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Foundation Treatment Work in the Oyama Dam Based on Hydrogeological Features

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ABSTRACT:
Oyama Dam is a concrete gravity dam, which is 94 meters high, 370 meters in crest length, 19.6 million cubic meters in storage capacity, located in the Chikugo River system in northern part of Kyushu. Construction of dam body works began in April 2007, and then a first impoundment has started since May 2011. Geological composition of the dam site and its neighboring area includes Pliocene of Neogene to Pleistocene volcanic rock and volcaniclastic rocks. It features the complex geological structure that is characteristic of areas covered with relatively new terrigenous rocks. Particularly foundation rock of the dam consists mainly of the Shakadake volcanic rocks formed three to four million years ago, and which are categorized into two types. One is andesites which are hard, but have many cracks, the other is autobrecciated andesite which is soft, but has few cracks. These two types of geology are distributed from left bank upstream to right bank downstream, appearing alternately in strata. The foundation rock of the dam also has a complex hydrogeological structure, therefore a foundation treatment work and its execution needed careful examination.
This paper focuses on grouting works in the Oyama Dam constructed on the volcanic rocks mentioned above, and describes general outlines of an initial design and a result of the grouting works advanced verifying its relevance.

Keywords: Foundation Treatment Work, Grouting, Andesite, Autobrecciaed Andesite, Hydrogeological Structure

1. INTRODUCTION

The Oyama Dam is a concrete gravity dam which is 94 meters high, 370 meters in crest length, 19.6 million cubic meters in storage capacity, located in the Chikugo River system in northern part of Kyushu. Purposes of the Oyama Dam construction are (1) flood control, (2) maintenance and promotion of normal functions of the river water (e.g. securing vested water and conserving the river environment) and (3) securing water for domestic. Dam body works began in April 2007, and then a first impoundment has started since May 2011. The foundation rock of the dam consists mainly of volcanic rocks formed in a relatively new geological era, and also has a complex hydrogeological structure; therefore a foundation treatment work and its execution needed careful examination. This paper focuses on the grouting work for the foundation rock in the Oyama Dam which has the complex hydrogeological structure, and describes general outline of initial design and redesign in the process.

2. TOPOGRAPHIC FEATURES AND GEOLOGY OF THE DAM SITE

2.1. Outline

The dam site is situated about 85 kilometers from the estuary of the Chikugo River. Stream bed altitude at the site is about 174 meters, and stream bed slope is about 1/30 to 1/33. Slope of both banks of the river is about 30 to 40 degrees and is steep. The geological composition of the site and its neighboring area includes Pliocene of Neogene to Pleistocene volcanic rock and volcaniclastic rocks. Table 1. shows geological composition of the dam site foundation. Fig. 1. shows geological plane figure of the dam site. Foundation rock of the dam consists mainly of the Shakadake volcanic rocks formed three to four million years ago, and which are categorized into andesites or autobrecciated andesite. These two types of geology are distributed from left bank upstream to right bank downstream, appearing alternately in strata.

2.2. Hydrogeological Features

Based on geological investigations, such as boring surveys, Lugeon tests and so on, executed before excavation works for the foundation, hydrogeological structure of the dam site were evaluated. The hydrogeological feature is shown below.

Table 1. Geological composition of the dam site foundation

Era		Stratum		Sign	Lithofacies	Remarks
TERTIARY	PLIOCENE	Shakadake volcanic rocks	Tuff breccia	Tb	It consists from tuff substrate of a lapillus and minute grain that exceeds the 10 cm of the composed volcaniclastic rock. It is often distributed between the lava units.	3.1 ~ 4.1 million years
			Autobrecciaed andesite	Au	It is a surrounding in a central continuousness part of lava, and it consists of the block lava composed of a porous quality, a soft andesite or the block and two parts of the substrate. It is possible to divide from the lithology into three.	
			Andesite	An	It is a continuousness part of lava at the center, and it consists of an andesite that firmly, and is exact that has organization of the groundmass and phenocryst.	
			Lapilli tuff	Lt	It consists of pyroclstic rock composed of the tuff substrate of a lapillus and minute grain of ϕ several cm level.	

