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Rationalizations of Curtain Grouting for Dams Based on the Revised Grouting Guidelines in 2003 in Japan and Their Evaluation

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ABSTRACT:
Construction plans of dry dams that allow riverbed materials to flow downstream have been increased, while preventing the water level from rising at normal times by installing outlet works near the elevation of the riverbed with a view to conserving the river environment. This paper summarizes the rationalization of curtain grouting based on analysis using documents of 78 dams that carried out first impounding after the 2003 revision of the Grouting Guidelines in Japan, and reviews the characteristics of curtain grouting rationalization. Of the dams surveyed, those with relatively large leakages during first impounding were extracted, the causes of leakages were analyzed, and the conditions to be noted in the rationalization of curtain grouting were studied.

Keywords: dam, curtain grouting, rationalization, guidelines, leakage

1. INTRODUCTION

Construction plans of dry dams that allow riverbed materials to flow downstream have been increased, while preventing the water level from rising at normal times by installing outlet works near the elevation of the riverbed with a view to conserving the river environment.

In the current practice of dam foundation treatment, mainly in the plan and design of curtain grouting, the unsteady seepage accompanying water impounding is not taken into account, but seepage is treated as steady state in the safety side judgement in foundation treatment. However, in a dry dam, the normal water level (NWL) is near the elevation of the riverbed, and the foundation of the abutment between the NWL and the surcharge water level (SWL) is impounded only temporarily during flood. In regard to the foundations, it is necessary to take into consideration of the unsteady seepage to positively assess the possibility of achieving rationalization by relaxing the improvement target Lugeon values in the shallow area of the foundation for curtain grouting, reducing the depth or narrowing the range, and thereby reducing construction costs, while at the same time ensuring the safety of the dam. However, in this rationalization of curtain grouting, it is necessary to investigate the ground conditions that are appropriate to rationalization and to take account of the possibility that water path in the grouted areas or ungrouted areas might give rise to leakage.

In this paper, documents were gathered on the curtain grouting of 78 dams that finished first impounding after the publication of the 2003 revision of the "The Japanese Technical Guidelines on Dam Foundation Grouting"(JICE, 2003)(hereafter Grouting Guidelines), and the characteristics of curtain grouting rationalizations were reviewed. Of the dams surveyed, those with leakages that were relatively large in first impounding were extracted, the causes of the leakages were analyzed, and the conditions to be noted in the rationalization of curtain grouting were studied.

2. SURVEYED DAMS

2.1. Surveyed Dams

Regarding the curtain grouting of dams that finished first impounding after the 2003 revision of Grouting Guidelines, fundamental investigation was made using documents about geological maps, rock classification maps, Lugeon-value maps before and after execution of curtain grouting and so forth. A total of 78 dams was selected for the survey, including four dams that had not executed curtain grouting.

2.2. Types of Surveyed Dams

Figure 1 shows a classification of the 78 surveyed dams by type. Of all the surveyed dams, 63 (80.8%) were concrete gravity dams, 12 (15.4%) rockfill dams, two (2.6%) earthfill dams and one (1.3%) a combined dam. The proportion of gravity concrete dams is predominant in surveyed dams.

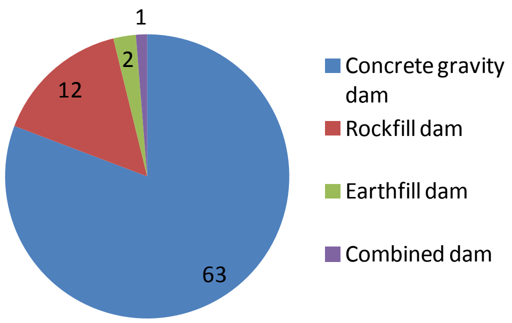

Figure 1. Types of surveyed dams

3. SUMMARY OF CHARACTERISTICS OF CURTAIN GROUTING RATIONALIZATION

The foundation grouting of the surveyed dams had been planned according to dam type, dam height and the properties of the foundation rock in conformity with the Grouting Guidelines. In 78 surveyed dams, reviews of grouting design were carried out to adapt to the revised Grouting Guidelines in 2003, and grouting was rationalized on the basis of new survey findings and grouting execution information.

