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A STUDY ON PREDICTION OF IMPROVEMENT OF WATERTIGHTNESS OF ROCK MASS BY GROUTING

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ABSTRACT

Grouting is a principal technique to improve watertightness of the foundation of dams. But it is not easy to predict the amount of grouting work until attaining the required improvement of watertightness of rock mass, since the improvement mechanism of watertightness by grouting is not understood comprehensively. Therefore, the grouting work is conducted with the split spacing method until attaining the required improvement. In this paper, the method to predict the effects of grouting is discussed analyzing grouting data obtained from the Hattabara Dam construction site. As the result of the analysis, it is understood that the logarithm of the Lugeon values (logLu) and the logarithm of the amount of cement take (logC) can be dealt with as statistic values and the relationships of their mean values between the i-th order of grouting holes and the i+1th order of grouting holes can be expressed as the recurrence equation. The improvement of watertightness of rock mass can be predicted according to these relationships.

KEYWORDS

Dam, Foundation Treatment, Curtain Grouting, Lugeon Value, Watertightness

INTRODUCTION

Grouting is a principal technique to improve watertightness of the foundation of dams. But it is not easy to predict the amount of grouting work before its execution, since the improvement mechanism of watertightness of rock mass by grouting is not understood comprehensively. Therefore, the required grouting work is decided according to construction achievement. However, in case that the watertightness of the foundation rock is not attained, additional grouting will be required and consequently will cause the delay of the dam construction. In order to avoid the delay, it is important to predict the improvement of watertightness of rock mass from the Lugeon values and amount of cement take through grouting. This paper describes the method of predicting the improvement of watertightness of rock mass through data analysis of grouting at the Hattabara dam, which is a 85m high concrete gravity dam.

METHOD OF PREDICTING THE EFFECTS OF GROUTING

Data Used in Analysis

The Lugeon values and the amount of cement take which were used in the analysis were obtained from curtain grouting works at the Hattabara Dam (See Fig.1). The site is mainly composed of medium-grained and coarse biotite granite with the dyke of porphyrite in the Cretaceous of the Mesozoic era. There is a highly permeable area at high elevation of the left abutment where Lugeon value is more than 20 Lu. The permeability of the rest area is not so high. The grouting holes consist of the pilot holes to the 3rd order holes, and they were executed by the split-spacing method. The interval of 3rd order grouting holes is 1.5m. The check holes were also executed at about 12m of interval. The numbers of data ( the number of stages ) in each order of grouting holes used in the analysis are as shown in Table.1.
Curtain grouting area

Fig. 1  Curtain grouting area for analysis

<table>
<thead>
<tr>
<th>order of holes</th>
<th>number</th>
</tr>
</thead>
<tbody>
<tr>
<td>pilot</td>
<td>417</td>
</tr>
<tr>
<td>first</td>
<td>360</td>
</tr>
<tr>
<td>second</td>
<td>635</td>
</tr>
<tr>
<td>third</td>
<td>1,157</td>
</tr>
<tr>
<td>check</td>
<td>320</td>
</tr>
<tr>
<td>total</td>
<td>2,889</td>
</tr>
</tbody>
</table>

Table 1  Number of data in each order of grouting holes

Statistical Characteristics of Grouting Data

The improvement of watertightness of rock mass by grouting can be evaluated through the Lugeon values and the amount of cement take. The distribution of the logarithm of the Lugeon values before grout injection (logLu) is shown in Fig. 2 as the Hazen plot. The distribution of the logarithm of the amount of cement take per unit length of holes (logC) is shown in Fig. 3 as well. These figures show that the both of them are nearly on a strait line.

Consequently, the distribution of these data is almost equal to logarithmic normality distribution. This means that logLu values and logC values should be used in the analysis.

The mean values and standard deviations of logLu with the progress of order of grouting holes are plotted in Fig. 4. It is evident that the mean value of logLu decreases with the progress of grouting. It is also noted that the standard deviation of logLu decreases with the progress. It means that the permeability of rock mass becomes smaller and uniform. The mean values and standard deviations of logC with the progress of the order of grouting holes is also shown in Fig. 5. The same tendency is observed as in the case of logLu.

Fig. 2  Distribution of logarithm of Lugeon values before grout injection

Fig. 3  Distribution of logarithm of amount of cement take per unit length of grouting holes

Fig. 4  Mean values (m) and standard deviations (σ) of logLu with progress of order of grouting holes

Fig. 5  Mean values (m) and standard deviations (σ) of logC with progress of order of grouting holes
Next, the Lugeon values were classified into 5 groups, namely $Lu < 0.5$, $0.5 \leq Lu < 1.0$, $1.0 \leq Lu < 2.0$, $2.0 \leq Lu < 5.0$, $5.0 \leq Lu$. Then, the mean values of logarithm of the amount of cement take and their standard deviations for each Lugeon group were plotted in Fig. 6, where all data from the pilot holes to the check holes are included. The figure shows that the smaller the Log Lu values become, the smaller the mean values and the standard deviations of the Log C values become.

