APPLICATION OF THE CONTINUOUS MIX-PROPORTION CHANGE METHOD OF GROUTING

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ABSTRACT

The geology at the Oyama Dam site in Japan is composed of approximately 3.1 million to 4.1 million years old andesite lava. It is characterized by high permeability in some deep spots. By taking into account these characteristics, it was planned to provide curtain grouting up to the depth deeper than the dam height. As a result, the amount of the curtain grouting became quite large. Change of the mix-proportion of cement grout for grouting was made by the step-by-step mix-proportion change method based on the criteria for each mix-proportion. The criteria were set up based on the assumption that the cement grout of each mix-proportion to be injected would be made in one batch volume each time. For this reason, as one of the efficient methods of curtain grouting, the continuous mix-proportion change method that can easily change the mix-proportion of the cement grout was adopted to inject the cement grout into the foundation rock of the Oyama Dam. It was confirmed by the test application that the method was effective as the same as that of conventional methods for foundation rock improvement but shortened grouting time by setting up a unique mix-proportion change criteria. This paper reports the results of the test application of the method and actual grouting work of the Oyama Dam.

INTRODUCTION

At the Oyama Dam site, the geology was very complicated and the permeability was very high even at the deep strata. In addition in the shallow part of the right bank abutment, it was difficult to conduct a single line curtain grouting. In these situations, efficient grouting of a large amount of cement grout was a major issue.

For the Oyama Dam construction, we focused on the mix-proportion of cement grout when injecting the grout and, as a result, the continuous mix-proportion change method was adopted in order to efficiently conduct grouting work.

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MIX-PROPORTION CHANGE OF CEMENT GROUT

Mix-proportion Change Criteria in the Step-by-Step Mix-proportion Change Method

Grouting work for the Oyama Dam was conducted by the commonly used step-by-step mix-proportion change method from the beginnings of construction. The mix-proportion change criteria were set up by taking into account the actual cases of other dams located in areas having similar geological condition, as shown in Table 1. Relationship between the grout mix discharge and grouting pressure for less than 20 Lugeons and the cement grout concentrations are shown in Figure 1.

Table 1. Mix-proportion Change Criteria.

Per one stage (5m)

Used mix-proportion (C:W)	Grout amount for mix-proportion (L)		Changed mix-proportion (C:W)
	Lu < 20	20 < Lu	
1:8	400	–	1:6
1:6	600	400	1:4
1:4	600	600	1:2
1:2	600	600	1:1
1:1	1,400	2,000	
Specified grout amount	3,600		

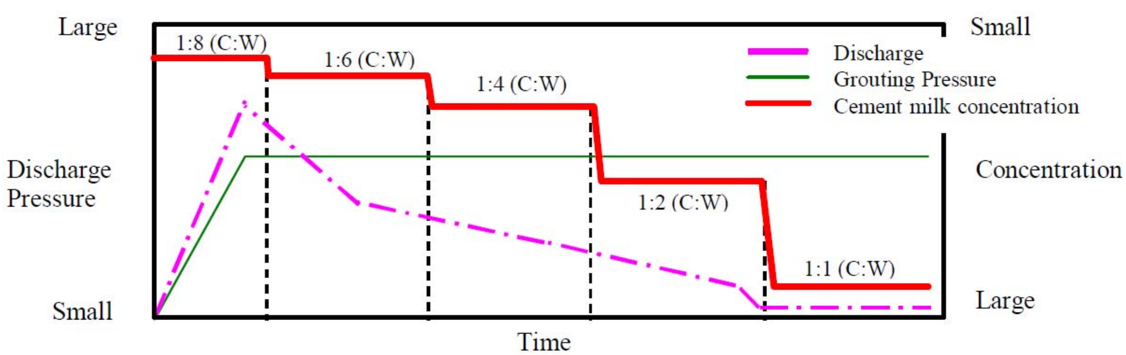

Figure 1. Concept of Relationship between Discharge, Pressure and Concentration.

The mix-proportion change was made for the purpose of effectively improving only a certain part of the foundation rock around the grout holes. The mix-proportion change was made using a relatively low concentration at first then, after injecting originally designed amount the concentration level was gradually raised.

