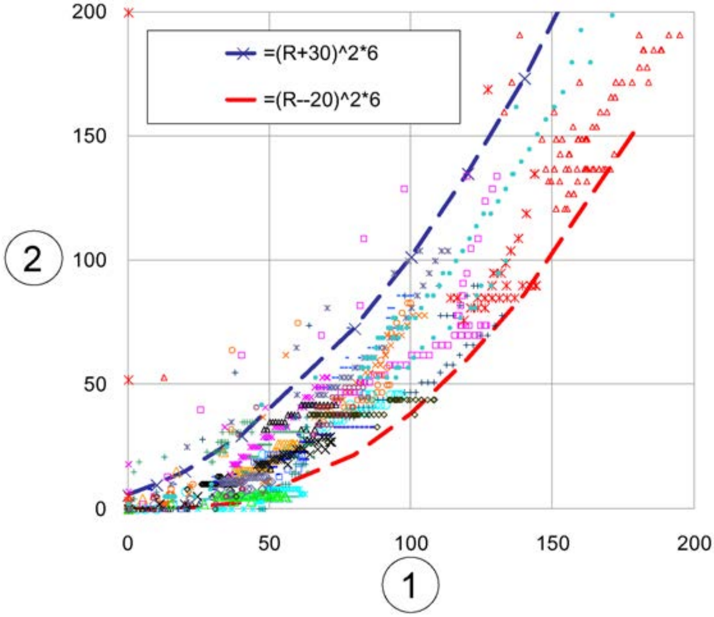

Fig. 6
Relationship of effective rainfall and seepage
Relation entre les eaux de pluie, la quantité des eaux de pluie efficaces et la quantité d'eau de percolation

① Effective rainfall considering ineffective rainfall (mm)

② Increase of measured seepage (L/min)

① *Quantité d'eau de pluie efficace en référence à la quantité d'eau de pluie non-efficace (mm)*

② *Quantité supplémentaire de la valeur calculée de la infiltration*

To study each parameter, firstly other parameters were fixed for the study on ineffective rainfall, effective rainfall constant *a*, power number of the effective rainfall *d*, and the delay time. These parameters are examined so that the predicted seepage closely fitted the measured value and the determination coefficient was the highest. These comparative studies could not be obtained by normal multivariate analysis etc. because the relationship is non-linear, and in fact, nearly round-robin study cases were performed.

Based on the above, a combination of constants which maximized the coefficient of determination obtainable by comparing measurements with approximate formulae was adopted. These constants were respectively a = 0.98, b = 0.0068,

c = 1.9, and d = 2.0, ineffective rainfall was 35mm, the delay time was 3 hours, and the coefficient of determination R^2=0.8985.

3.5. REPRODUCIBILITY OF STUDY RESULTS

Fig. 7 compares the maximum increase of seepage measured for each rainfall used for this prediction with the maximum value of the increase based on the prediction formula. Excluding cases where the actually measured seepage was extremely small or large, it was possible to obtain results that generally conformed.

These errors are believed to occur because each constant is uniformly set regardless of the quantity of rainfall. It is thought when the impact of rainfall is small, for example, ineffective rainfall varies according to the dampness of the natural ground, but this study incorporated uniform ineffective rainfall. On the other hand, when the impact of rainfall is large, the underground water level in the downstream rock zone could rise and flow into the collection weir, resulting in an increase of the seepage.

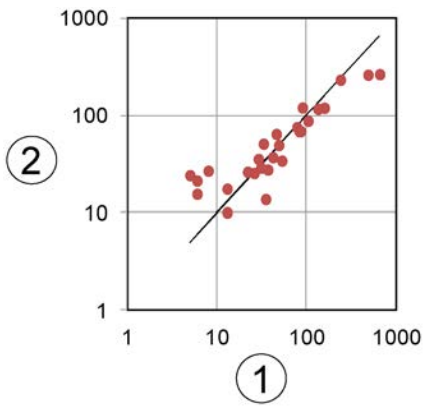

Fig. 7
Correlation of measured seepage and predicted seepage
Corrélation entre la valeur prédite et la valeur réelle de la quantité d'eau de percolation

①	Measured increase of seepage (L/min)	①	*Mesure effectuée - calculée de la quantité infiltration (L/min)*
②	Predicted increase of seepage (L/min)	②	*Prévisions –calculée de la infiltration (L/min)*