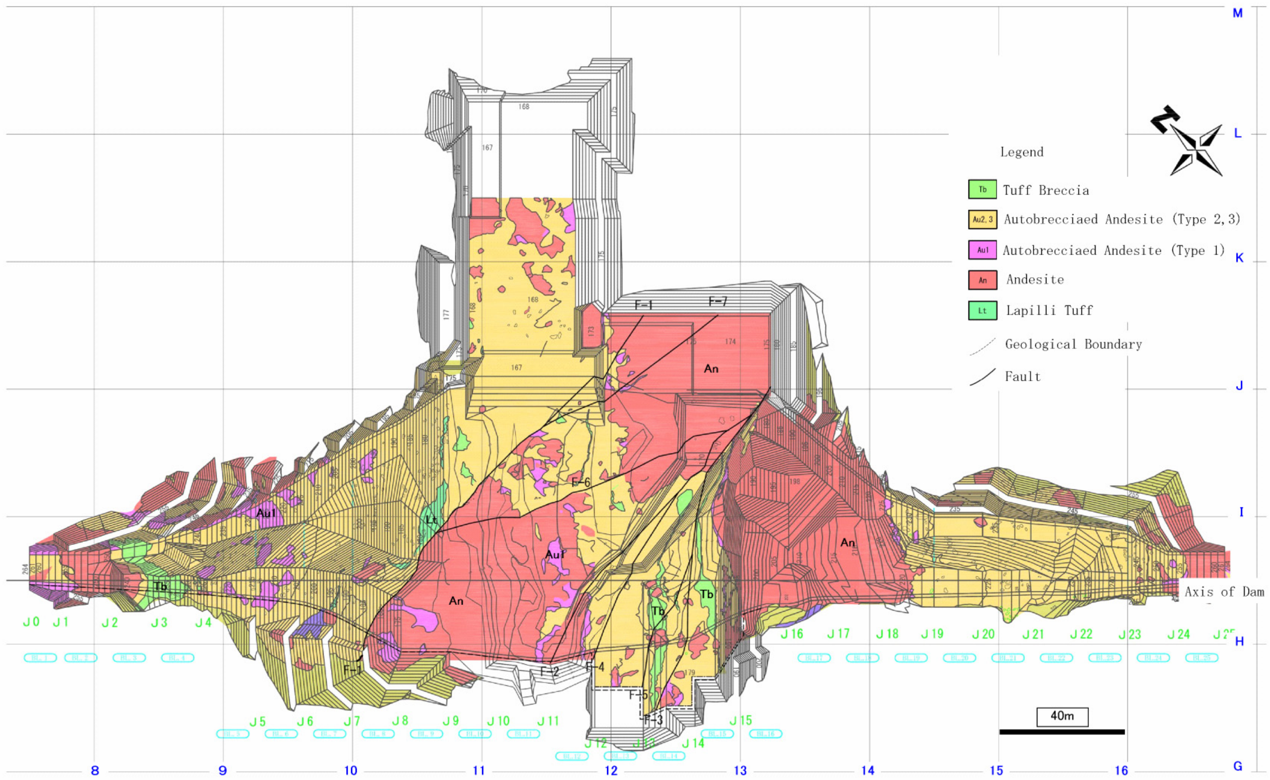

Figure 1. Geological plane figure of the dam site (after excavation)

2.2.1. Condition of rock

The foundation rock of the dam is categorized into two groups**.** One is andesites group which are hard, but have many cracks, the other is autobrecciated andesite group which is soft, but has few cracks. There were almost no continuous cracks which connect each of groups according to observation of outcrops, adits and borehole scanner image.

2.2.2. Permeability

Fig. 2. shows curtain grout hole row. Fig. 3. shows cross sections along the row (geological map, rock classification map and Lugeon map). There are some highly permeable zones near surface of the earth (shallower than the depth of 50 meters