Individual aspects of rationalization in grouting plans and specifications of execution for the surveyed dams are investigated based on documents about curtain grouting.

Incidentally, grouting plans have been often reviewed in conjunction with a revision of technical guidelines on grouting. The technical guidelines on grouting can be seen in the following three chronological phases in Japan:

(1) November 1983, "The Japanese Technical Guidelines on Dam Foundation Grouting, with Commentaries" (JICE, 1983)
(2) April 2002, "The Japanese Technical Guidelines on Dam Foundation Grouting (draft), with Commentaries" (MLIT, 2002)
(3) April 2003, "The Japanese Technical Guidelines on Dam Foundation Grouting, with Commentaries" (JICE, 2003)(published in July 2003)

Rationalization of curtain grouting was carried out with the revision of Grouting Guidelines by changing initial plans or specifications. We find that the characteristics of curtain grouting rationalization for the surveyed dams can be mainly classified into two, changes of grouting plans and changes of grouting specifications as discussed below.

Figure 2 shows the number of dams with rationalization for curtain grouting in surveyed 78 dams. 66 dams carried out rationalization of curtain grouting. Recently constructed dams have been making efforts to achieve the cost reduction.

The number of dams with rationalizations in plans for curtain grouting in 66 dams with rationalizations is 64 in Fig.3. Plans of curtain grouting are often changed considering the results of previous executed curtain grouting because 2003 Grouting Guidelines recommend review of grouting plans during execution.

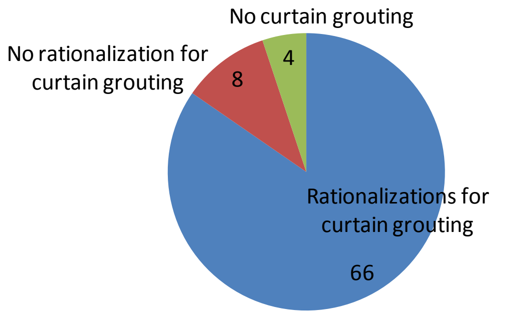

Figure 2. The number of dams with rationalizations for curtain grouting in surveyed 78 dams

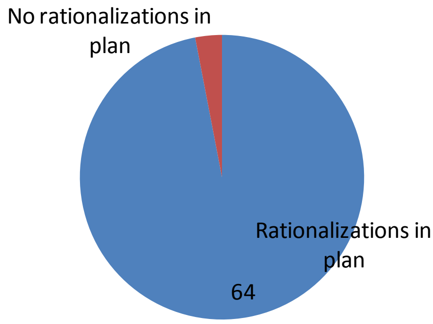

Figure 3. The number of dams with rationalizations in plan for curtain grouting in 66 dams with rationalization in Fig.2.

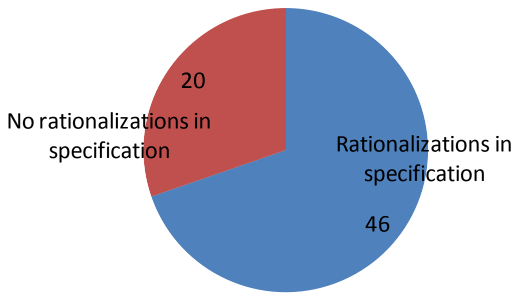

Figure 4. The number of dams with rationalizations in specification for curtain grouting in 66 dams with rationalization in Fig.2.

Rationalizations in specification for curtain grouting are taken in 46 dams by the document investigation in Fig.4.

Because specifications have a lot to do with plans, 20 dams that cannot be found rationalizations in specifications in document investigation have possibility to carry out the rationalizations in specifications in real.

