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INNOVATIVE TECHNOLOGIES FOR DAMS AND RESERVOIRS TOWARD THE FUTURE GENERATIONS

Construction of Apporo Trapezoidal CSG Dam

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ABSTRACT:
The Apporo Dam is the second trapezoidal CSG dam in Hokkaido, following the Tobetsu Dam. At the Apporo Dam, the shale is used as the CSG material, which is the dam body material, and the dam is constructed on the foundation of the shale and shale-sandstone alternative layer. Shale has the characteristic which causes the slaking phenomenon when it is dried, so various technical studies were conducted to prepare for its use. For the concrete gravity dam, shale or mudstone cannot be used as the aggregates, so the aggregate for the Apporo Dam with original concrete gravity type was planned to purchase from quarry place.
Furthermore, the foundation surface of the dam is extremely uneven and bumpy, so the investigation was carried out to select the execution machinery. According to the extent and depth of undulation, the proper spreading and compaction machinery are used in the Apporo Dam. As existing Tobetsu Dam and Kim Dam with trapezoidal CSG type had an even foundation surface, large-size construction machine was chosen. So, this kind of investigation has an important role for the construction of the new Trapezoidal CSG dams.

Keywords: Apporo Dam, trapezoidal CSG dam, shale, slaking.

1. INTRODUCTION

Figure 1. Drawing of completed Apporo Dam

The Apporo Dam is a multi-purpose dam under construction in Hokkaido as a trapezoidal CSG (Cemented Sand and Gravel) dam as shown in Table 1 and Fig. 1. Apporo Dam was initially planned as a concrete gravity dam, but when surveys and studies to adopt the new technology, the trapezoidal CSG dam, were undertaken, this new method was adopted in light of its economic and environmental superiority.

Placing the dam body material started on April 30, 2015, and about 50% of the dam volume has been completed on November 15, 2015.

Apporo Dam is not only constructed using shale, which shows slaking properties, as the CSG material for the dam body, but also constructed on foundation rock of shale. This paper reports on the investigation results concerning foundation rock and dam body material, which are prone to slaking. The standard cross section of the dam is illustrated in Fig. 2.

2. MAIN FEATURES OF A TRAPEZOIDAL CSG DAM

The type of trapezoidal CSG dam is developed in Japan to contribute to improving economic efficiency and reducing the environment impact (JDEC, 2012).

The trapezoidal CSG dam is shaped like a trapezoid, lowering stress produced inside the dam body. Highly durable concrete is placed on the surfaces of the dam body. The required performance of CSG is that its strength should be greater than produced stress inside the dam body with an appropriate design allowance.

Thus, CSG material has a wide range of applicable qualities, enabling the use of low quality material. On the other hand, the method of quality control to ensure the required strength is very important.
Furthermore, at a trapezoidal CSG dam, the adhesion of the foundation rock with the dam body plays an in important role in ensuring the sliding stability, requiring careful treatment of the rock contact surface and attentive CSG execution.

Table 1. Main feature of Apporo Dam

Type	Trapezoidal CSG
Height	47.2 m
Crest length	516 m
Volume	481,100 m^3
Catchment area	105.3 km^2
Ponding area	3.03 km^2
Total reservoir capacity	47,400,000 m^3
Effective reservoir capacity	43,100,000 m^3

3. THE FOUNDATION ROCK AND DAM BODY MATERIAL AT APPORO DAM

The foundation rock at Apporo Dam, is Neogene – Miocene sedimentary rock, with alternating layers of shale and sandstone but mainly shale. This rock is prone to the slaking phenomenon caused by repeated wetting and drying action (Figs. 1 and 2).

Table 2. Basic physical properties of CSG material

Physical properties	value
Surface dry density	2.2 – 2.3 g/cm3
Water absorption coeff.	10 -15 %

The dam body material is easily obtained near the dam site and sedimentary soft rock similar to the foundation rock distributed inside the reservoir (Figs. 3 and 4).

The properties of this material are shown in Table 2 and this kind of low quality material could not be used asaggregate for concrete.

4. TECHNICAL SOLUTIONS AT THE APPORO DAM

The following are the technical solutions faced regarding the foundation rock and CSG material of the Apporo Dam.

4.1 Technical solutions related to the foundation rock

In the foundation rock of the Apporo Dam, the rock contact surface after excavation was uneven (level differences from 30 to 80cm) as a result of cracks along bedding planes and cracks caused by weathering near the surface (Fig. 5).

It was, therefore, necessary to improve the reduced workability of the CSG caused by the unevenness on the rock contact surface. Additionally, the countermeasure against the slaking was also required.

The foundation rock of Apporo Dam could not be dried to prevent the slaking, so investigations were required to adopt shotcrete and to establish a rational execution method which can enable the certain contact between rock and dam body. These investigations were intended to ensure the required performance (slide resistance) of the rock contact part.