![Graph showing mean values and standard deviations](image)

Fig. 6 Mean values (m) of logarithm of amount of cement take and their standard deviations (σ) for each Lugeon group.

The similar plots were drawn for each order of grouting holes in Fig. 7. It is noted that the amount of cement take decreases with the progress of the order of grouting holes even if the Lugeon values are same. It means that smaller cracks which are not easy to be injected remain in the progress of grouting.

![Graph showing mean values for each Lugeon group](image)

Fig. 7 Mean values of logarithm of amount of cement take for each Lugeon group.

Prediction of Improvement of Watertightness by Grouting

The Lugeon value of the grouting hole is not the true index of watertightness of rock mass because the test is conducted before grout injection. Therefore, the method of predicting watertightness of rock mass after grouting is desired to be developed.

Fig. 8 shows the relationship of the mean values of log Lu between the successive orders of grouting holes. The figure indicates that the mean value of log Lu of the i-th order of grouting holes (log Lu_i) and that of the i+1-th order of grouting holes (log Lu_{i+1}) are almost in a linear relationship expressed by

$$
log Lu_{i+1} = A + B log Lu_i
$$

(1)

This recurrence equation means that the prediction of the improvement of watertightness will be possible if the coefficients of A and B is well estimated through the progress of grouting. In addition, the limitation of improvement of watertightness by grouting can be estimated since the equation can be rewritten as

$$
log Lu_{i+1} = B' \left( log Lu_i - \frac{A}{1-B} \right) + \frac{A}{1-B}
$$

(2)

Under the condition of $B<1$, log Lu_i converges on $A/(1-B)$ when the value i becomes infinite. The value of $A/(1-B)$ is therefore considered as the limitation of improvement of watertightness by grouting.

![Graph showing relationship between log Lu](image)

Fig. 8 Relationship of mean values of log Lu between successive orders of grouting holes.

On the other hand, Fig. 9 shows the relationship between the mean value of log C for the i-th order of grouting holes and the mean value of log Lu for the i+1-th order of grouting holes. The figure shows that they are in a linear relationship expressed by

$$
log Lu_{i+1} = D + E log C_i
$$

(3)
This regression equation provides another method of predicting the improvement of watertightness. The prediction of improvement of watertightness by Equation (3) is called as Procedure 1, and the prediction by Equation (2) is called as Procedure 2 in this paper.

![Graph showing the relationship between mean value of \( \log C \) for i-th order and mean value of \( \log Lu_i \) for i+1-th order.]

**Fig. 9 Relationship between mean value of \( \log C \) for i-th order and mean value of \( \log Lu_i \) for i+1-th order**

**Application of procedures to grouting at Hattabara Dam**

The above mentioned procedures were applied to the prediction of watertightness by grouting at the Hattabara Dam. The two stages of prediction were made: Case 1 is the prediction of the mean Lugeon value for the 3rd order of grouting holes from the results of grouting until the 2nd order of grouting holes and Case 2 is the prediction of the mean Lugeon value for the check holes from the results of grouting until the 3rd order of grouting holes. Each regression equation is as follows and the results of prediction are as shown in Table 2.

Case 1:

- Procedure 1
  \[ \log Lu_{i+1} = -0.135 + 0.980 \log Lu_i \]  
  (4)

- Procedure 2
  \[ \log Lu_{i+1} = -1.01 + 0.748 \log C_i \]  
  (5)

Case 2:

- Procedure 1
  \[ \log Lu_{i+1} = -0.152 + 0.818 \log Lu_i \]  
  (6)

- Procedure 2
  \[ \log Lu_{i+1} = -0.948 + 0.678 \log C_i \]  
  (7)

Table 2 shows the prediction values of \( \log Lu \) compared with the true values. The deviation is less than 5% compared with the true values. The accuracy of Case 1 is a little higher than that of Case 2.

**CONCLUSION**

In this study, the methods to predict the improvement of watertightness by grouting are discussed analyzing grouting data obtained from the Hattabara Dam construction site. Results of the study are as follows.

1) The Lugeon value and the amount of cement take are dealt with as the values under the logarithmic normality distribution.

2) The relationship of the mean values of the logarithmic Lugeon values between the i-th order of grouting holes and i+1th order of grouting holes can be expressed as the recurrence equation.

3) The Lugeon value decreases as geometric series and converges on the limit value which shows the limitation of improvement.

4) The relationship between the mean value of the logarithmic cement take of the i-th order of grouting holes and the mean value of the logarithmic Lugeon values of the i+1-th order of grouting holes can be expressed as the linear equation.

5) It is possible to predict the improvement of watertightness of rock mass according to the above relationships.

**REFERENCES**