3.1. Rationalization of Grouting Plans

The starting dates of curtain grouting execution of the surveyed dams are distributed over a period of almost 10 years from 1998 to 2007. Similarly, the completion dates of curtain grouting execution span a period of approximately 10 years from 1999 to 2009.

The design of many of these dams was first carried out according to the former Grouting Guidelines in 1983, and these plans were revised for adaptation to the revised Grouting Guidelines (draft) in 2002 and final revised Guidelines of 2003.

The aspects of rationalization involved in changes of grouting plans include the followings:

(1) Changes of curtain grouting area
Reduction of depth of curtain grouting can be adapted in 2003 Guidelines, requiring depth setting differentiated by each block in connection with the relaxation of target Lugeon values for deeper areas. Abrupt difference of curtain grouting depth between adjoining blocks was used after 2003 Guidelines in some dams.

While the 1983 Guidelines defined the rim grouting range between the surcharge water level and the ground water level or the impermeable zone, the 2003 Guidelines changed the rim grouting range to the intersection between the normal water level + α and the ground water level or the impermeable zone considering the hydrogeological structure.

(2) Changes of improvement target Lugeon values
The improvement target Lugeon values were relaxed in the downward direction, from unilateral setting for all foundation rock under the 1983 Guidelines to differentiation by the depth zone under the 2003 Guidelines.

(3) Changes of final order of design holes of curtain grouting
After the revision of Grouting Guidelines in 2003, some dams changed final order of design holes. For example, final order of design holes changed from tertiary to secondary.

(4) Changes of standards of additional holes of curtain grouting

Based on the 1983 Grouting Guidelines additional holes were executed to all possible surrounding holes, but only parts with larger Lugeon values were executed as additional holes in 2003 Grouting Guidelines.

(5) Others
Others include abolition of auxiliary curtain grouting or change of hole arrangement from single row to double row, etc.

Figure 5 shows the number of each rationalization type in plan, (1) to (5) described above. Because sometimes a dam takes several rationalization types in plan, the total number of Fig.5. is more than the total number of dams with rationalization in plans. From Fig.5., we find that many dams take mainly three rationalization types; changes of curtain grouting area, changes of improvement target Lugeon values and changes of final order of design holes.

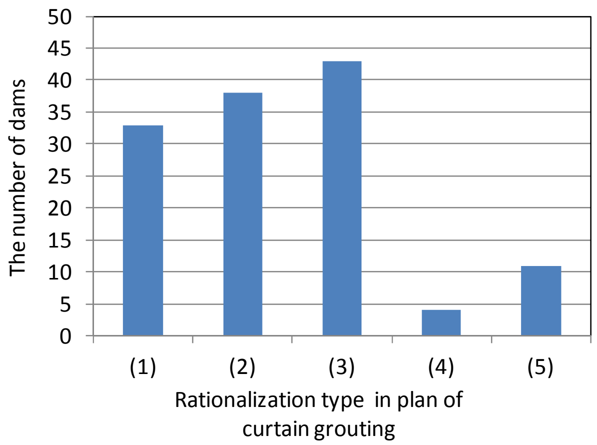

Figure 5. The number of each rationalization type in plan for curtain grouting in 64 dams with rationalization in Fig.3.
* (1) to (5) means below;
(1) Changes of curtain grouting area
(2) Changes of improvement target values
(3) Changes of final order of design holes of curtain grouting
(4) Changes of standards of additional holes of curtain grouting
(5) Others

3.2. Rationalization of Grouting Specifications

The characteristics of the main rationalization items related to specification changes are as follows:

(1) Changes of injection pressure
Where there is a change in injection pressure, maximum pressures and pressure steps of permeability tests are also changed.

In many cases, the identification of critical pressure makes it necessary to reduce the injection pressure.

In deeper areas of foundation rock, the injection pressure is sometimes raised in some cases but that is lowered in others, especially in shallow areas.

