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A study of the grouting at the bottom of the Yashio dam reservoir and the evaluation of the leakage by grouting

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ABSTRACT: In the Yashio dam reservoir, there is a network of fissures which assumed open fissures of the high dip angle that has the hydrothermal alternation and a large-scale bedrock creep regarded as the main generation factor of the subject in deeper areas. As a result of the test grouting which we performed before the construction for leakage stoppage, we utilized an injection pressure and a limit sedimentation velocity of cement particles and performed effective grouting for fissures of the big width at the bedrock of the bottom of the reservoir filled with water. Further, we confirmed that the leak had been reduced. In this article, we have conducted a qualitative consideration of the grouting mechanism.

1 INTRODUCTION

The Yashio dam reservoir is the upper reservoir of the Shiobara pumped storage power plant (Cf. figure 1). An upper reservoir is generally made in the vicinity of mountaintop area to get a large head. Leakage tends to be a problem at such spot, because the permeability coefficient is high and the groundwater level is low. The original ground is thin at the right bank of the reservoir, and a lot of porphyrite has been distributed. In addition, the Groundwater level is generally low and falls to the right bank from the left bank in the reservoir. Given the concern for the leakage of the brooks in the Hokikawa River's drainage system from the right bank in the reservoir, we carried out construction to stop the leakage (Cf. figure 2,3). We conducted grouting from the grouting tunnel which we made in the right bank of the reservoir to the rim grouting tunnel in the right bank of the dam, and made a curtain to stop the leakage. As a result of the borehole of addition and extension based on the initial ponding results, the depth of the borehole in the curtain for leakage stoppage came to around 200–400 m, and the interval became 1.5–12 m (Cf. figure 4).

The additional grouting had some effect. However, since there was still much leakage, we investigated the place that was deeper than the curtain by the check borehole. As a result, there was not the convergence of permeability coefficient to the deep part direction, and points more than 10~100 Lu was distributed locally. All the tracers that we cast into a part of the point where permeability coefficient is high were confirmed in the brooks in Hokikawa river's drainage system (Cf. figure 5,6).

As a result of a diving investigation (We sprinkled the bentonite beforehand and investigated the trace of crater occurrence brought about by seepage water), we carried out the grouting in the bottom of Ichinosawa which has a lot of "Craters" ("Craters" is a dent in the bottom area created by seepage water) (Cf. figure 7, photo 1). Since the leakage was decreased quite substantially, we expected that the accumulation of solid particles would naturally block fissures and discontinued the leakage stoppage work at that juncture (Cf. figure 5).

We conducted an investigation and test grouting in the bottom of the reservoir filled with water afterwards, because more leakage reduction was necessary (Cf. figure 8). Grouting

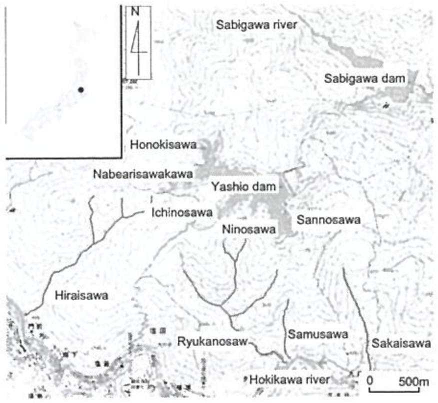

Figure 1. Map of Yashio dam and surroundings.

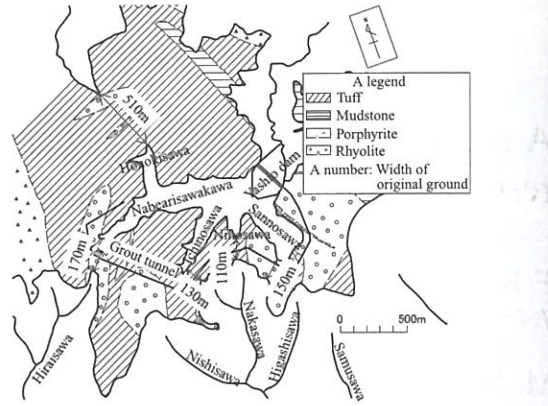

Figure 2. Planimetric map of geological features around Yashiodam.