4.2 Technical solutions regarding the dam body material

CSG has features which allow change of the grain size distribution of the material. On the other hand, in order to ensure the stipulated CSG strength, it is important to clarify the variation of the grain size distribution of the CSG material.

The refining of the gradation of the CSG material by slaking impacts the variation of its gradation distribution. Therefore, quality control must consider the scale and configuration of the stockpile of CSG material, the stocking period, and other aspects of the execution process.

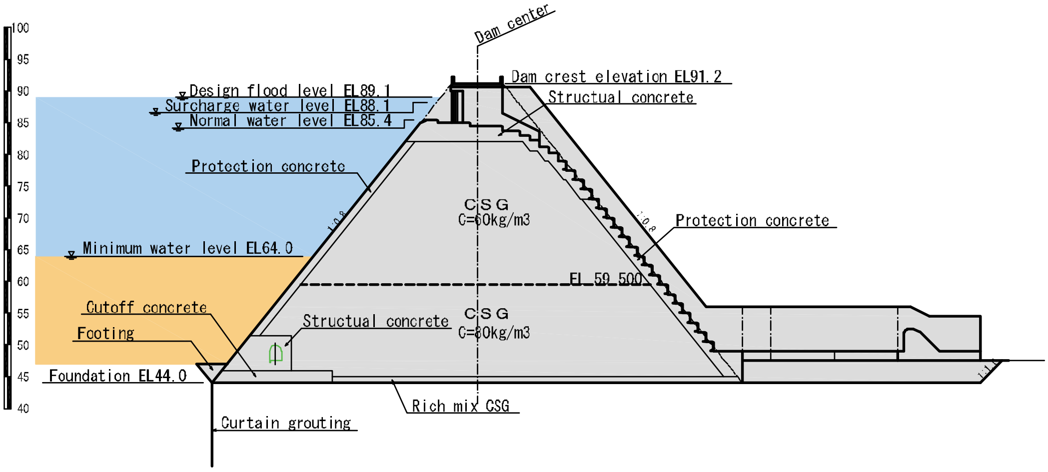

Figure 2. Standard cross section of Apporo Dam

Figure 3. Foundation rock (fresh)

Figure 4. Slaking property of foundation rock after 23-day exposure

Figure 5. CSG raw materials (fresh)

Figure 6. Slaking of CSG raw materials after 28-day exposure

The slaking increases the finer gradation fraction (0.075mm or smaller) of the CSG material, and this finer gradation material is caused to adhere to relatively large grain size material by rain water (Figs. 8 and 9). This prevents the uniformity of the mixed material with cement, causing anxiety about ensuring the required strength and scattering of its quality.

Figure 7. Unevenness of foundation rock

Figure 8. CSG materials just after crushing

Figure 9. Aggregated CSG materials

5. TECHINCAL SOLUTIONS

There were several technical solutions on the slaking rock for the foundation and the dam body materials.

5.1 Confirming slaking of the foundation rock

In-situ testing under the following conditions was executed in order to clarify the progress rate of slaking of the foundation rock and to investigate a curing method between finishing excavation of the foundation rock and placing work of CSG (See Table 3).

When the foundation rock of Apporo Dam was left standing in natural condition, honeycomb cracking occurred in about 1 hour (Fig. 10). On the other hand, if it was maintained in wet condition, the slaking of the foundation rock did not occur.

Table 3. Investigation cases

Foundation rock (4 types)	Shale (Hard and weak), Alternation of Shale and Sand stone (Hard and weak)
Test conditions (3 cases)	Natural state, Wet state (water sprayed), Wet state (curing mat)

Figure 10. State of foundation rock (after 1-hour exposure)

5.2 Confirming the rock contact part execution method

To execute the rock contact part, the application of shotcrete in order to deal with the unevenness of the rock surface and the slaking by filling the concave parts with CSG reliably and improving the workability (convenience and execution speed while ensuring quality) was studied.

The existing trapezoidal CSG dams were executed by carefully performing manual work and using compact machines in order to fill concave parts with CSG reliably as shown in Fig. 11.

Though treating the unevenness of the rock surface by the same execution procedure would be extremely inefficient at Apporo Dam. Because of anxiety about the filling of concave parts with CSG, the improvement of efficiency by placing the CSG using a bulldozer and a large compactor were investigated with the spread mortar on the rock contact surface as a supplementary measure as shown in Figs. 12 and 13 (Study Committee, 2014).

Regarding the execution properties, the cement ratio of the mortar was varied to confirm the adhesion properties and mortar thickness on the foundation rock. The basic mortar mix was set considering specifications of the construction machinery, and the required performance of the rock contact part as the foundation of Trapezoidal CSG dam.

Furthermore, the test surface of rock contact part was excavated and visually observed, clarifying that the CSG reliably filled the concave parts of the rock contact part as shown in Fig.14.
The above also confirmed the suitability of shotcrete execution as shown in Fig.16.