(2) Changes of switching standard of grout mix proportion
The switching of the initial grout mix proportion differs slightly from dam to dam.

Common patterns include starting with a thinner mix proportion where there is less permeability in foundation rock, and the same mix proportion is applied to the first 200 to 800 litters of injection, followed by switching to a thicker mix proportion where there is no possibility of completing the injection execution.

Changes of switching standard of grout mix proportion include an addition of 1:1.5 between 1:2 and 1:1 in the cement-water ratio, or of adding 1:0.8 after 1:1, and changes in the initial thinner blend.

(3) Changes of grout materials
For some dams where it was difficult to improve upto the target Lugeon value, grout material was sometimes changed from normal cement to finer cement.

(4) Standards on omission of grout injection
Standards on the omission of grout injection are generally set in terms of Lugeon value. For example, when Lugeon value is less than 0.2, grout injection is omitted because it is thought that grout will not be injected into low permeability rock.

(5) Prestage injection
In some cases, where a leakage or some similar problem exist, and where the range of curtain grouting in the rim section is deeper than the surcharge water level, prestage injection is called for in the area above and the specifications are changed accordingly.

4. SUMMARY OF DETAILED INVESTIGATION ON CURTAIN GROUTING OF REPRESENTATIVE DAMS WITH RELATIVELY LARGE LEAKAGE FROM DRAIN HOLE DURING FIRST IMPOUNDING

Table 1 presents a list of eight dams extracted from the surveyed dams, showing the problems of relatively large leakage in first impounding. All of eight dams are concrete gravity dams.

The following problems were identified at the time of first impounding in the dams listed in Table 1.

(1) Dam A
In the riverbed section, a leakage that peaked at 37.63L/min was observed at a drain hole, and the washout of fault clay was also observed. A substitute drain holes were drilled, and additional consolidation grouting was carried out.

(2) Dam B
A leakage from a drain hole in the riverbed section was not so large 14L/min at maximum, but much larger leakages of up to 215L/min and 432 L/min were observed at two drain holes in the cross gallery and the downstream area in dam body. When the downstream ground water level was lowered approximately 10m by drainage wells, the leakages from two drain holes were reduced by almost half.

(3) Dam C
A leakage that peaked at 49.95L/min was observed at a drain hole in the right bank abutment section. This was the only hole from which a large leakage was found, and the uplift pressure of this hole was low.

Table 1. List of dams with the problems of relatively large leakage in first impounding in surveyed dams

Name of dam	Type of dam	Dam height (m)	Rock Type of foundation
A	Concrete gravity dam	65	Cretaceous granodiorite
B	Concrete gravity dam	66.2	Cretaceous granodiorite
C	Concrete gravity dam	49	Cretaceous biotite granite
D	Concrete gravity dam	64	Tertiary granodiorite
E	Concrete gravity dam	93.5	Cretaceous granodiorite
F	Concrete gravity dam	72	Cretaceous rhyolites, quaternary volcanic rocks
G	Concrete gravity dam	125.5	Cretaceous granite
H	Concrete gravity dam	98	Cretaceous granite

(4) Dam D
A leakage that peaked at 23.8L/min was observed at a drain hole in the right bank abutment section. The area around the drain hole estimated a high permeability based on the Lugeon value distribution before curtain grouting execution.

(5) Dam E
A leakage that peaked at 49.9L/min was observed at a drain hole in the riverbed section. This hole was also in a state of high uplift pressure.

(6) Dam F
A leakage that peaked at 39.6L/min was observed at a drain hole in the right bank section. Only this hole posed a problem.

(7) Dam G
Seven drain holes were found leakages more than 20L/min and these holes were located mainly in the

riverbed section. Since the earlier time of first impounding, an increase in leakages was recognized, and regrouting was carried out around these drain holes. Reinforcing curtain grouting works were conducted from the gallery. Leakages from joints were also significant, and drainage holes to dam body were bored to lower the water level.