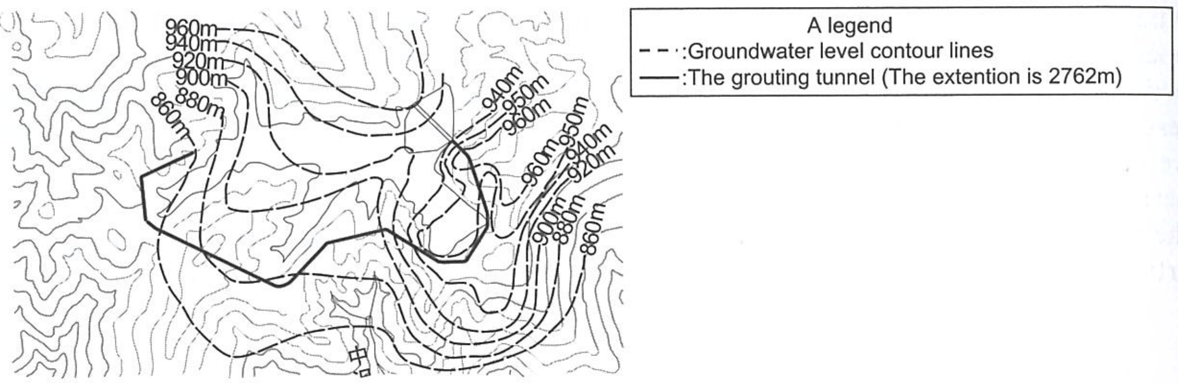

Figure 3. Groundwater level contour lines.

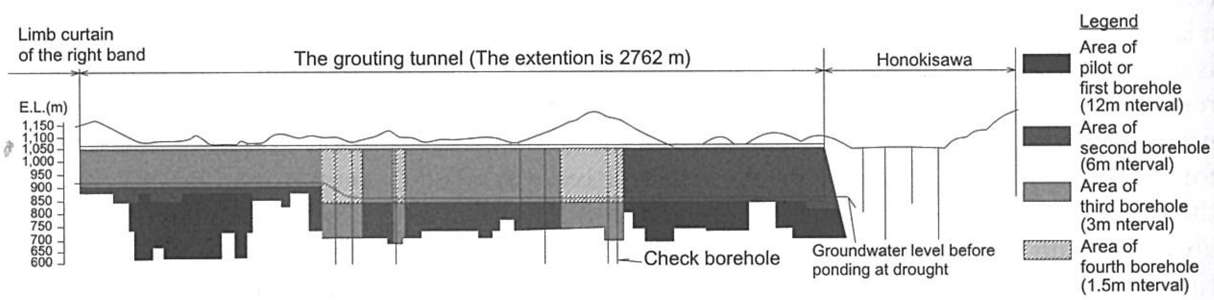

Figure 4. Development of curtain grouting for leakage stoppage.

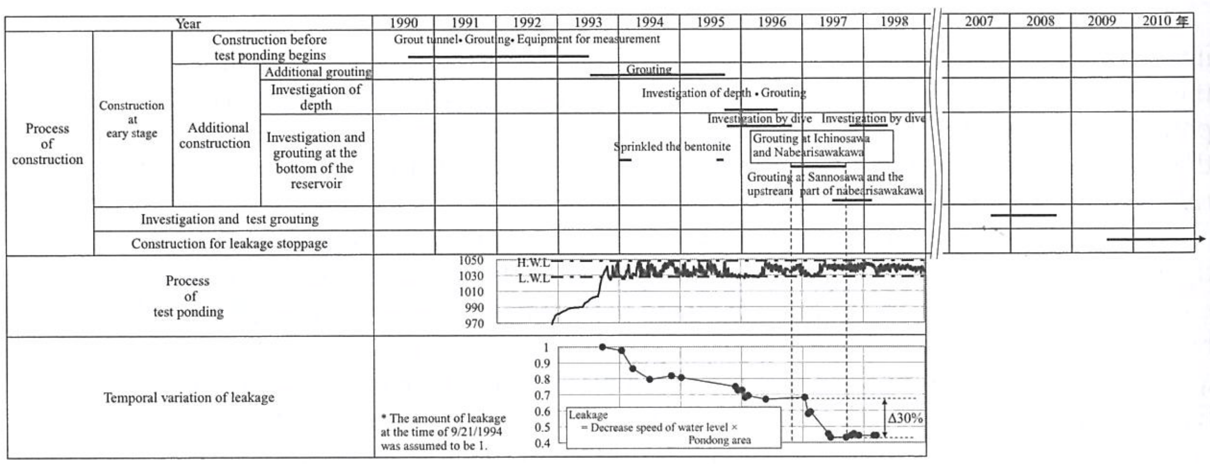

Figure 5. Construction process and the effect of leakage stoppage.