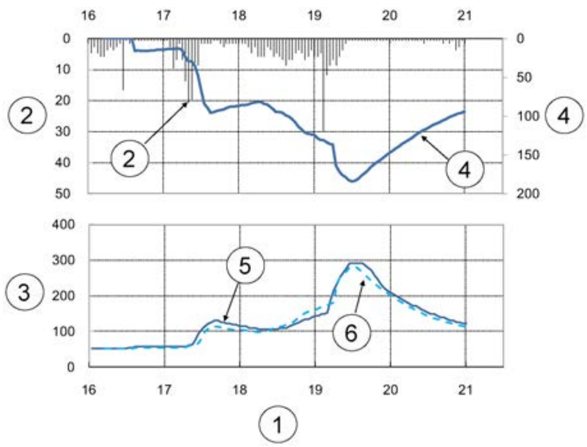

Fig. 8
Change over time of measured seepage and predicted seepage
Variation dans le temps de la valeur prédite et de la valeur réelle de la quantité d'eau de percolation

①	Days	①	*Jour*
②	Rainfall (mm)	②	*Quantité de precipitations (mm)*
③	Seepage (L/min)	③	*Quantité de infiltration (L/min)*
④	Effective rainfall with delay time	④	*Quantité de pluie efficace ajoutée au temps de retard (mm)*
⑤	Measured	⑤	*Valeur mesurée*
⑥	Predicted	⑥	*Valeur prévue*

It is important to clarify the causes of these errors and differing phenomena in advance in order to perform monitoring at normal times. Fig. 8 shows the change over time of seepage of rainfall according to measured values and the prediction formula. The process of the seepage variation due to the impact of rainfall is generally reproduced.

4. RESULTS OF APPLICATION TO A SAMPLED DAM

This section describes the results of applying the monitoring when the impact of rainfall is small and when rainfall has an impact.

Fig. 9 shows the result of evaluating seepage from 2008 to 2012 assuming the impact of rainfall is small at the sampled dam. This chart excludes the data of 7-day rainfall of 50mm or higher. Almost all observation results were between the upper limit and lower limit. The chart also shows that the evaluated seepage were not always at a fixed position in the dispersion, but moved back and forth between the upper and lower limit. In about October 2011, there is a point where the upper limit was exceeded. If the method proposed in this paper is used, it is possible for anyone to judge whether or not an abnormality has occurred using a simple index when such a peculiar phenomenon has occurred. It is thought that sometime after the upper limit is exceeded, seepage will return to between the upper and lower limits and will remain stable if it continues to be excessive or if the separation from the upper limit was not an increase.

Next, Fig. 10 shows the situation during rainfall. Using the method described in 3.4, the effective rainfall and its impact on seepage are calculated in a case where the cumulative rainfall exceeds 35mm. It is possible to evaluate safety concerning seepage also during rainfall by comparing the upper and lower limits, which are set based on the results of subtracting the impact of rainfall from the measured seepage and the RWL. Fig. 10 shows that the upper limit was

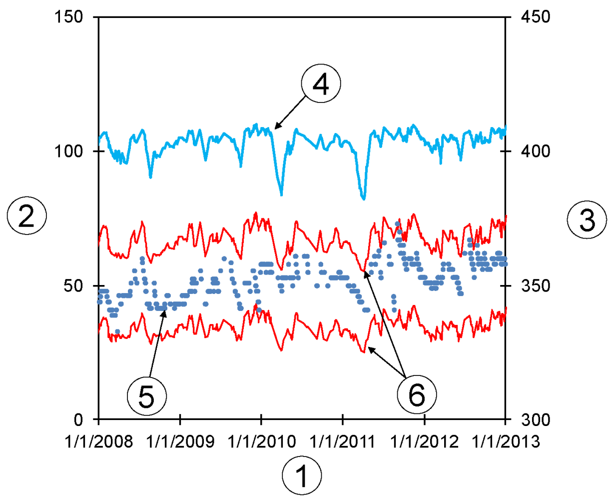

Fig. 9
Evaluation of seepage from 2008 to 2012
Estimation de l'eau de percolation entre les années 2008 et 2012

①	Year	①	*Jour*
②	Rainfall (mm)	②	*Quantité de precipitations (mm)*
④	RWL (EL.m)	④	*Niveau du réservoir (EL.m)*
⑤	Measured values *(L/min)*	⑤	*Quantité de infiltration (L/min)*
⑥	Upper/Lower limit	⑥	*Limite maximale / minimale*

temporarily exceeded when the impact of rainfall increased. This phenomenon is assumed to be caused by discrepancies in various parameters between different rainfalls. When there is no impact by rainfall as shown in Fig. 9, judgement criteria are needed in order to, for example, judge abnormality in a case where the upper limit or lower limit ranges are exceeded for several consecutive hours.