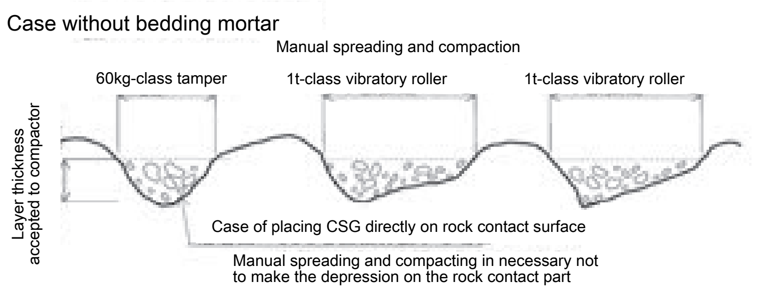

Figure 11. Conventional execution method of rock contact part

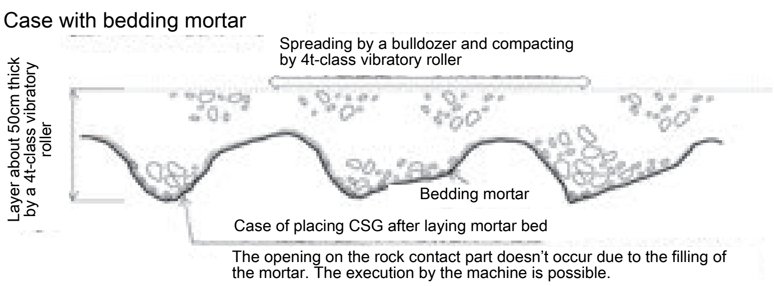

Figure 12. Improved execution method of rock contact part

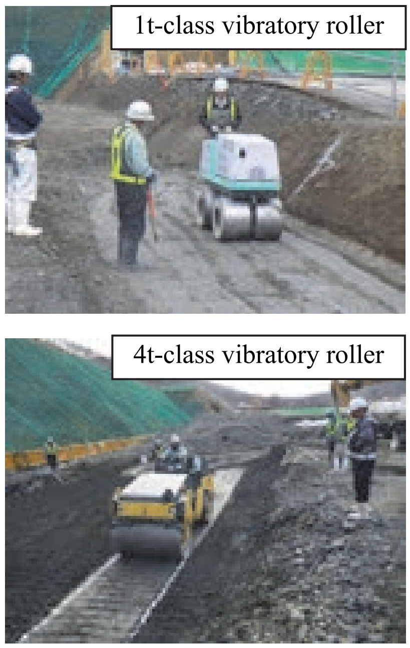

Figure 13. Execution of rock contact part

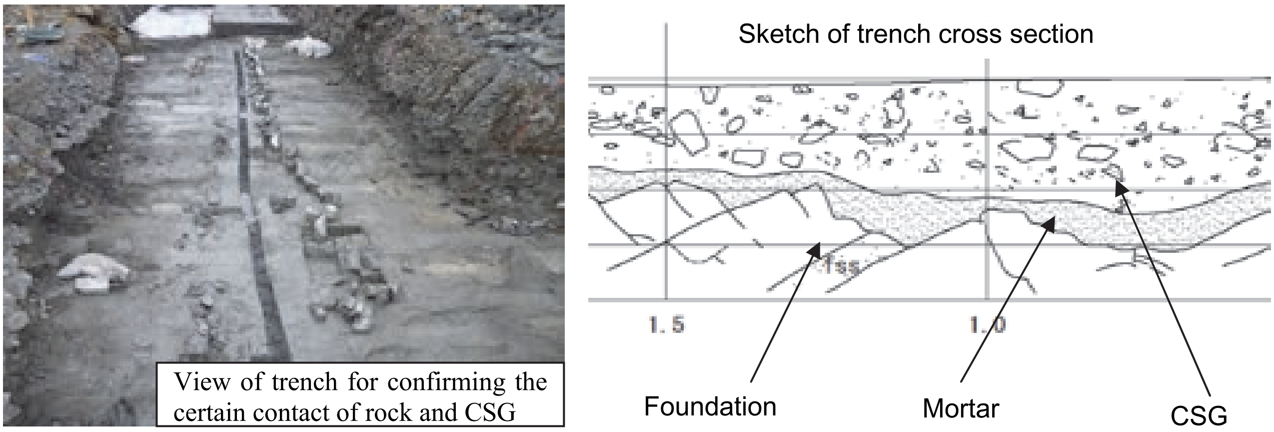

Figure 14. Filling of CSG to concave parts of foundation rock

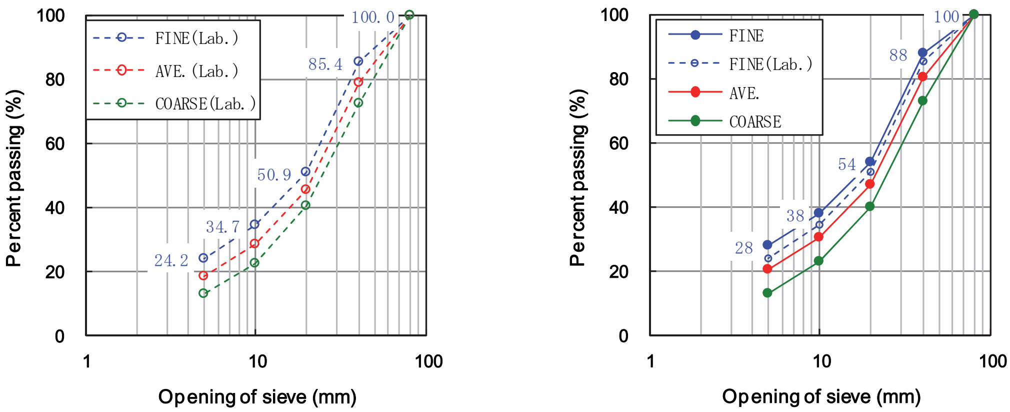

Figure 15. Quality control of grain size distribution range

Figure 16. Shotcrete with mortar

5.3 Impacts of slaking on dam body materials

To clarify affected depth of slaking during stocking of CSG material, a stockpile was built and used for an exposure test. The test results clarified that the refining of the CSG material by slaking occurs for about 100mm deep from the pile surface which is exposed to the effects of the outside air, but does not occur any deeper than that.

The percentage of CSG material in which occurs slaking will be only about 1% of all the stock volume. The results also show that the influence on change of the grain size distribution will be extremely small. But, in order to perform certain quality control, the range of the grain size distribution of the CSG material was widened to include finer grain particles as shown in Fig. 15.

It also confirmed the influence of the increase of the finer gradation fraction by slaking on scattering of the required CSG strength and CSG quality. Newly prepared material and material aggregated by adherence of finer gradation fraction on the surface of material were used to perform strength tests of CSG with the standard specimens. The grain size distributions of both materials tested were adjusted to have the same gradation.

As shown in Fig. 17, it has been clarified that equal strength has been obtained, and non-uniformity caused by aggregation during mixing will have no influence, and that the normal production method can be applied.

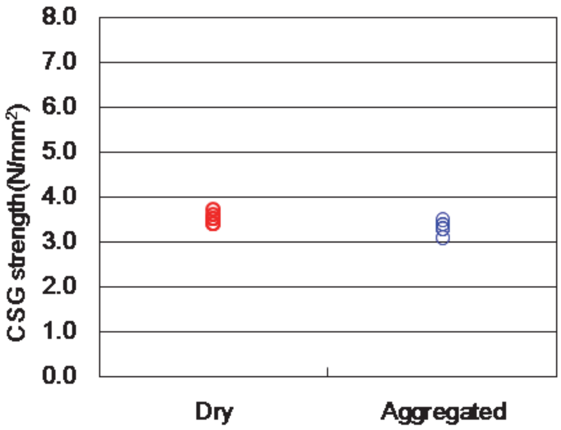

