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SLAKING COUNTERMEASURES RELATED TO ROCK CONTACT EXECUTION AT THE SOFT ROCKS FOUNDATION(*)

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1. INTRODUCTION

Apporo dam was originally planned as a concrete gravity dam, but survey and investigation aiming at trapezoidal CSG (Cemented Sand and Gravel) dam started in 2003, and ultimately the type of trapezoidal CSG dam was selected from the view points of the economic and environmental advantages as the second following Tobetsu dam in Hokkaido prefecture. Apporo dam used soft rock as the CSG material for dam body, and its dam foundation is also soft rock. Properties of the soft rock in area of Apporo dam showed slaking caused by cyclic wetting and drying. Additionally, it is known that its foundation is dominated by cracks which extend at an angle of about 20° on the upstream side of left abutment parallel to the bedding plane, and that unevenness along the cracks tends to be formed on its excavated surface.

(*) *Contre-mesures de relâchement liées à l'exécution de contact rocheux sur la fondation de roches tendres*

2. OUTLINE OF APPORO DAM

Apporo dam is a multi-purpose dam now under construction at the Azuma river in Horonai frontage of Atsuma town, Yufutsu district of Hokkaido prefecture as part of comprehensive development of the Azuma river. The dam is, as shown in Table 1, 47.2 m in height, 47,400,000 m^3 in total reservoir capacity, and 43,100,000 m^3 in effective reservoir capacity. The purpose of dam is to regulate flooding, maintain the normal functions of the river flow, and to supply water to irrigation systems and to urban area. As shown in Fig. 1, the construction of main dam body has been completed and initial impoundment started in October 2017.

Table 1
Main feature of Apporo dam

Dam type	Trapezoidal CSG
Dam height	47.2 m
Crest length	516 m
Body volume	481,000 m^3
Catchment area	105.3 km^2
Reservoir area	3.03 km^2
Total storage capacity	47,400,000 m^3
Effective storage capacity	43,100,000 m^3

Fig. 1
Apporo dam under construction
Barrage d'Apporo en construction

3. TOPOGRAPHY AND GEOLOGY AT THE DAM SITE

3.1. OUTLINE OF THE TOPOGRAPHY

The dam site is surrounded by medium to low relief-mountains with elevations less than 300 m. The alluvial lowland about 60m wide has formed along the Azuma river which meanders across this lowland. Both left and right abutments at the dam site are formed by the slope of gentle mountainside with gradient of about 25º, and three terrace plains.

3.2. OUTLINE OF THE GEOLOGY

At the dam site, Karumai formations consisting of Neogene-Miocene sedimentary rock are distributed. The dam foundation is mainly shale strata (*sh strata*) and alternation strata of shale and sandstone (*shal strata*), enclosing thinner stratum of conglomerate (*cg strata*) or tuff (*tf strata*) (see Figs. 2 and 3). These layers of foundation bedrock are covered with fallen volcanic ash and pumice stone in the Quaternary distributed to a depth of about 10 m. The strata of the foundation bedrock are inclined at an angle of about 20º on the upstream side of left abutment, but no large-scale fault fracture zones are distributed. The shale strata (*sh strata*) and the alternation strata of shale and sandstone (*shal strata*) of the dam foundation form massive bedrock with few cracks and with unconfined compressive strength from about 20 to 50 N/mm^2 in the fresh parts. Additionally, its concreteness of bedrock permits to occur cracks of its own when struck hard by a hammer, but in the shallow bedrock, cracks to form along the bedding plane has been confirmed [1].