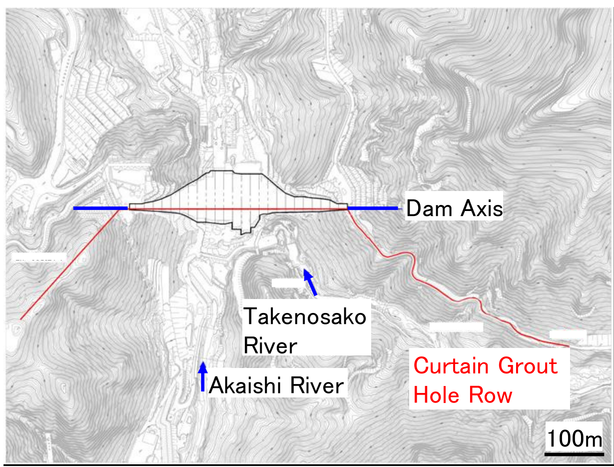

Figure 2. Curtain grout hole row

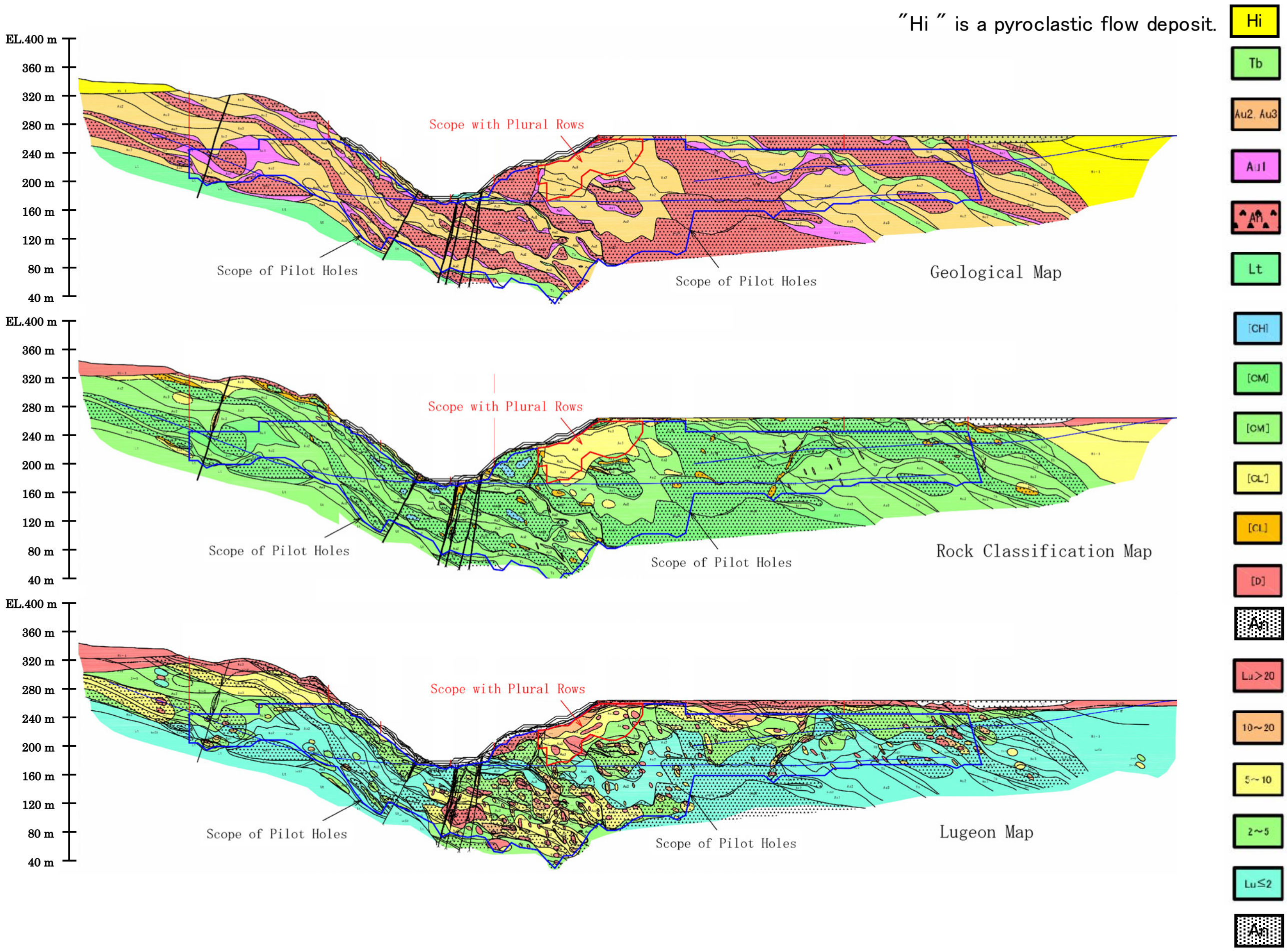

Figure 3. Cross sections along impermeable line

approximately) due to weathering or looseness. However in the range of depth deeper than 50 meters, there is a difference of highly permeable zone (20 Lugeon and over) between andesite group and autobrecciated andesite group. In other words, andesite group are dotted with some highly permeable zones, while in the autobrecciated andesite group it is hardly seen them. Paying attention to the possibility to form water paths, it was presumed as shown below.