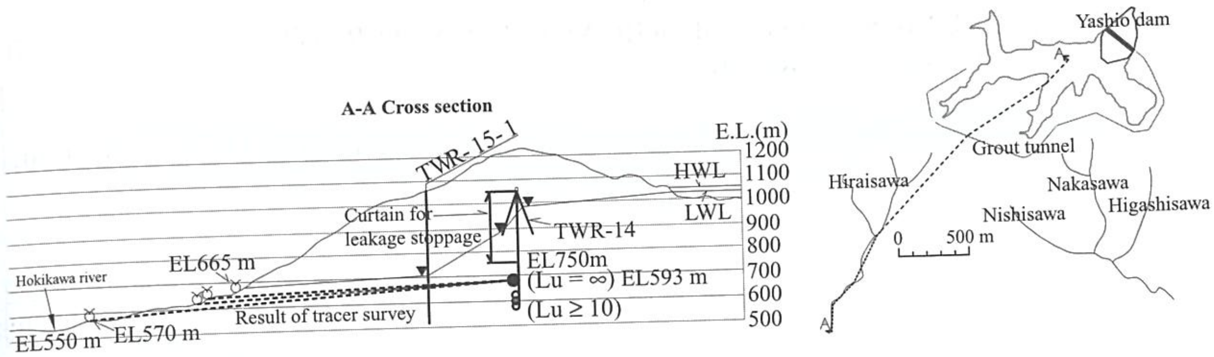

Figure 6. One example of results of the investigation of the depth at the curtain for leakage stoppage.

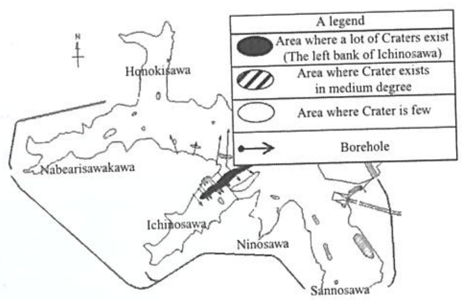

Figure 7. Results of the dive survey of the bottom of the reservoir.

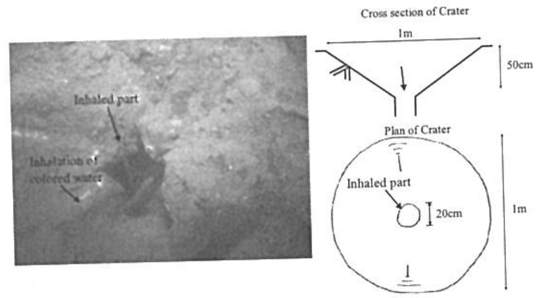

Photo 1. A crater sample.

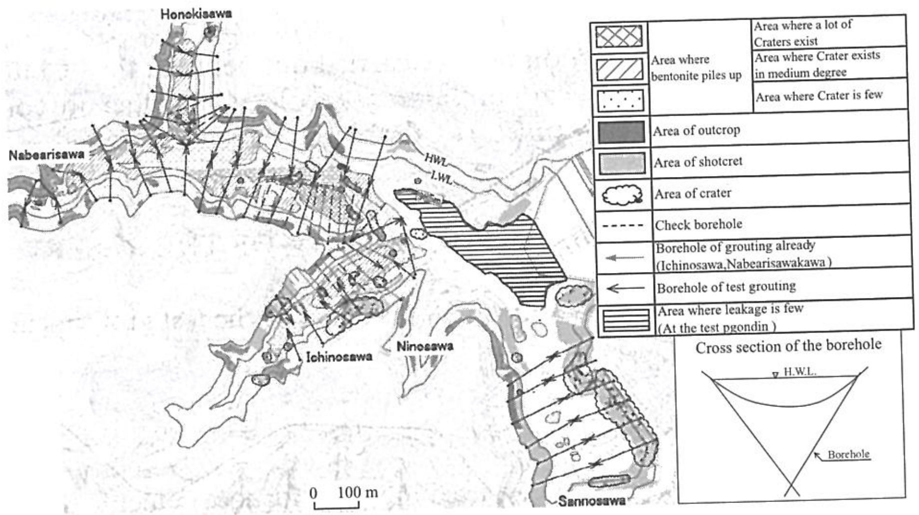

Figure 8. Layout drawing of the boreholes for test grouting.

was conducted in earnest due to remarkable reduction leakage. A characteristic of carrying out the grouting is what the seepage velocity utilizes as well as the injection pressure now to perform effective grouting.

In this article, we show the results of the test grouting, a confirmation result of the improvement degree of bedrock by checking the borehole, the changed situation of the leakage and the groundwater level. Further, we will qualitatively consider the mechanism of the grouting at the bottom of the reservoir filled with water. In addition, the Hydraulics and Geology characteristics of the foundation rock that such grouting is possible was concluded in a report in an annual symposium of No. 78 of 2010 ICOLD ("A STUDY FOR THE BEHAVIOR OF GROUNDWATER FLOW ALONG THE OPEN FISSURES WITH HIGH DIP ANGLES").

2 THE HYDRAULICS AND GEOLOGICAL CHARACTERISTICS OF THE FOUNDATION ROCK

We show below the main point of the Hydraulics and Geological characteristic of the foundation rock at the bottom of the reservoir.

(Permeability coefficient)

- A high place of permeability coefficient more than 100 Lu has been distributed over the whole area (About 2% number of the investigated stage), and the permeability coefficient and depth are not correlated with each other.