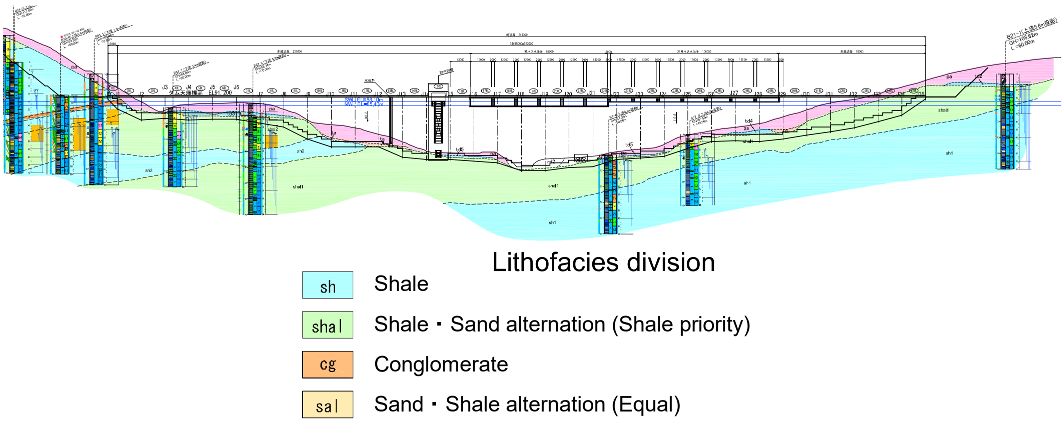


Fig. 2
Geological longitudinal section of dam site
Coupe longitudinale géologique du site du barrage

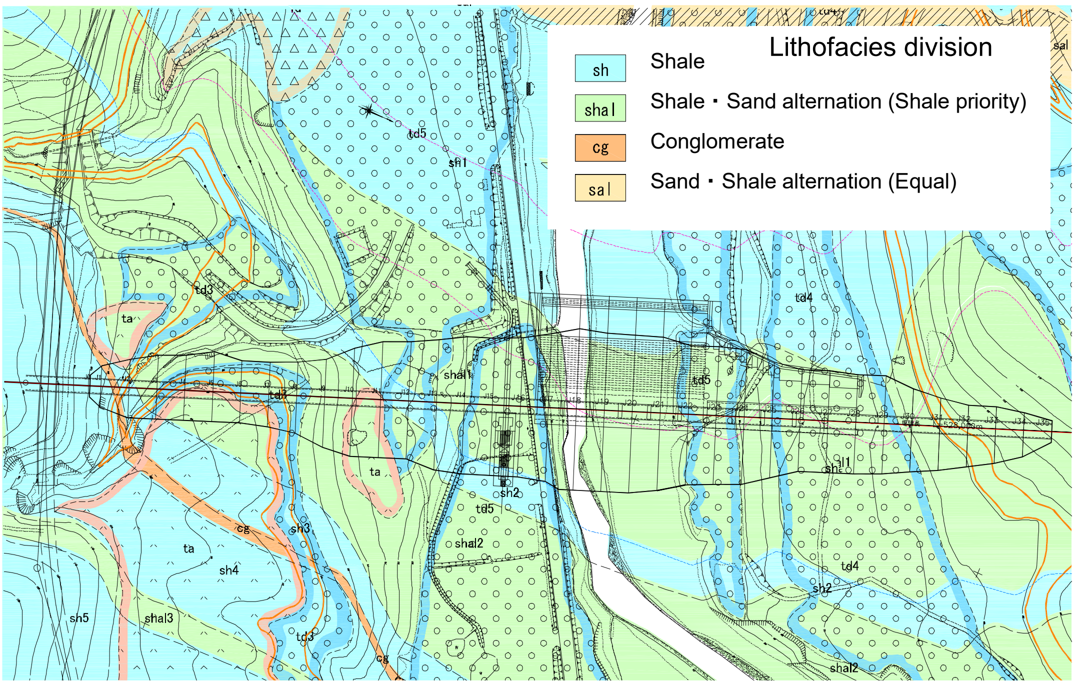


Fig. 3
Geological plan of dam site
Plan géologique du site du barrage

However, where the surface of bedrock is exposed, hexagonal cracks caused by slaking occur and leads to fine fragments of bedrock (see Fig. 4). So, since the start of the survey, it was understood that this would be a problem to be solved for dam construction. As a result of a past survey, it was known that if bedrock surface was exposed, hexagonal cracks occurred in about 2 days, but they did not become mud, and that when the surfaces were protected by submersion or mortar, hexagonal cracks did not occur.