1) Typical andesite group has many cracks; therefore there is a possibility of forming water paths in continuous andesite unit leading to a downstream earth surface from the reservoir.

2) The autobrecciated andesite group is dotted with some linear or tubular cracks, though they are independent. Especially in the range deeper than 50 meters with little influence of weathering, possibility to form water paths is low.

2.2.3. Groundwater level

In the left bank of the dam site, rise of the groundwater level proportional to altitude is seen from river bed to mountain ridge of the rim. On the contrary, in the right bank, groundwater level is almost the same as a river level, and it is constant from river bed to mountain ridge of the rim. Even in the depths of a natural ground, the rise of the groundwater level proportional to altitude is not seen. Furthermore, double groundwater level is seen along impervious line in neighboring area of a branch, Takenosako River.

3. FOUNDATION TREATMENT WORK

3.1. Basic Strategy

The foundation treatment work has two objects that the one of water interception refinement, and the other reinforcement of weak part. Current technical grouting guideline, to attempt to curtail construction cost for grouting, has revised on the premise absolutely not spoiling safety by Ministry of Land, Infrastructure, Transport and Tourism in 2003. Basically, the revised points are as follows.

1) To define the primary construction purpose and construction range

2) To execute suitable grouting for the condition of foundation rock

3) Continuously reexamination of a design specification on grouting at the beginning, according to a situation

According to the revised technical grouting guideline, initial objective and basic strategy for the foundation treatment works in the Oyama Dam were formulated based on the complex hydrogeological features described

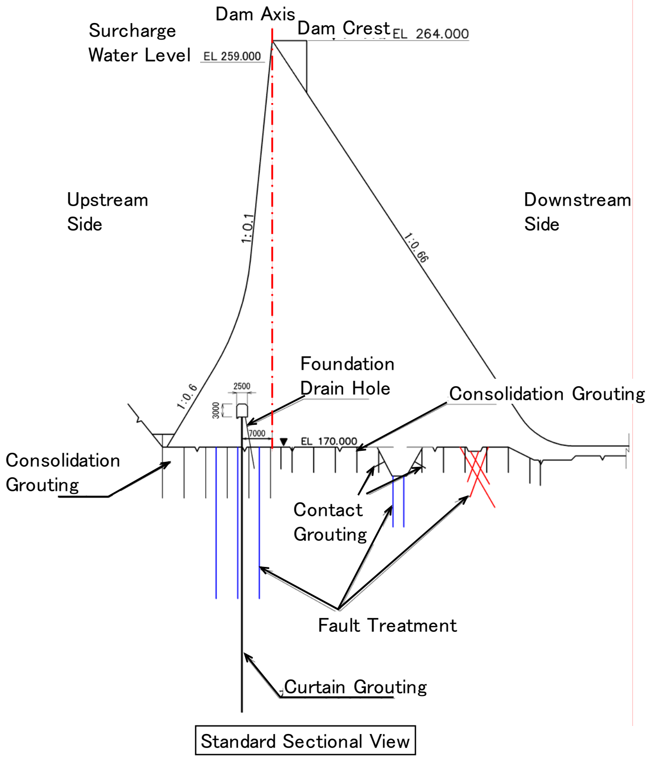

Figure 4. Foundation treatment work

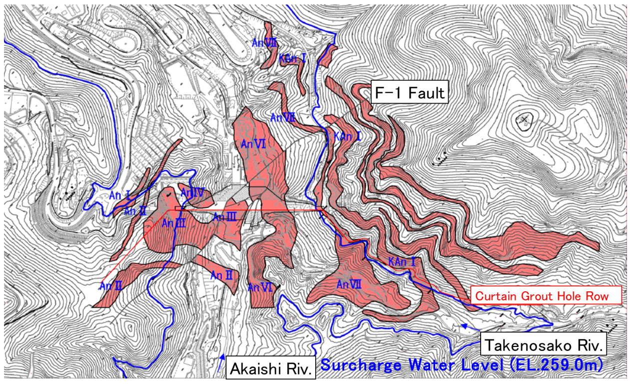

Figure 5. Location of andesite units which lead to a downstream earth surface from the reservoir