(Open fissures)

- There were open fissures (Width more than 1 mm) in the whole area. The open fissures tends to excel in these high angle open fissures that were more than it at about 60°.
- The surface of the open fissures of the boring core changed to a brown color and varies to brown from the fissures to the bedrock inside.
- As a result of restoring the boring core's both sides as much as possible, they were exactly fitting. (They were fitted without displace, or were fitted if they were displaced.) It is thought that open fissures was caused by the tensile stress because there is no streak on boring core's both side.
- Because the Yashio dam reservoir is located at the edge of the caldera, the factor that the tensile stress produced is regarded as being due to the large-scale bedrock creep from the gravity instability of the caldera wall.
- The main factor of the leakage is the network of fissures continuing on to a deep area to the subject in the open fissures of the high dip angle. It is thought that the hydrothermal alternation and a large-scale bedrock creep were the main factors, and the open fissures of the high dip angle were created.

(The characteristic of the groundwater flow)

- As a result of the tracer investigation that we carried out between the "Craters" and the test borehole, that is all for about 1 cm/s of the seepage velocity. Further, we confirmed that the seepage velocity (About 4 cm/s or less) of the plumb direction excelled.

3 THE RESULTS OF GROUTING AT THE BOTTOM OF THE RESERVOIR

We show below the specifications, the results and the effect of the test grouting at the bottom of reservoir.

3.1 *The specifications of the test grouting*

The method was the stage grouting, and we used the blast furnace cement. An initial mixing of cement paste was assumed to be C:W = 1:6–1:0.8 according to the lugeon value ahead of the grouting. The injection pressure was set according to the thickness of the original ground, 0.3–3.0 MPa. Moreover, when the rise of the injection pressure was not admitted because of the efficiency of the grouting, mixing was switched to high density promptly. And the grouting was continued for as long a time as possible (For about 10 hours or less).

3.2 *The results and the effects of the test grouting*

1. The results of the test grouting

The amount of all the cement of the grouting was about 29,000 t. There were 120 st in stages where a large amount of grouting was done that was 10 t/m or more, and the maximum value was 108 t/m. In a part of those stages (There were 42 stages), they were injected without a rise of the injection pressure in early period of injection.(However, injection pressure finally rose to a regulated value at those stages.) (Cf. table 1, figures 9, 10). The open fissures of the

Table 1. Result of the test grouting.

Place	A number of stage (st)	Lugion value before injection: Average[*1)] (Lu)	Loss probablity of 10Lu (%)	Loss probablity of 100Lu (%)	MAX (Lu)	Injection results, Quantity of unit cement injection: Average (t/m)	Loss probablity(%): 10t/m	10t/m patarn 1[*2)] (%)	50t/m	50t/m patarn 1[*2)] (%)	MAX (t/m)	Quantity of Cement injection (t)
Ichinosawa, Nabearisawakawa, Honokisawa	1,821	>15	35 (639st)	2 (30st)	∞	3	6 (106st)	2 (39st)	<1 (9st)	<1 (9st)	108	27,188
Sannosawa	521	>12	27 (139st)	2 (12st)	∞	1.4	3 (14st)	<1 (3st)	<1 (1st)	<1 (1st)	71	3,600
Total	2,342	>14	33 (778st)	2 (42st)	∞	2.6	5 (120st)	2 (42st)	<1 (10st)	<1 (10st)	108	30,788

*1) ∞ Lu is removed in average (∞:23st).
*2) patarn 1: Stage where grouting without injection pressure among.