These methods, i.e., Fig. 9 (method A) and Fig. 10 (method B), are used selectively as explained below. At normal times, evaluation is performed using method A. In cases where rainfall has occurred, up to a cumulative rainfall of 35mm, method A is still used, and when cumulative rainfall exceeds 35mm, method B is used. Method B is implemented until the quantity removed is within a range of 1mm observed at a triangular weir, which is the error range of seepage measurement. Later, evaluation is performed by method A.

These methods can be used for continuous evaluation of seepage, which used to be impossible.

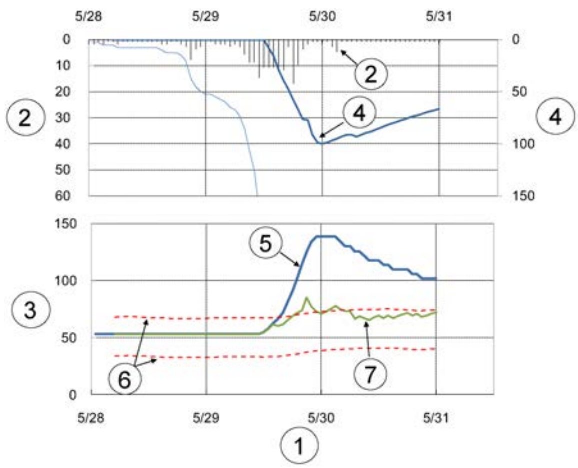

Fig. 10
Evaluation of seepage during rainfall
Estimation de l'eau de percolation lors de précipitations

①	Days	①	*Jour*
②	Rainfall (mm)	②	*Quantité de precipitations (mm)*
③	Seepage (L/min)	③	*Quantité de infiltration (L/min)*
④	Effective rainfall with delay time added (mm)	④	*Quantité de pluie efficace ajoutée au temps de retard (mm)*
⑤	Measured	⑤	Valeur mesurée
⑥	Upper/Lower limit	⑥	*Limite maximale / minimale*
⑦	Seepage without impact of rainfall	⑦	*Infiltration sans impact de pluie*

5. CONCLUSIONS

In this research, two methods were studied: first, a method that evaluates seepage when rainfall has no impact, and second, a method that eliminates the impact of rainfall on seepage when rainfall has an impact. At the sampled dam it was confirmed that these evaluation methods can be used for continuous monitoring.

The following conclusions were drawn from this study:

1) Because the reservoir water level (RWL) – seepage relationship is not necessarily linear, at a dam where the RWL fluctuates greatly, it is appropriate to prepare a RWL – seepage relationship independently for each RWL ranges.

2) According to a detailed examination of past RWL – seepage relationships, scattering is caused by uncertain factors that cannot be attribute only on RWL and rainfall.

3) If it is based on the rainfall – seepage declining trend, analysis based on effective rainfall is appropriate. This method is useful at a dam which has been affected by rainfall for a long time.

4) In the early stage of rainfall or when rainfall is light, seepage may not increase, and the concept of ineffective rainfall, which is ineffective up to a specified rainfall, is suitable.

5) In the study of the sampled dam, it was found that the seepage fluctuation by rainfall lineally relates to the square of the effective rainfall. The practical formulation of the effective rainfall is proposed

6) It was possible to perform continuous evaluation of seepage by a combination of the above methods.

Phenomena 1), 3), 4) and 5) results from the fact that the relationship between rain and seepage is non-linear. Regarding 2), presumably it is necessary to narrow the width that is considered normal by clarifying the uncertain factors.

Seepage at rock fill dams, particularly the relationship of RWL and seepage, and the degree of impact of rainfall are strongly affected by topography, geology, embankment materials, and the layout and structure of measurement instruments. Therefore, the applicability of methods and concepts to other rock fill dams must be verified, and methods suited to each dam must be studied.

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