In reality, the criteria for the step-by-step mix-proportion change method are set up by taking account of the past cases based on the Lugeon value. As the cement grout characteristics vary from grout hole to grout hole even though the Lugeon values are the same, the amount of cement grout to be injected greatly varies often times. Thus, it is difficult to predict the amount of cement grout until actual grouting work take place. For this reason, grouting amount tends to be either increased or decreased from the originally designed amount.

Change of the mix-proportion of cement grout for grouting was made by the step-by-step mix-proportion change method based on the criteria for each mix-proportion. The criteria were set up based on the assumption that the cement grout of each mix-proportion to be injected would be made in one batch volume (100 litters or 200 litters) each time.

The step-by-step mix-proportion change method abbreviates it to Step-by-Step Method afterward.

Application of the Continuous Mix Proportion Change Method

The continuous mix-proportion change method is able to change the mix-proportion of cement grout depending upon grouting time, grouting pressure and discharge for each hole, was recently developed.

In accordance with the test application of this method at the Takizawa Dam, it is reported that the grouting effect was almost the same as that by conventional step-by-step change method and that the grouting time was shortened approximately 30% from the conventional method, reported by Aoyama(2006).

At the Oyama Dam, the test application of this method was conducted for the purpose of achieving efficient and effective shortening of cement grout grouting time by continuously changing the mix-proportion of cement grout to suit the grout-hole conditions.

The continuous mix-proportion change method is abbreviated to the Continuous Method hereafter.

Setting up of Mix-proportion Change Criteria for the Continuous Method

The Step-by-Step Method is a method to change the mix-proportion of cement grout from low concentration to high concentration of cement. This method has two main issues. First, Figure 2 left shows, when grouting pressure does not increase, mix-proportion change has to be repeated many times. Thus, it takes a long time to attain a high cement grout concentration. Second, Figure.2 right shows, concentration of the cement grout does not change to a higher level until a certain amount of cement grout is injected. When low concentration cement grout is injected with a low discharge rate, efficient grouting may not be achieved.

In order to resolve the above two issues, criteria to change mix-proportion depending on discharge rate and grouting pressure at each stage were set up for the Oyama Dam and grouting work was largely divided into the following four stages (refer to Table 2).

In first stage (to maintain mix-proportion), initial low mix-proportion of C:W=1:1 should be grouted for the first 5 minutes period.

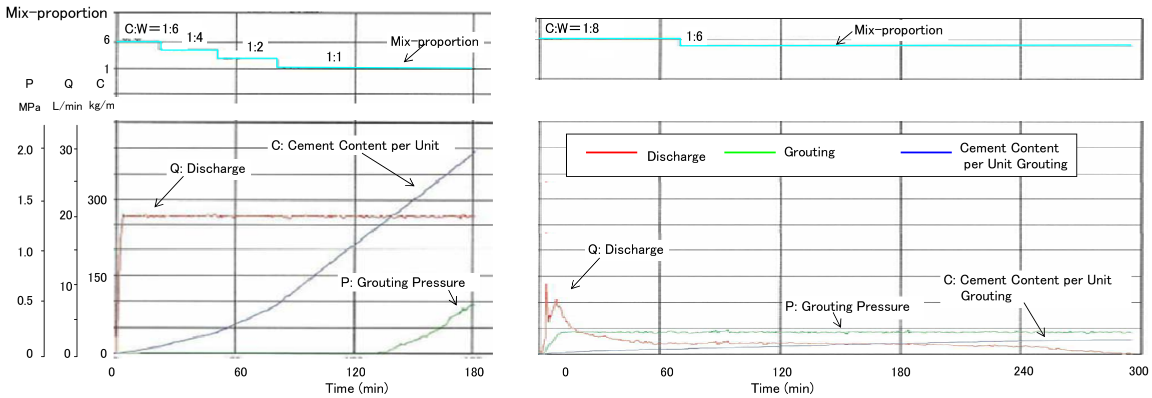

Figure 2. Two Example of the Change of Grouting Elapsed Time by Step-by-Step Method.