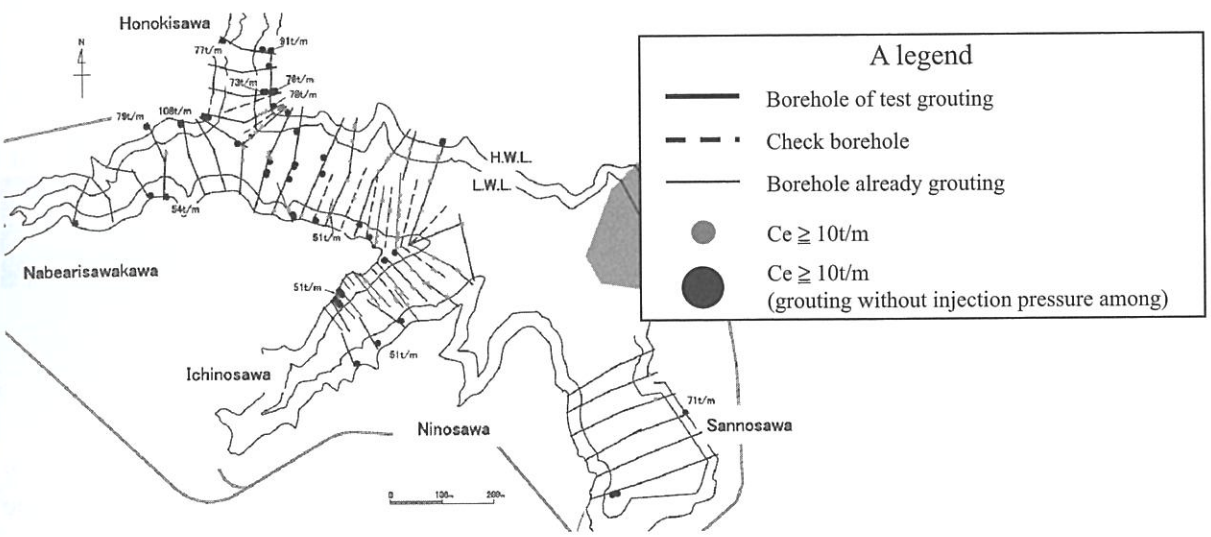

Figure 9. Distribution of the stage with a large amount of grouting.

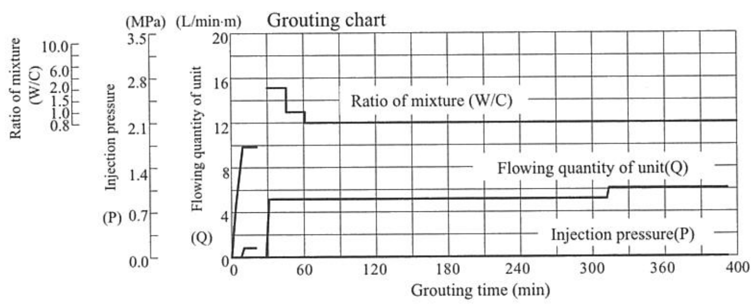

Figure 10. One example of the stage of grouting minus injection pressure.

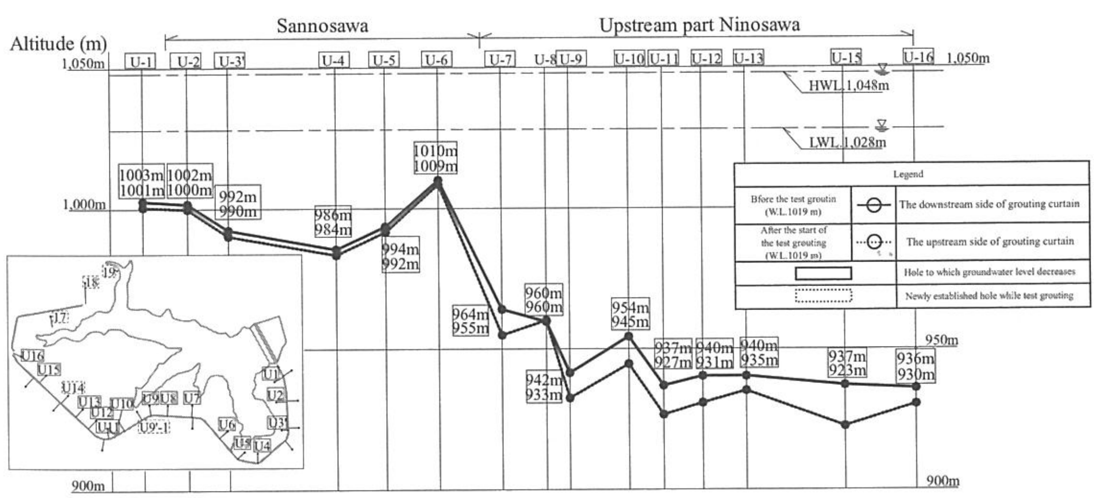

Figure 11. Groundwater level distribution along the curtain.

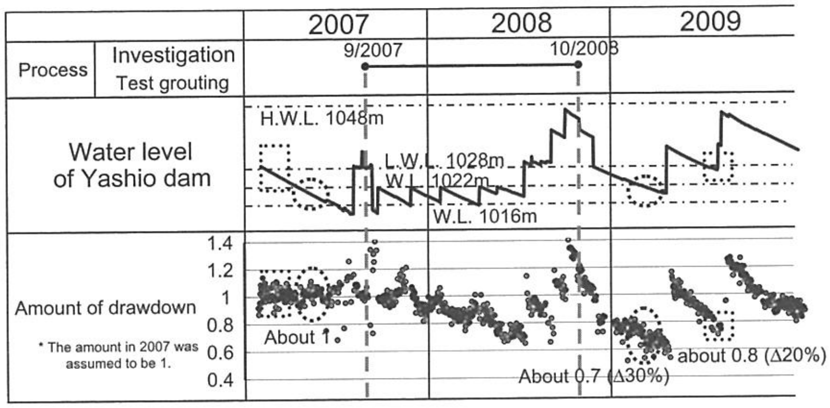

Figure 12. Changed situation of reservoir water level.