Table 2. Predetermined standard of water tightness

Grouting depth	Target Values for Improvement
0 ～H/4	2 Lugeon approximately
H/4～H/2	5 Lugeon
H/2～	10 Lugeon

H : 94 meters (high)

previously. Fig. 4. shows the standard sectional view in the direction of upstream and downstream to explain the foundation treatment work. The following paragraphs show the design specification of grouting for every kind. Actual construction is, however, advanced carrying out obtained data verification suitably, and reexamining a design specification at the beginning.

3.1.1. Curtain grouting

(1) Design for curtain grouting

i) Depth of curtain grouting

Curtain Grouting is targeted for short seepage paths and highly permeable sections that are likely to form water paths to the outside of the storage reservoir. Basically up to the depth of the height of a dam, design for curtain grouting is to an extent that the permeability of the ground reaches its target value per depth. Fig. 5. shows a location of andesite units which lead to a downstream earth surface from the reservoir. It judged that these units have a possibility of forming a water path; therefore highly permeable zones of the units which has not reached its target value are included in the grouting scope.

ii) Rim section

Lateral extent of the curtain grouting in left bank is designed up to an intersection of the normal water level and groundwater level. In right bank, it is designed up to the scope containing the andesite units to improve.

(2) Predetermined standard of water tightness

The depths of curtain grouting have a longer infiltration path and a smaller hydraulic gradient; this allows the improvement necessity to ease and to use the following values, Table 2., as target improvement goals.

Furthermore in the direction of rim lateral depth, it is considered as the above explanation similarly.

(3) Grouting positions and timing for grouting

i) Dam foundation

It is preferable to place grouting after the dam body, which acts as overburden. The schedule of curtain grouting in the construction process is carried out after concrete placing not less than 15 meters in height, and the curtain grouting is executed from a gallery as a principle. However, construction has been actually performed from surface of the earth to restricts some parts that deeper than 25 meters in abutment of both banks and shallow plural rows of right bank.

ii) Rim section in left bank

The groundwater level rises in proportion to altitude in the mountain ridge of the left bank. Therefore, the curtain grout hole row is set up to direction of the mountain ridge from the dam axis. The execution is conducted from the rim tunnel.

iii) Rim section in right bank

The groundwater level is not so high as is presumed from geographical feature. If an execution of grout is conducted from a rim tunnel, it is possible to decrease the quantity of curtain grouting. For this reason, construction was considered as a plan to carry out from surface of the earth along the Takenosako River.

(4) Arrangement of holes

The pilot holes which serve as the investigation purpose made a 12 meters interval the standard. The plan for the standard arrangement of holes was made as shown in the Table 3..

(5) Injection plan

Injection materials, mix proportion, injection pressure, mix proportion switching standard and specified value of total grouting amount are defined the example of former dams as reference.

Table 3. Arrangement of curtain grouting holes

Predetermined standard of water tightness	The standard arrangement of holes
2 Lugeon approximately	Tertiary holes (1.5 meters interval)
5 Lugeon	Secondary holes (3 meters interval)
10 Lugeon	Secondary holes (3 meters interval)

Table 4. Constructed results of grouting

	Total length of scope	Total cement injection	Total injection duration
Curtain Grouting	52,566 meters	4,474.48 tons	30,607 hours
Consolidation Grouting	16,010 meters	712.67 tons	9,354 hours

3.1.2. Consolidation grouting

(1) Scope for consolidation grouting

i) Consolidation grouting for improvement of impermeability is implemented for sections with a short seepage paths and large hydraulic gradient within the scope from the upstream end of the dam body site to the foundation drain holes.

ii) Consolidation grouting for reinforcement of weak places targets andesite in class CL, autobrecciated andesite in class CL' in abutment and fractured zone around the faults.

(2) Predetermined standard of water tightness

Basically it uses the following values as target improvement goals.