In Second stage (to rapidly increase the concentration), a criteria should be set up to gradually make a higher concentration from the initial concentration depending upon the discharge rate and grouting pressure utilizing the merits of the Continuous Method until the grouting pressure increases to the designed value. The concentration increase rate should be set up as criteria of the discharge rate and grouting pressure so that the concentration increases quickly when the grouting pressure does not increase and the discharge is large, and so that the concentration increase rate becomes small when the discharge rate decreases. The coefficient of the criteria for 20 Lugeons or smaller should be set up so that the concentration increases from C:W=1:10 to C:W=1:1 in about 40 minutes when the discharge is large and the concentration increases to C:W=1:1 in about 4 hours when the discharge is small. On the other hand, for larger than 20 Lugeons, the coefficient shown in Table 2 of the criteria should be set up so that the concentration increases to C:W=1:1 in about 20 minutes when the discharge is large and the concentration increases to C:W=1:1 in about 4 hours when the discharge is small.

In third stage (to slowly increase concentration), a criteria should be set up so that the concentration increases with time responding to the decrease in the discharge after the grouting pressure reaches to the designed value. The concentration increase rate should be set up so that the concentration quickly becomes thicker when the discharge does not decrease and the concentration slowly increases when the discharge decreases, depending upon the discharge decrease rate. The coefficient of the criteria should be set up for less than 20 Lugeons so that the concentration of C:W=1:10 increases to C:W=1:1 in about 4 hours when the discharge does not decrease and the concentration continues the same level when discharge decrease rare is approximately 2 litters a minute. On the other hand, for larger than 20 Lugeons, the coefficient of the criteria should set up so that the concentration of C:W=1:10 increases to C:W=1:1 in about 30 minutes when the discharge does not decrease and the concentration remains the same level when the discharge decreases with a rate of 7.5 litters a minute.

In fourth stage (to maintain mix-proportion), the mix-proportion should be maintained when the discharge decreases below the designed rate and grouting should be continued for 30 minutes. 0.4 litter per minute of discharge, twice of ordinary grouting completion criteria, for smaller than 20 Lugeons and 1.0 litter per minute of discharge, i.e., five times of ordinary grouting completion criteria, for larger than 20 Lugeons should be set up as the discharge coefficients.

Figure 3 shows the relationship (image) between the discharge and grouting pressure, and the concentration for continuous mix-proportion change, and the image of cement grout concentration.

Table 2. Grouting Specifications for Continuous Mix-proportion Change.

1st Stage	Maintain Specific Gravity (Initial Mix-proportion) For 5 Minutes
2nd Stage	$\alpha \times Q/Q_{max} \times (1 - P/P_{max}) + \beta$
3rd Stage	$\alpha 2 \times (\Delta Q/\Delta T) + \beta 2$
4th Stage	$Q_{min} \times C$

Lugeon Value Range	α	β	$\alpha 2$	$\beta 2$	C
Lu<20	0.01	0.002	−0.001	0.002	2
20<Lu	0.02	0.002	−0.002	0.015	5

note: Q: Discharge (liter/min), Qmax: Designed Discharge (4 liter/min), P: Pressure (MPa), Pmax: Designed Grouting Pressure (MPa), ΔQ/ΔT: Discharge Change (Calculation Interval: 120 seconds)