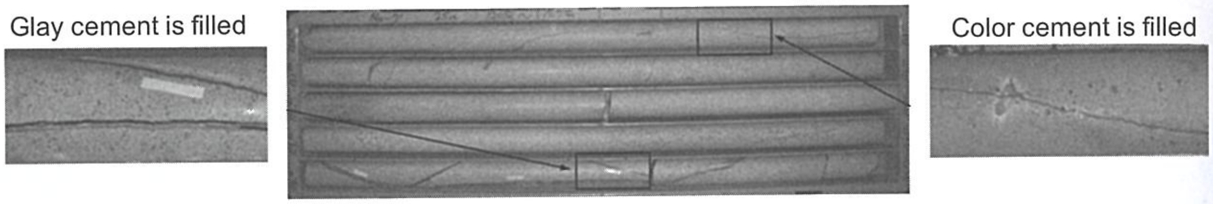

Photo 2. One example of a situation of filled cement.

high dip angle was admitted in these stages where grouting without injection pressure among them. As for such a grouting pattern, it is estimated that the grouting was previously done toward the depth direction by grouting directly into these open fissures.

2. The effectiveness of the test grouting
The groundwater level of the reservoir surround was widely decreased by the test grouting. The leakage was decreased by about 30% of the water level of the reservoir though it still has an influence. (Cf. figure 11, 12)

4 RESULTING CONFIRMATION OF IMPROVED SITUATION VIA BOREHOLE VERIFICATION

After the test grouting, we investigated the improved situation by checking the boreholes (11 totals) (Cf. figure 8). We injected the cement paste mixed the color powder into the check borehole, because it was possible to distinguish from cement injected from the other boreholes. (Cf. photo 2).

We arranged the result of the investigation under the following three conditions. The first condition is the water level of reservoir when adjacent boreholes of the check borehole was injected (The water level of reservoir is about EL.1020 m or about EL.1040 m). The second condition is the altitude or injection pressure (More than EL.1020 m: Injection pressure is 0.3~1.0 MPa, Fewer than EL.1020 m: Injection pressure is 1.0~3.0 Mpa). The third condition is the distance from the adjacent borehole. (Cf. Table 2).

If the injected stage nearby the check borehole is below the water level of the reservoir, in a check borehole where the distance from the near borehole is about 20 m or less, the open fissues are almost filled with cement covering a width of 3 mm or more (filled ratio is about 90%).

However, if the injected stage nearby the check borehole is above the water level of the reservoir, even if it is the same as the aforementioned injection pressure, open fissures of 3 mm or more in their width are not so filled with cement. (filled ratio is about 20%).

As shown above, the correlativity is high in the improvement degree of the bedrock by grouting and the water level of the reservoir after grouting. The cement reaches horizontally from the borehole within the range of about 20 m by grouting in the stage below the water level of

Table 2. Cement filling into open fissures in checking the borehole.

Water level of reservoir when the adjacent borehole grouting	Distance with check borehole and the adjacent	Cement filling results to open fissures in check borehole	Injection pressure	Number of check borehole	Cement	0<W<1	1≤W<2	2≤W<3	3≤W<5	W≥5
About W.L. 1,040m	10 ~ 15m	Stages that are shallower than E.L.1020m	0.3 ~ 1.0MPa	1	Color cement	0	0	0	0	0
					Grey cement	4	0	0	0	0
					No cement	32	35	2	1	0
		Stages that are deeper than E.L.1020m	1.0MPa	1	Color cement	5	2	0	0	1
					Grey cement	8	4	5	1	7
					No cement	55	29	2	0	0
	15 ~ 20m	Stages that are shallower than E.L.1020m	0.3 ~ 1.0MPa	3	Color cement	13	6	1	1	1
					Grey cement	11	21	15	10	37
					No cement	94	17	7	1	0
		Stages that are deeper than E.L.1020m	1.0MPa	3	Color cement	51	4	4	1	4
					Grey cement	65	38	28	22	33
					No cement	344	25	3	0	0
	20m ~	Stages that are shallower than E.L.1020m	0.3 ~ 1.0MPa	1	Color cement	2	5	1	0	1
					Grey cement	1	3	1	1	4
					No cement	39	27	9	5	2
		Stages that are deeper than E.L.1020m	1.0MPa	2	Color cement	46	15	3	7	6
					Grey cement	31	11	4	6	9
					No cement	270	40	2	0	1
About W.L. 1,020m	~ 10m	Stages that are shallower than E.L.1020m	0.3 ~ 1.0MPa	3	Color cement	2	0	0	1	0
					Grey cement	24	5	9	3	3
					No cement	101	8	0	6	0
		Stages that are deeper than E.L.1020m	1.0 ~ 3.0MPa	2	Color cement	6	1	1	1	0
					Grey cement	12	2	2	5	1
					No cement	143	11	0	0	0
	15 ~ 20m	Stages that are shallower than E.L.1020m	0.3 ~ 1.0MPa	1	Color cement	25	14	10	7	6
					Grey cement	2	0	2	0	0
					No cement	35	11	2	0	0
		Stages that are deeper than E.L.1020m	1.0 ~ 3.0MPa	1	Color cement	16	0	1	0	0
					Grey cement	31	9	6	9	9
					No cement	163	5	0	0	0
	20m ~	Stages that are shallower than E.L.1020m	0.3 ~ 1.0MPa	3	Color cement	38	10	1	5	4
					Grey cement	15	6	4	9	4
					No cement	102	38	5	0	0
		Stages that are deeper than E.L.1020m	1.0 ~ 3.0MPa	5	Color cement	269	55	26	14	20
					Grey cement	72	19	11	6	15
					No cement	1536	69	3	1	0