Fig. 4
Slaking of shale strata exposed at long period
Relâchement de la couche de schiste exposée à longue période

4. SLAKING PROPERTIES OF FOUNDATION BEDROCK

To clarify the slaking properties of *sh strata* and *shal strata* distributed at the dam site, in-situ slaking tests were carried out during the preliminary survey and in a laboratory.

4.1. OUTLINE OF THE SLAKING TEST AT THE PRELIMINARY SURVEY

Heavy machinery was used to remove only the loosened and weathered parts (about 30 to 50cm in depth) at the trench bottom which was excavated and exposed for several years. On the fresh *shal strata* of the riverbed trench, another deeper trench was excavated to prepare three test surfaces (each, 1.5m×1.5m): non-protection, protection by submergence, and protection by mortar (see Fig. 5).

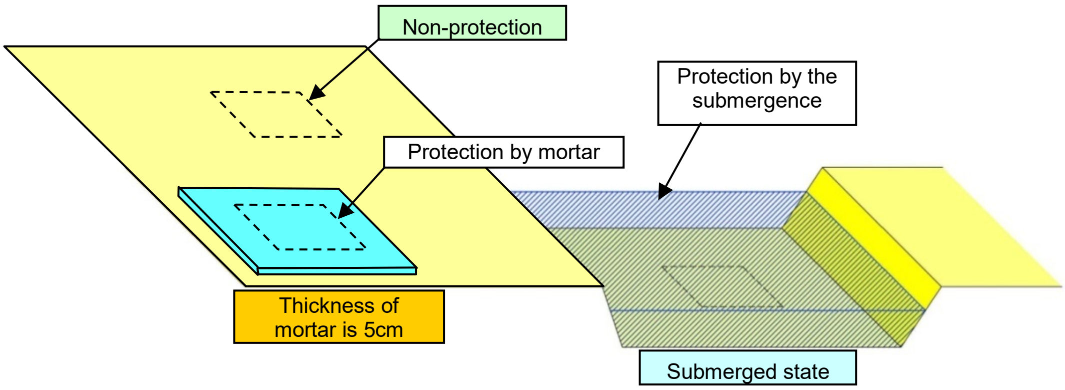


Fig. 5
Schematic view of in-situ slaking test at preliminary survey
Vue schématique du test de relâchement in situ à l'enquête préliminaire

On the submerged surface, a lower surface was excavated to form steps, and after initial observation of the test surface was completed, it was maintained in moist condition with a curing sheet and then submerged. The mortar protected surface was covered by mortar immediately after initial observation of the test surface.

Each test surface was confirmed the state of cracks 3 hours, 6 hours, 1 day, 2 days, 3 days, 7 days, 26 days, 45 days and 1 year after the excavation(see Fig. 6), then the slaking depth was measured by cores sampled 26 days, 45 days and 1 year after the excavation. Locations of cores are shown in Fig. 7.

In the laboratory tests, the core of 1.0 m long sampled just after the excavation in Fig. 7 was repeatedly wetted and dried (10 cycles), confirmed the change of their water absorptions and splintering.