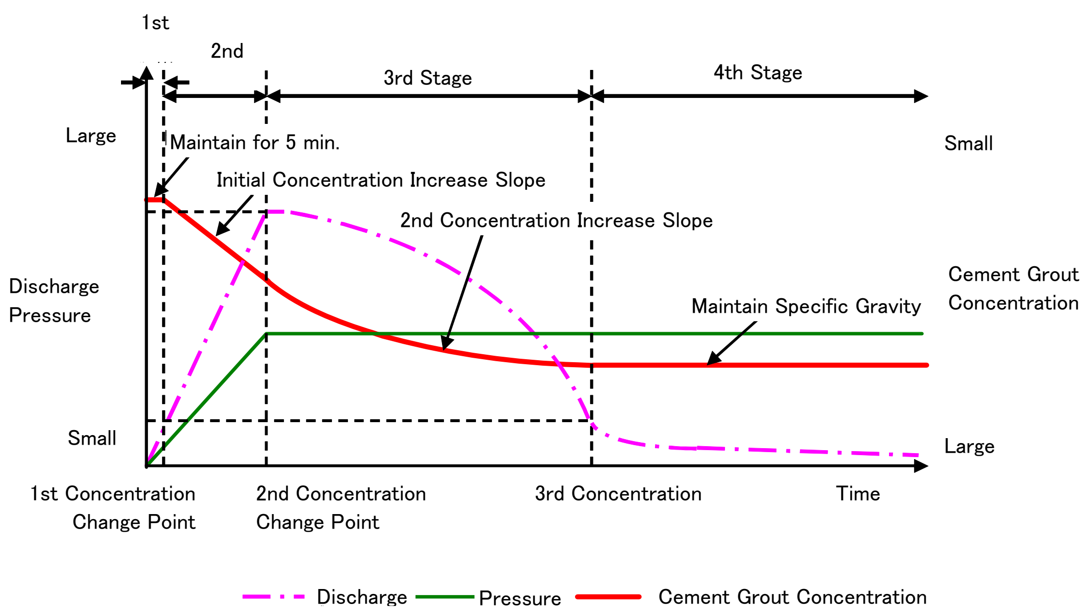

Figure 3. Concept of Relationship between Discharge, Pressure and Concentration.

TEST APPLICATION OF THE CONTINUOUS MIX-PROPORTION CHANGE METHOD

Grouting Characteristics at the Oyama Dam Site

The following three points are the characteristics of the grouting work at the Oyama Dam site. First, the geology was very complicated and the permeability was very high even at the deep strata. A large amount of cement grout grouting was required. Thus, it was necessary to provide deep curtain grouting by taking into consideration the hydrogeological structure of the ground. Second, at the shallow part of the right bank abutment, it was difficult to conduct a single line curtain grouting. Thus, double-line curtain grouting was provided. Third, as the groundwater level did not rise at the right bank limb, grouting area became very large. In the above situations, efficient grouting of a large amount of cement grout was a major issue.

Purpose of the Test Application

The test application was conducted to confirm the effectiveness of the Continuous Method and applicability of the method to the foundation ground of the Oyama Dam. As the method can make cement grout concentration high much quicker than the Step-by-Step Method, a special attention was paid on the aspect of the effectiveness for foundation rock improvement.

Location of the Test Application

The test application of the Continuous Method was conducted in two parts, double curtain of BL45 at the right bank abutment (1 to 10 stages: 0 to 50m) and deep part of the main curtain (21 to 36 stages: 100m to 180m). Figure 4 show the location map and the plan view of the test application respectively.

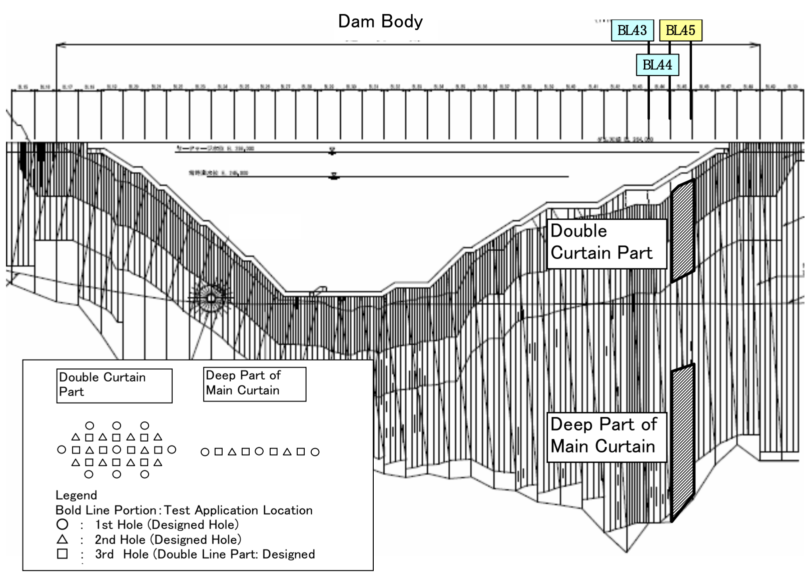

Figure 4. Location Map of the Test Application.