W : Fissures width (mm); fissure number

Cement filling rate of open fissures (t ≥ 3mm) (The distance from the adjacent hole is about 20m or less.)	Water level of reservoir when the adjacent borehole grouting: About W.L.1,040m	About W.L.1,020m
Stages that are shallower than about 1020m	47/51 = 92%	6/13 = 46%
Stages that are deeper than about 1020 m	63/69 = 91%	6/7 = 86%

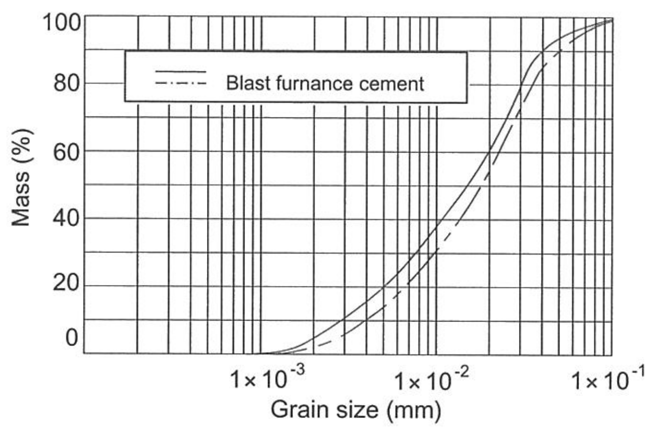

Figure 13. Grain-size distribution of cement particles.

the reservoir and according to the specification of the grouting. Further, it can be thought that grout cement is almost filled most of extreme open fissures that width is 3 mm or more.

5 THE MECANISM OF THE GROUTING AT THE BOTTOM OF RESERVOIR FILLED WITH WATER

It is believed that the grouting was effective because the reservoir was filled with water. This mechanism has been considered as follows. At first, the mechanism of the grouting that undertook the influence was first occupied only to the injection pressure, At last, the effect of the grouting where the reservoir was filled with water in addition to the influenced injection pressure was considered.

5.1 *The specifications of the test grouting*

The concept of the mechanism in which the open fissues are filled with grout cement is shown below. The relation between the distance "r" to the point and flow velocity "V" in the point is shown as follows if it is thought that cement extends in the open fissures (Parallel horizontal monotony is assumed, width:a) from the borehole like a concentric circle (Injection flowing quantity:Q).