(8) Dam H
In the earlier time of first impounding, leakages from drain holes in the deepest riverbed area increased, and four holes of over 10L/min were recognized, the largest being 40L/min.

Out of the eight dams listed in Table 1, seven dams were mainly composed of granitic foundation rocks. Since the permeability of granite itself is too low to pose a problem as a source of water flow path in dam foundations, it is possible that the water flow path may be located in the discontinuous weathered areas, alteration zones, joints, cracks and faults and areas that have suffered weather damage.

The results of the detailed investigation into Dam H are summarized in the next section.

5. DETAILED INVESTIGATION INTO DAM H

5.1. Summary of Drain Holes with Relatively Large Leakages

At the earlier time of first impounding in Dam H, the quantity of leakages was relatively large in five drain holes as shown in Table 2.

Table 2. Relatively large leakages in Dam H

Number of drain hole	Position and water level of drain hole		Maximum drainage quantity
14-D001	Riverbed EL.214.5	about EL.220.0 (below low water level)	12L/min
17-D002	Riverbed EL.214.5	about EL.220.0 (below low water level)	17L/min
18-D001	Riverbed EL.214.5	about EL.220.0 (below low water level)	15L/min
19-D001	Riverbed EL.214.5	(about EL.220.0 below low water level)	40L/min
20-D002	Riverbed EL.214.5	(about EL.220.0) below low water level	7.5L/min

* Dam foundation : EL.207.0

In Dam H, both plan and specification rationalizations of curtain grouting were carried out. Because of relatively large leakages from drain holes at the foundations, investigations were carried out to identify the causes of leakages. The rationalizations in plan and specification of the execution for the areas in Table 2 were investigated.

5.2. Rationalization of Plan

At Dam H, many rationalizations in curtain grouting plan conducted.

Long-time water pressure tests were conducted, and where the P-Q curve revealed a decreasing pattern of quantity in water pressure test in Fig.6, a Lugeon value of 2.9Lu in normal water pressure test was considered to correspond to less than 2.0Lu in long-time water pressure tests as shown in Fig.7. The improvement target Lugeon value was changed based on the results of Fig.7.

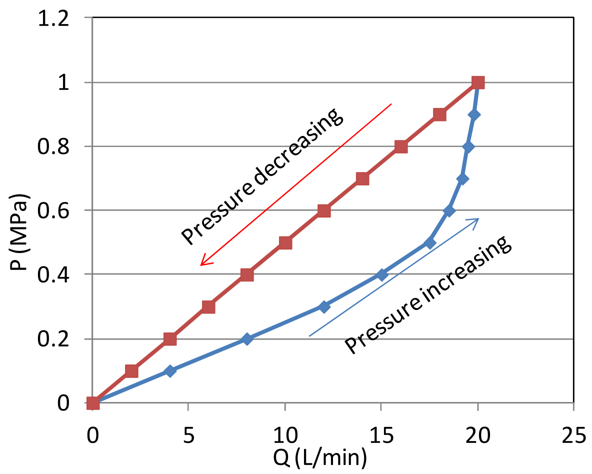

Figure 6. Example of decreasing pattern of quantity in water pressure test

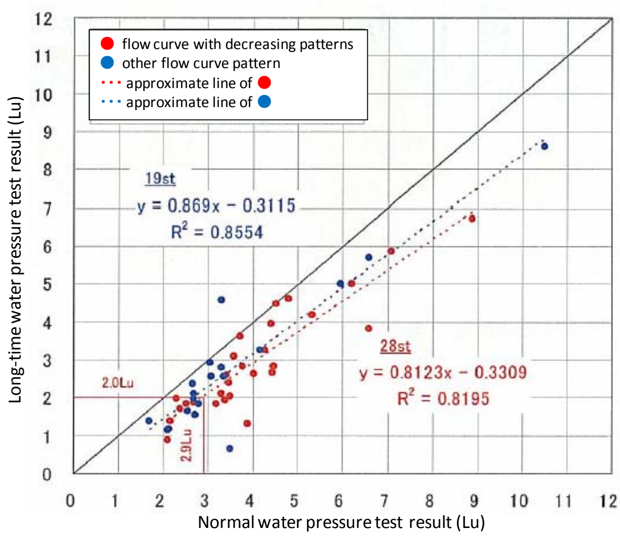

Figure 7. Comparison of Lugeon values between flow curves with decreasing patterns and other flow patterns