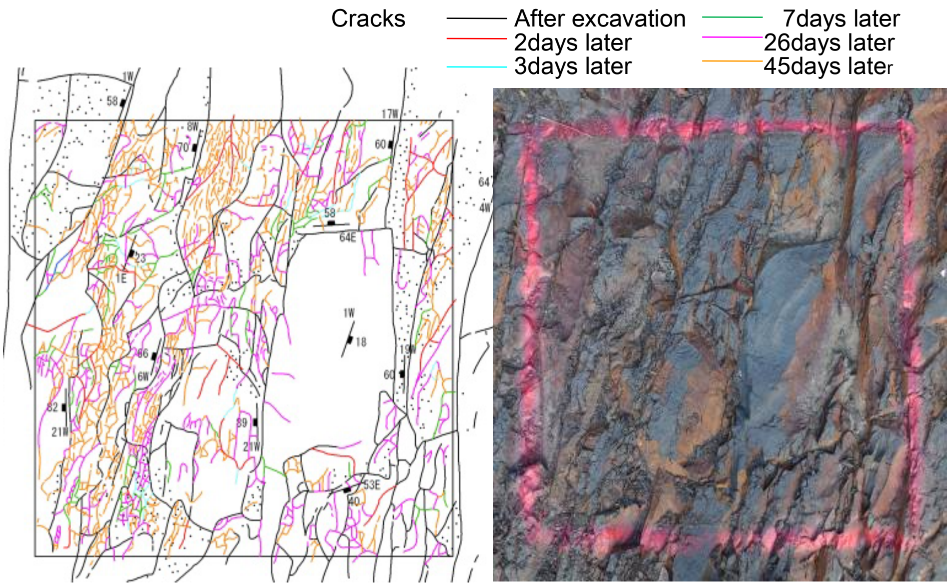


Fig. 6
In-situ test, non-protection surface (45 days after exposure)
Test in situ, surface non-protectrice (45 jours après l'exposition)

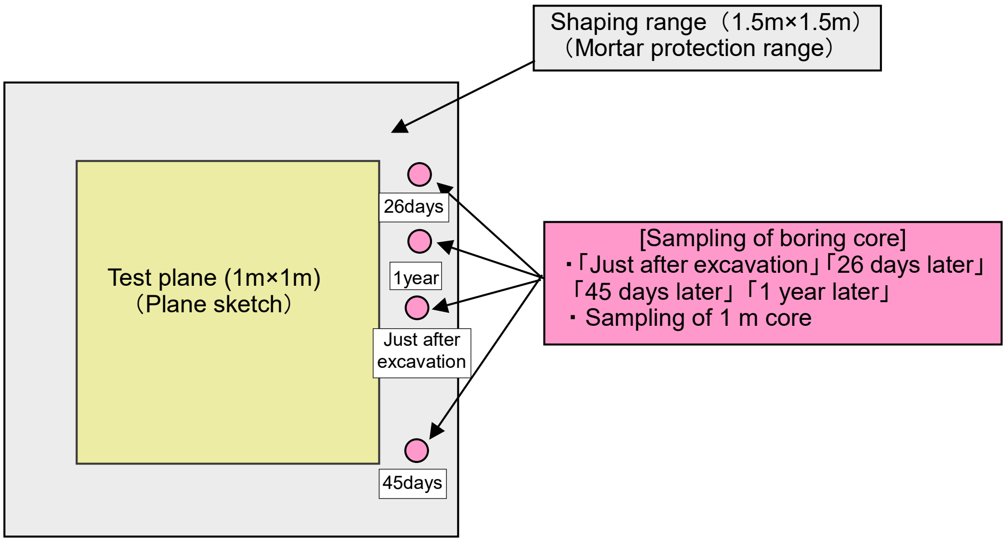


Fig. 7
Schematic plan of test surface
Plan schématique de la surface de test

4.2. TEST RESULTS AND CHARACTERISTICS OF SLAKING

The in-situ test of the unprotected surface indicated almost no change immediately after, 3 hours after, and 6 hours after the excavation. However, it was found that cracks appeared 2 days after the start of the test and that the cracks advanced with the passage in time. Seven days later, hexagonal cracks partially increased and partial exfoliation occurred. But the depth of cracks was a few centimeters from the surface. The results up to 45 days after the excavation did not show any transformation into mud. However, until 1 day after the start of test, the test surface was maintained wet condition by rainfall. Cores sampled from the unprotected surface after one year confirmed that the cracks caused by slaking reached to a depth of only 8 cm.

On the submersion protected and mortar protected surfaces, no cracks occurred 26 days, 45 days, and 1 year after the excavation.

The laboratory test using specimens sampled from the unprotected section and mortar protected section, showed splintering after wetting and drying for two cycles and advancing of splintering of fine fragments to several millimeters for 10 cycles. Furthermore, test results indicated the increase of water absorption from 10% to 15%. But the specimen did not dissolve into mud.