$$V = Q/(2\pi ra) \qquad (1)$$

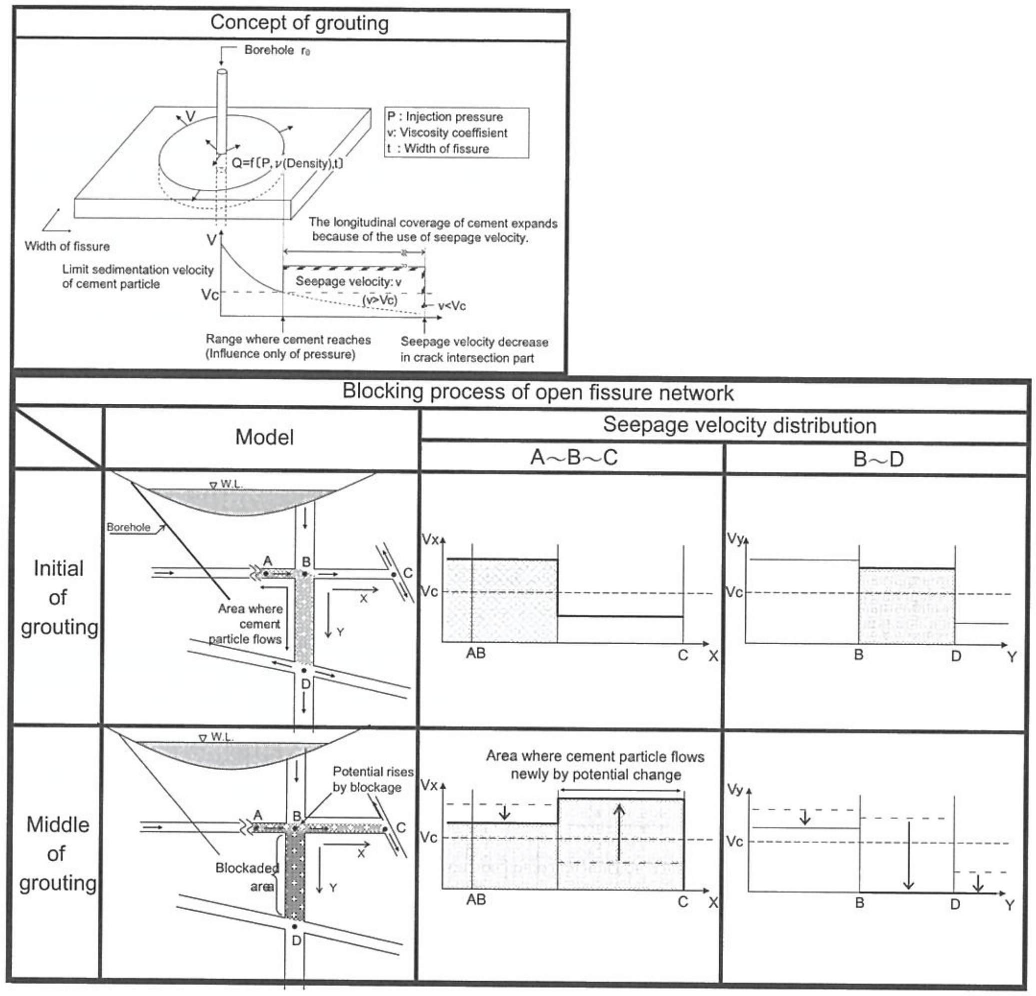

Figure 14. Concept of grouting at the bottom of the reservoir filled with water.

When r grows, V becomes small. It subsides because it came below the limit subsidence velocity of the cement particles. Further, the subsidence of the cement particles progresses toward the borehole, and the fissures were blocked at the end (Cf. figure 14).

The blast furnace cement was used for this grouting (Brain: 3000 cm^2/g or more). It became D_{10} = about 3~4 μm if the effective diameter of the cement particles are 10% diameter. Further, if the specific gravity of the cement particles is assumed to be 3.2 g/cm^3, it becomes that the limit subsidence velocity (The limit velocity of JUSTIN) of the cement particles becomes about 0.8 cm/s. That is, it is thought that the subsidence of the cement particles and the blockage of the crack progress toward "A" when the flow velocity of cement paste reaches the point where it becomes about 0.8 cm/s or less.

5.2 *The grouting at the bottom of the reservoir filled with water*

It was roughly 1 cm/s or more as a result of the investigating seepage velocity in the bottom of the reservoir. The seepage water, that velocity was more than the limit sedimentation velocity of the cement particle, wash out the tip of the cement paste. So the subsidence of the cement particle is controlled, and transported with the seepage water further far away. And it is thought that the cement particles subside due to a flow velocity decrease such as the intersection parts on the network of the open fissures, and blockage proceeds to the upstream. It is thought that the potential changes brought about by blocking the open fissures according to the shape of the network of the open fissures, the hydraulic gradient grows, the flow seepage velocity become fast, and there were fissures that were newly filled with cement too (Cf. figure 14).

6 CONCLUSION

In the Yashio dam reservoir, there is a network of fissures which assumes open fissures at a high dip angle that the hydrothermal alternation and a large-scale bedrock creep are regarded as a main generation factor of the subject in deeper areas.

① The grouting at the bottom of the reservoir filled with water is being executed now. As a result of the test grouting executed prior to this, the range of reaching cement was comparatively large (About 15–20 m horizontally) though the injection pressure was about 1.0 MPa or less when the grouting was executed below the water level of the reservoir. Further, cement paste was almost filled to fissures with a width of 3 mm or more, and a decrease of comparatively big leakage was able to be confirmed.

② The seepage velocity of the water investigated at the bottom of the reservoir was approximately 1 cm/s or more (About 4 cm/s or less). The test grouting blockaded the open fissures effectively, the seepage velocity more than the limit subsidence speed of the cement particles in addition to the injection pressure.

③ Such a grouting is effective for the network of open fissures that has a moderate seepage velocity. It is possible that the injection doesn't settle according to the forms of the path of infiltration such as extremely fast seepage flow velocities and continuous, single open fissures. Therefore, at the stage of selection of construction method, the investigation of the state of groundwater and the open fissures in the bedrock is important.

This time, utilization of the injection mechanism was qualitatively considered, we will clarify the experimental aspects of the mechanism and analyze it in the future.

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