For improvement of impermeability; 5 Lu

For reinforcement of weak places; 10 Lu

(3) Grouting positions and timing for grouting

The schedule of consolidation grouting in the construction process is carried out after concrete placing not less than 3 meters in height, and the consolidation grouting is constructed from a top of cover concrete as a principle.

(4) Arrangement of holes and depths

For improvement of impermeability; It was determined that the standard hole was to the secondary holes (5 meters grid), and the holes depth shall be approximately 10 meters as standard.

For reinforcement of weak places; It was determined that the standard hole was to the secondary holes (7.1 meters grid), and the holes depth shall be approximately 10 meters as standard.

(5) Injection plan

Injection plan of consolidation grouting defined the example of former dams as reference like curtain grouting.

3.2. Result of Grouting

Grouting work began in June 2008. Its execution was carried out verifying validity and was completed in April 2011. Fig. 6. and Fig. 7. show range of curtain grouting and consolidation grouting. Table 4. shows the constructed results of grouting.

3.3. Problems and countermeasures on geographical feature and geology

As regards some problems on the geographical feature an and geology described below, it takes countermeasures against them appropriately with investigations in the process.

3.3.1. Faults in riverbed

After the foundation excavation work at the dam site, 7 faults (F-1 to F-7) were identified in the riverbed. F-2 fault was the largest one among the faults which were discovered, and there were D class rock mass widely along the fault on the foundation excavated. Additionally bouring surveys were carried out to the F-2 fault. Furthermore, to reduce the D class rock mass, it excavated the D class rock mass deeply and replacing it with concrete. Also it ensured the factor of safety to make original fillets large in the design of dam body. On the other hand, in upstream side of the F-2 fault, it carried out consolidation grouting for improvement of impermeability from the surface of excavated foundation to the depth of 35 meters due to highly permeable zones with the D class rock mass widely.

3.3.2. Autobrecciated andesite with a difficult improvement

The curtain grouting was executed in the abutment of right bank first, then it became apparent that it is difficult to improve CL class rock mass in shallow part of them with almost 2 Lugeon, which is the predetermined standard of water tightness for curtain grouting. Test grouting was planned on trial based on the situation, and the grouting feature at the shallow part of the right bank was examined. As a result of this, (1) the original curtain grouting row modified into plural from single at a part of abutment in the right bank, in other words the impermeable zone is made thicker and (2) the predetermined standard of water tightness eased 5 Lugeon.

3.3.3. Topographic features like a steep escarpment at just upstream part of dam site near the abutment in right bank

There is at just upstream part of dam site near the abutment in right bank, a steep escarpment, approximately 20 meters high and some part has overhung. It was formed due to Takenosako River, which meander sharply and make an undercut slope. Its geology mainly consists of CM class of andesite, however it is a rock mass which has cracks with high water permeability. It was not seen looseness in the rock mass clearly by additional geological investigations. However,