Judging from the test results during the preliminary survey, it has been clearly shown that if the foundation bedrock at this site was left unprotected, cyclic wetting and drying would advance cracks and cause splinter-shaped exfoliation. It was also confirmed that, (1) splintering is caused by cyclic wetting and drying but the material is not dissolved into mud, (2) at the first stage of cyclic wetting and drying, cracks occur, but the affected depth is less than 10 cm after 1 year, and (3) the protection work by submergence or mortar can restrict the progress of slaking.

4.3 . DEALING WITH SLAKING AT THE STAGE OF PRELIMINARY SURVEY

As described above, it has been confirmed by slaking tests during the preliminary survey that the foundation bedrock of Apporo dam shows slaking properties. On the other hand, the base of a trapezoidal CSG dam in contact with the foundation ground is divided into seepage control concrete area, unified CSG area, and cohesive CSG area [2] (see Fig. 8).

The foundation treatment method that includes rough excavation, secondary excavation, bedrock cleaning, and placing is categorized for seepage control concrete area and unified CSG area those require foundation treatment similar to that of a concrete gravity dam, and for cohesive CSG area where exfoliated or loosened rock, etc. caused by rough excavation are removed. Therefore, for each foundation of seepage control concrete area, unified CSG area and cohesive CSG area, it was necessary to establish the foundation treatment method considering slaking from rough excavation, secondary excavation, bedrock cleaning, and placing [3]. In the following chapter, practical treatment method during execution will be described.

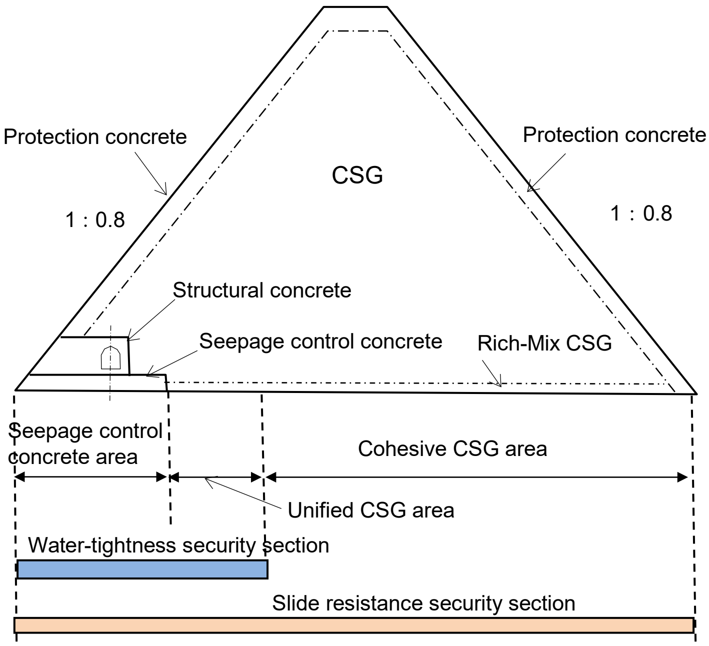


Fig. 8
Rock contact division at the base of CSG dam
Division du contact rocheux à la base du barrage de type CSG

5. SLAKING CONFIRMATION TEST BEFORE CONSTRUCTION (INCLUDING LOOSENESS CONFIRMATION TEST OF FOUNDATION BEDROCK)

Regarding the suitability of foundation treatment method at Apporo dam, as shown in Fig. 9, the duration and construction cycles required to spray mortar to protect the exposed surface after the rough excavation were investigated by confirmation test. As the next step, the duration and construction cycles required to maintain moisture condition using a curing mat after removal of the sprayed mortar (and secondary excavation), were also studied by the same test. Fig. 9 shows the foundation treatment for cohesive CSG area. Just before the construction of CSG part in rock contact, the confirmation test to verify the process of foundation treatment for slaking (including test to confirm looseness of foundation bedrock) was performed.