Result of the Test Application

Figure 5 shows the Lugeon value of 15% exceedance probability and the relationship between the average the Lugeon value and the order of holes of the Step-by-Step Method and the Continuous Method. When the order of holes increases the Lugeon value decreases. The Continuous Method achieved the same ground improvement effect as the Step-by-Step Method.

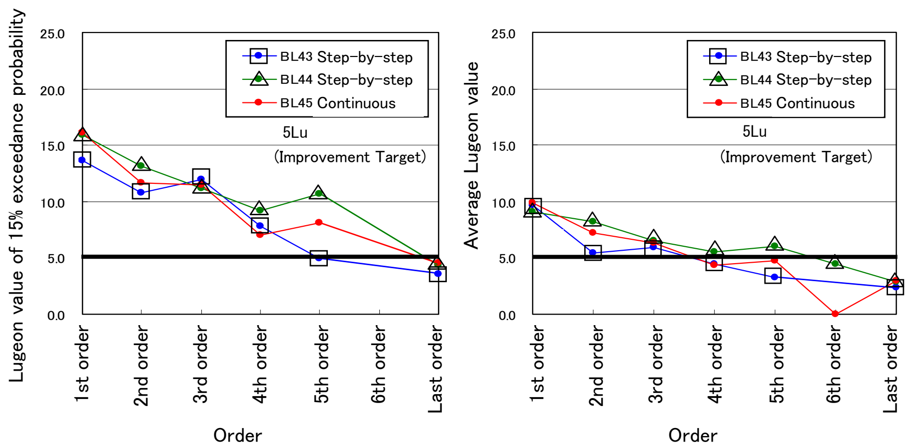

Figure 5. The Lugeon value Decrease Diagram at Each Hole Order (Double line curtain part)

The average grouting time of BL. 45 conducted by continuous method was approximately 40% shorter than BL. 43 and BL. 44 conducted by the Step-by-Step Method as shown in Figure. 6.

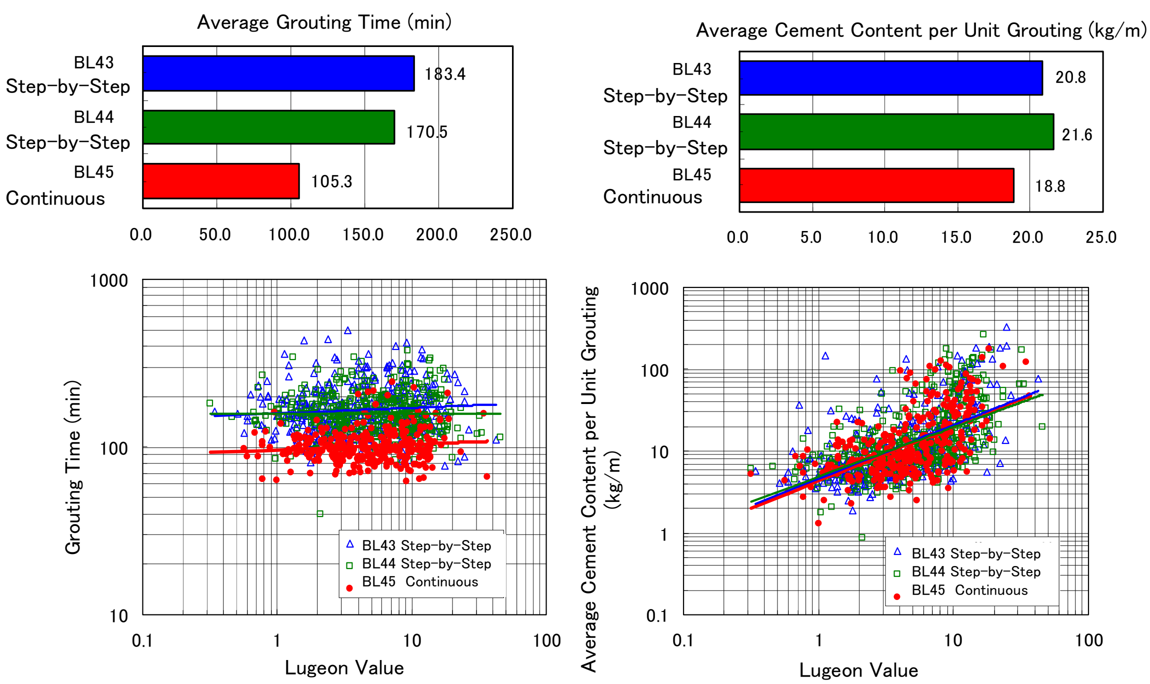

Figure 6. Grouting Time and Grout Cement Content Analyses Graph (Double curtain line part)

The average grout cement content of the Continuous Method was slightly less than that of the Step-by-Step Method as shown in Figure. 6. As for the cement content per unit grouting (1 m) for The Lugeon value, it was almost the same that of the Step-by-Step Method.