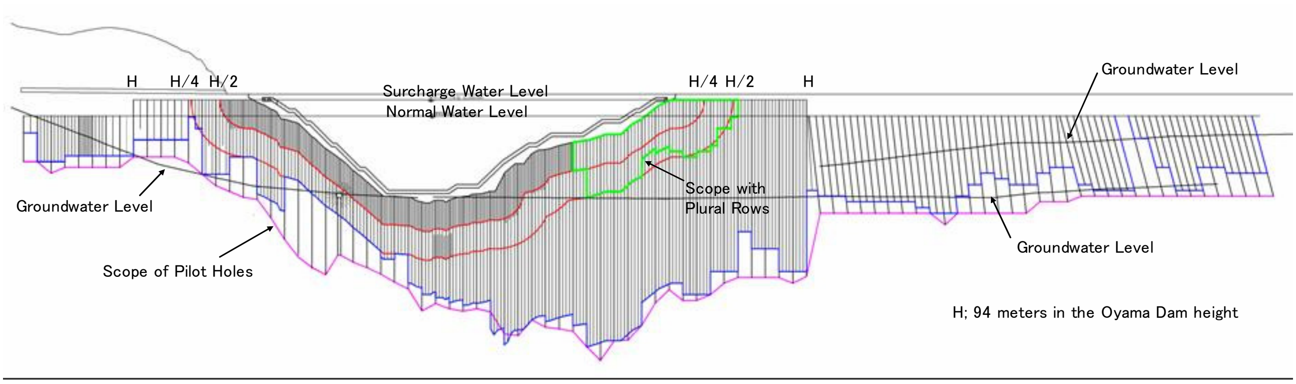

Figure 6. Range of curtain grouting

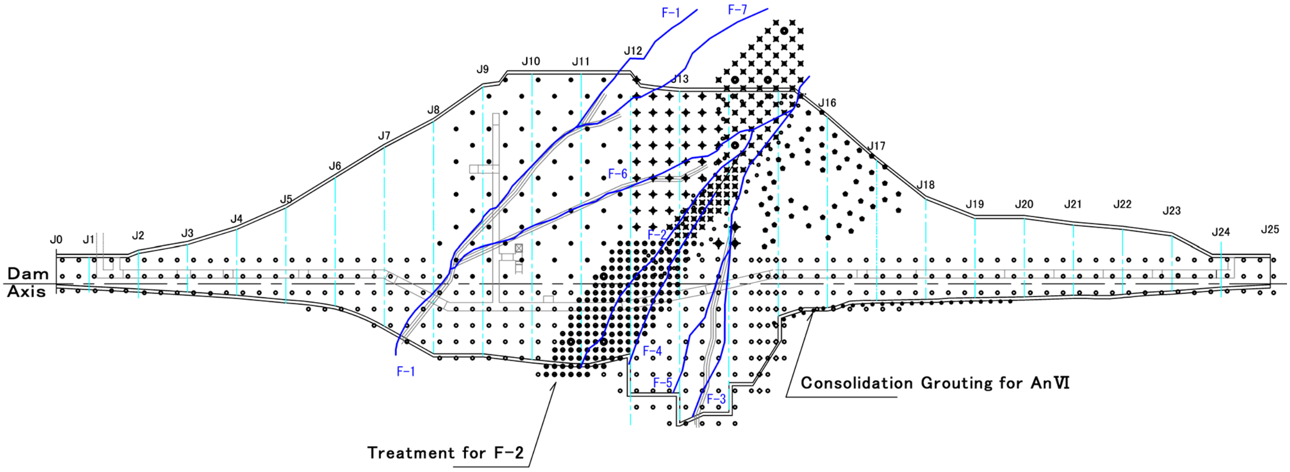

Figure 7. Locations of standard holes for consolidation grouting

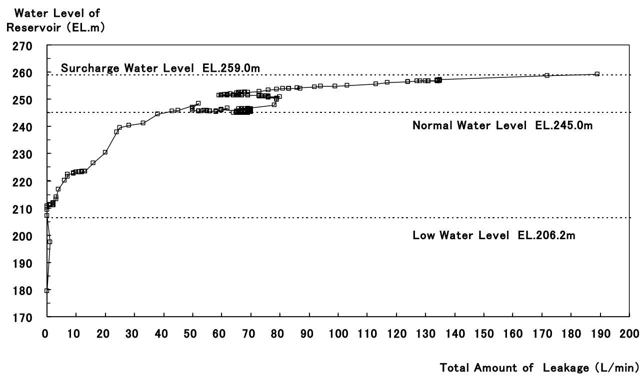

Figure 8. Relationship between water level of reservoir and amount of leakage

consolidation grouting for improvement of impermeability which is targeted for a relevant layer of andesite (AnⅥ) was newly added and was implemented, considering that seepage paths to the foundation drain holes is short and hydraulic gradient is large.

3.3.4. Others

As others, the main change matters which should be mentioned especially are shown below.

(1) Revision of predetermined injection pressure of grout

When curtain grouting was executed in the rim of left bank and the depths of right bank abutment, a high frequency of critical pressure and a tendency for cement injection to increase were seen. Therefore, the highest injection pressure of standard was improved from 2.5 to 1.5 MPa.

(2) Adoption of ultra fine particle cement

In the plural curtain grouting area at the abutment of right bank, enormous numbers of additional holes was occurred. Additionally in this area, there were little cement injection and its effect, therefore injection material was changed with ultra fine particle cement.

4. CONCLUSION

First impoundment of the Oyama dam has started since May 10th 2011. Fig. 8. shows a progress of amount of leakage as of March 2012. The dam is safe enough to storage water so far and it has not been a serious situation where an addition grouting is needed. First of all, the test ponding is made to complete safely, and it endeavors to provide a utility of the dam as soon as possible.