The geology of the foundation bedrock of the dam site is Karumai formation consisting mainly of shale enclosing shallow strata of sandstone, hard shale, tuff, tuffaceous mudstone, and conglomerate. Of these, enclosed parts with sparse sandstone and those with dense sandstone were categorized as shale strata (*Sh strata*) and alternation strata of shale and sandstone (*Shal strata*) respectively. It was confirmed that in shale, cyclic wetting and drying cause slaking very rapidly. This test confirmed the slaking rate of alternating shale and sandstone strata (*Shal strata*) and of shale strata (*Sh strata*), and verified the number of days allowed until the foundation bedrock loosens before specified slaking countermeasures have been taken.

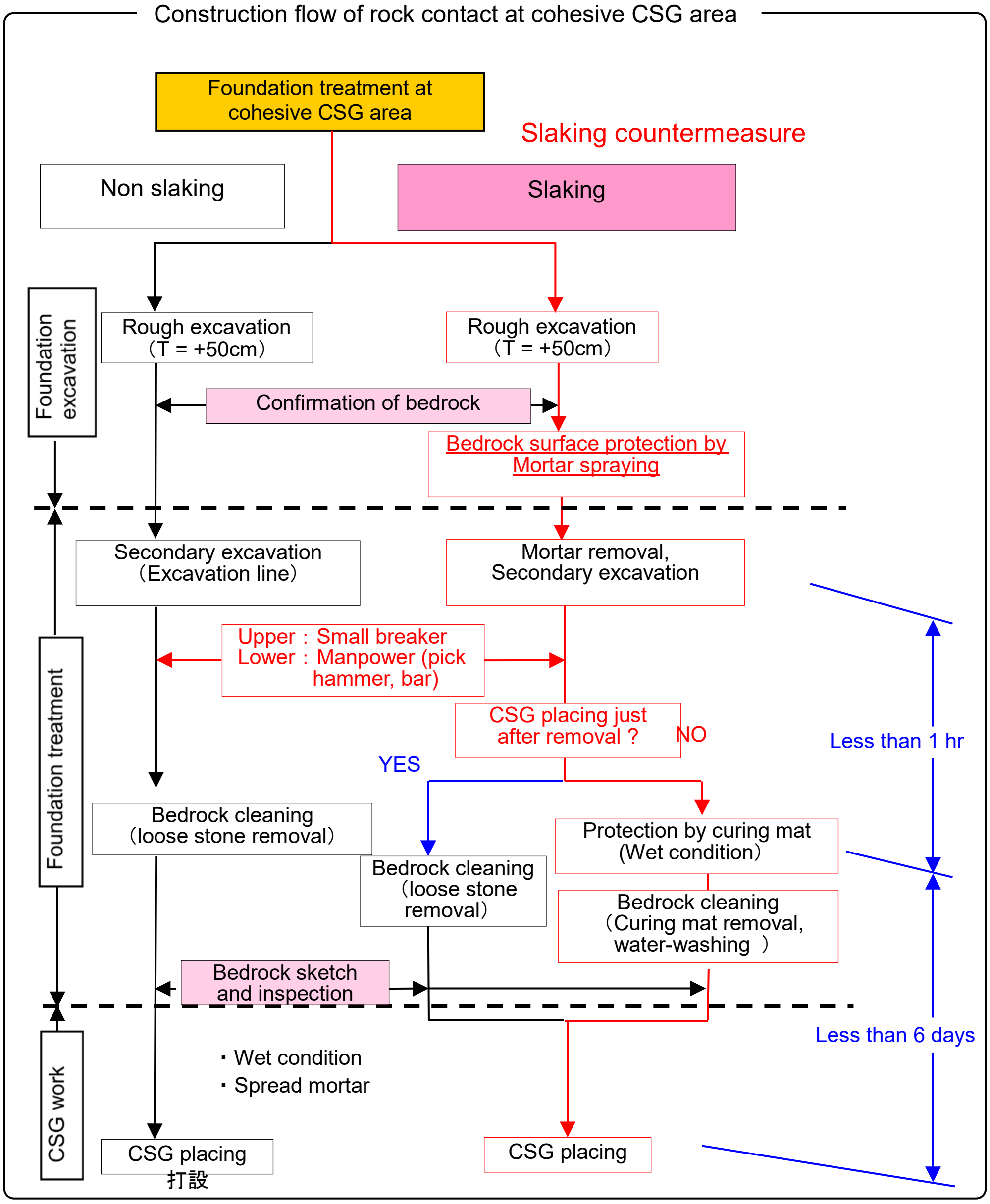


Fig. 9

Construction flow of rock contact at the dam foundation (cohesive CSG area)

Flux de construction du contact rocheux à la fondation du barrage (zone cohésive CSG)

5.1. OUTLINE OF THE TEST

The tests were executed as follows.