Figure 17. Comparison of CSG strengths with laboratory specimens

6. SUMMARY

Slaking of the foundation rock at the Apporo Dam can clearly be resolved by wet curing and spraying mortar.
In addition, the decline of workability on uneven parts was avoided by spraying mortar and using large construction machines.

And for the actual execution, based on the results of the above studies, an execution method and various machines suited for the degree of unevenness (level differences) have been adopted.

It was confirmed that the slaking of the dam body material will have extremely small influence both on the grain size distribution by refinement of the CSG material and on the aggregation by an increase of the finer gradation fraction. The results of these studies have been reflected in the CSG quality control methods.

7. CONCLUSIONS

The Apporo Dam was initially planned as a concrete gravity dam, but in 2003, surveys and studies to adopt the trapezoid CSG dam were started, and in light of its economic and environmental superiority, a decision was made to construct it as the second trapezoidal CSG dam in Hokkaido, following the Tobetsu Dam.

The type of trapezoidal CSG dam was developed to rationalize “design”, “execution”, and “materials” simultaneously, and technical development of this type of dam is continuing in an effort to achieve further rationalization.

The results from the Apporo Dam reported in this paper are results of efforts to overcome unprecedented problems, but the rationalized rock contact part execution method can be applied to other dams with similar unevenness of foundation rock. Consequently, using material susceptible to slaking as CSG material must have broadened the diversity of CSG materials.

The construction work of dam body started in October 2014, CSG placing started on April 30, 2015. 247,000m^3 of the total volume of 481,100m^3 including the CSG and ordinary concrete has been placed as of November 10, 2015.

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