The comparison of the additional number of holes in the double curtain area for the Continuous Method and the step-by-step mix-proportion change method. The number of additional holes at BL 45 was 143 and the occurrence rate of the additional holes was 51%. On the other hand, the occurrence rate of additional holes for the Step-by-Step Method was 40% at BL 43 and 68% at BL 44 respectively, almost the same as those for the Continuous Method.

Figure 7 and Figure 8 show the grouting discharges and pressures of the Step-by-Step Method and the Continuous Method for the cases of almost the same The Lugeon value, grouting cement content and the change of the elapsed time for mix-proportion changes. Figure 6 is an example of the Step-by-Step Method. As shown in Figure 6, the constant grouting of the initial mix-proportion of 1 to 10 (C to W) finished after 60 minutes then mix-proportion was changed to 1 to 8. After that, relatively small amount of grouting with the designed pressure was continued. After the grouting of the 1 to 8 mix-proportion for 130 minutes, the grouting rate became less than the designed amount (less than 0.2 L/min/m) and the grouting was completed.

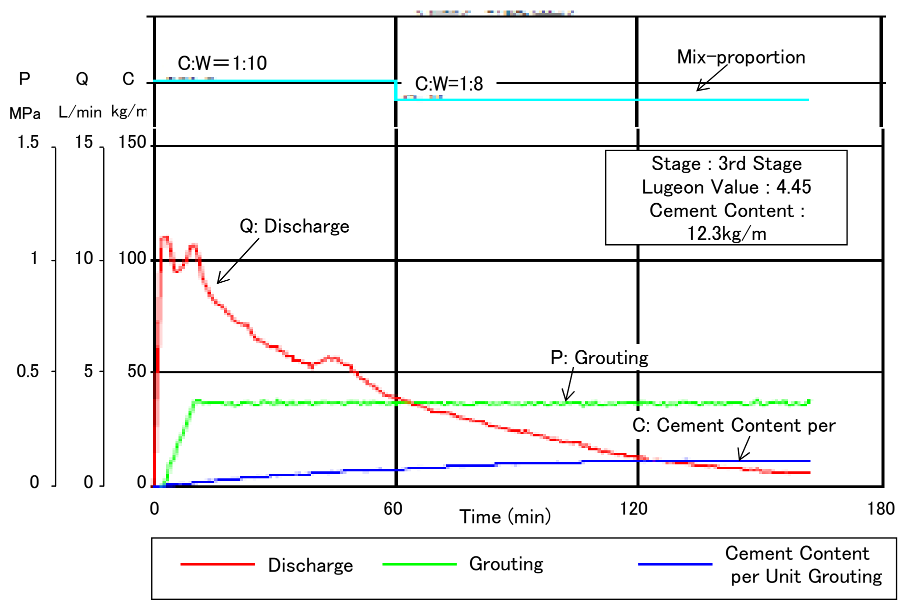

Figure 7. Example of the Change of Grouting Elapsed Time
(step-by-step mix-proportion change)

Figure 8 shows the example of the continuous mix-proportion change. During the second stage prior to the grouting pressure reached to the designed pressure, the mix-proportion changed from 1 to 10 (C to W) to 1 to 8 in 10 minutes. In the third stage after the grouting pressure reached to the designed pressure, the mix-proportion changed to 1 to 4 in 70 minutes corresponding to the decrease rate of the grouting amount. After that time, the grouting rate became smaller than the designed amount and extra grouting was made by keeping the same mix-proportion.