In the evaluation of final order holes, Lugeon values from 2.1 to 2.9 where the flow curves show decreasing patterns are evaluated as having reached the improvement target Lugeon value of 2Lu.

Further, based on the results of test execution of curtain grouting, the order of final design holes was changed from the primary to the tertiary.

5.3. Rationalization of Specification

Test execution of curtain grouting was done in the areas in Table 2. This involved a rise in injection pressure and an addition of thinner mix proportion grout of a water-cement ratio of 10:1. These changes of specifications resulted in effective improvement.

5.4. Investigations of Causes of Leakages

Since the leakages from the drain holes were relatively significant at earlier time of first impounding, investigation was conducted near the areas in Table 2 based on the following factors.

(1) Confirmation of grouting results
Those cracks that were recorded strike-dip directions on the sketches of the foundation excavation surface were investigated as follows.
(a) those cracks that may have had insufficient improvement were extracted, and
(b) those cases where it was impossible to identify the cracks by vertical boring were also picked up.

As a result, it was found that some cracks had possibility to exist that not be improved by design and additional holes of curtain grouting. It was discovered that there was a very strong possibility that many of these cracks were continuous in the vicinity of areas of drain holes with large leakage in Table 2, and that the remainder of these cracks was very probable the cause of relatively large leakages.

(2) Investigation into foundation drain holes by the additional boring holes
Additional boring holes were executed upstream near the existing drain holes for detailed investigation on account of relatively large leakages. The main investigation items included (a) measurements of sectional leakage in the vertical direction, (b) water pressure tests and (c) tracer tests. After the end of these investigations, grouting was carried out using the additional boring holes.

An analysis of the summary of the findings of the additional investigation attributes the main cause of the leakages to low-dip cracks with the appearance of openings and high-dip cracks with decomposed granite.

6. CONCLUSIONS

In order to investigate the characteristics of curtain grouting rationalization, we investigated using technical documents about curtain grouting of 78 dams that carried out first impounding after the 2003 Grouting Guidelines. Of the dams reviewed, relatively large leakages in first impounding were found, the causes of their leakages were analyzed, and the conditions to be noted in the rationalization of curtain grouting were studied. Summaries of the findings are presented below.

(1) This research reveals that dams that carried out first impounding after the revision of the Grouting Guidelines in 2003 took many rationalizations of curtain grouting, and rationalization items were mainly divided into two categories, plan changes and specification changes. Many rationalization items in curtain grouting were carried out in many dams and it seems that considerable progress can be achieved in the rationalization of curtain grouting.

(2) Of the 78 dams surveyed, eight dams, about 10% of all, had relatively large leakages during the first impounding. Of these eight dams, seven dams were composed of granitic foundation rocks. A detailed further investigation into these dams regarding possible causes for leakages suggested that they might be caused by low-dip cracks with the appearance of openings in granite or high-dip cracks involving decomposition granite. We should pay attention to such geological conditions when rationalizations of curtain grouting are considered in dam construction.

REFERENCES

Japan Institute of Construction Engineering (JICE) (1983) : Guidelines on Dam Foundation Grouting. (In Japanese)

River Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2002) : Guidelines on Dam Foundation Grouting (draft). (In Japanese)

Japan Institute of Construction Engineering (JICE) (2003) : Guidelines on Dam Foundation Grouting. (In Japanese)