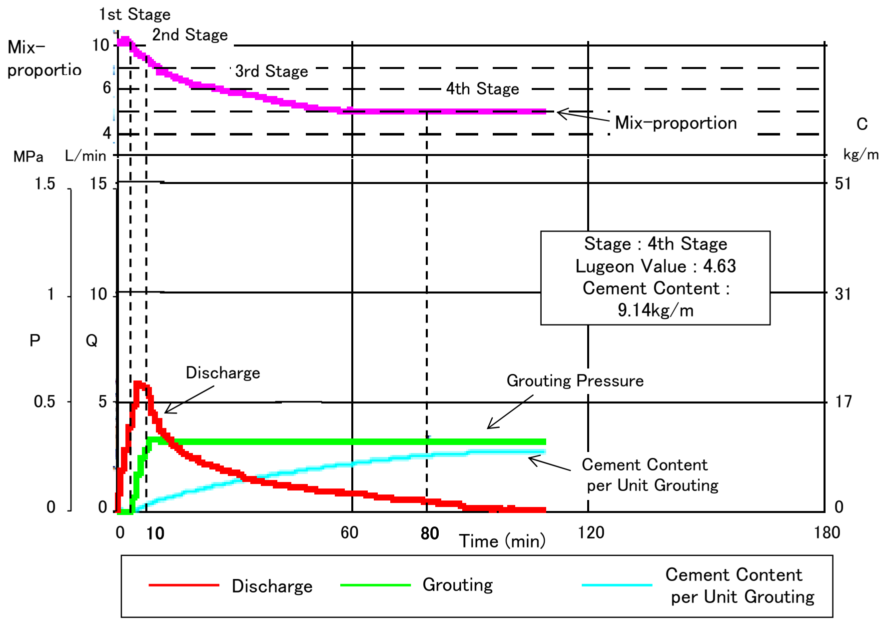

Figure 8. Example of the Change of Grouting Elapsed Time
(continuous mix-proportion change (right))

<u>Evaluation of the Test Application</u>

The following points were confirmed as the evaluation of the test application of the Continuous Method to the Oyama Dam. First, the Continuous Method can shorten the grouting time approximately 40% comparing with the Step-by-Step Method. Second, there were no great differences in the decrease-rate effect of the Lugeon value in the Continuous Method and the Step-by-Step Method. Third, the Continuous Method was almost the same to the Step-by-Step Method in view of the cement content of unit grouting and the number of additional holes required.

In view of the above confirmation, it is considered that the Continuous Method is more effective for shortening of grouting time than the Step-by-Step Method. Thus, it was decided upon to adopt the Continuous Method for grouting at the right bank limb.

IMPLEMENTATION CONDITION OF THE CONTINUOUS MIX-PROPORTION CHANGE METHOD

Grouting time to be saved by the Continuous Method comparing to that by the Step-by-Step Method was calculated from the total number of stages completed by the Continuous Method at blocks following after BL 58 at the right bank limb and un-grouted remaining stage numbers based on the average grouting time obtained from the test application results. The grouting time per one stage by the Step-by-Step Method was set up as 3.5 hours and that by the Continuous Method was set up as 2.5 hours respectively based on the actual grouting time. So number of stages at the right bank limb conducted by continuous method is 1,247, that it is expected to shorten 1,247 hours of grouting time by applying the Continuous Method comparing with the Step-by-Step Method. Grouting time to be shortened by the use of the Continuous Method would be approximately 15 days if four sets of grouting equipment will be used.

CONCLUSION

It was confirmed from the result of the test application of the Continuous Method to the curtain grouting work of the Oyama Dam that the ground improvement effect was almost the same to that by the Step-by-Step Method and that grouting time can be shortened by approximately 40% from that by the Step-by-Step Method. In addition, based on the test application result, the Continuous Method was applied to actual grouting work.

At the Oyama Dam, a large amount of grouting was required. For this reason, it is considered that the shortening of grouting time by the use of the continuous mix composition method may result in not only the reduction of base rock treatment costs but also the shortening of construction period of the dam.

REFERENCES

Aoyama, 2006, New Technology for Takizawa Dam Foundation Treatment (Successive Mix-proportion Change Method) ; Application Result, Dam Engineering No. 239, pp. 49 - 60, (in Japanese).