(1) Secondary (finishing) excavation by manpower is performed.

(2) The objects of the test are for four geological properties (rock-mass classification BIIIb and BIIIc of *Shal strata*, and rock-mass classification BIIIb and BIIIc of *Sh strata). A*fter the bedrocks with prescribed four rock-mass classifications are exposed by the excavation, loosened and weathered parts are manually removed. Here, the criteria of rock-mass classification are shown in Table 2.

Table 2
Parameters of rock-mass classification of Apporo dam

Item	Symbol	Subdivision criteria	
		Boring core	Trench (Bottom)
Hardness	A	Very hard, does not break easily by the strike by hammer.	Same
	B	Hard, break by the strike of hammer. Sound of strike is scream or impure.	Same
	C	Medium hard, break easily by the strike of hammer. Sound of strike is impure.	Same
Crack interval	I	Stick-type core of more than 50 cm	Same
	II	Stick-type core of 30 cm to 50 cm	30 ~ 50cm
	III	Stick-type core of 5 cm to 30 cm	15 ~ 30cm
	IV	Disc-type or stick-type core of less than 5 cm. Disc-type core of 1 cm.	5 ~ 15cm
State of crack	a	Cohesive, unweathering along the cracks.	Same
	b	Crack surface is weathering. Clast is unweathering.	Same
	c	Weathering along cracks. Softening along cracks. Cracks catch the clay.	Same

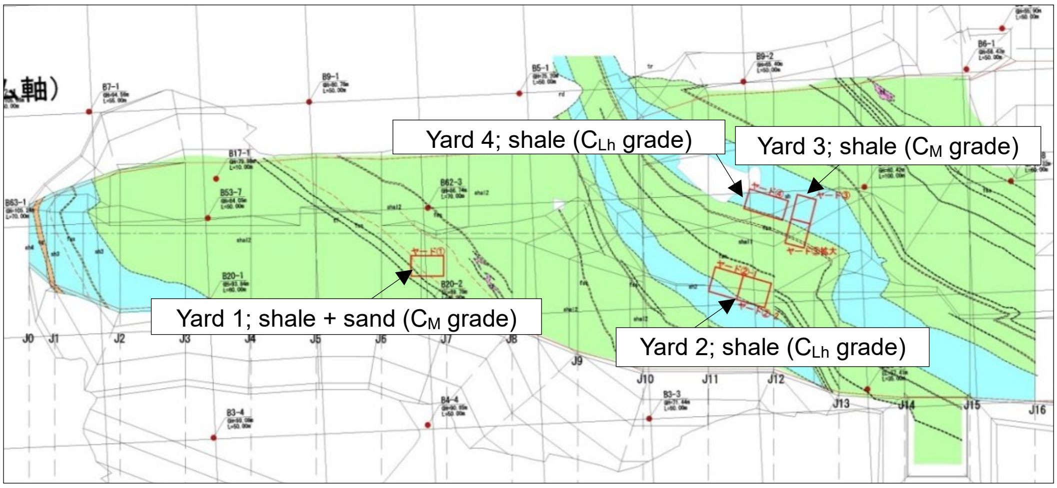


Fig. 10
Locations of slaking confirmation test (left side of the dam base)
Emplacements du test de validation de relâchement (côté gauche de la base du barrage)

Fig. 10 shows the locations of the four test yards selected.

(3) The test was, as shown in Fig. 11, done for three cases: "continuous water spraying", "moisture mat curing", and "non-protection" where any curing of

exposed surfaces was not performed. The exposed surface with non-protection was observed at every one hour to confirm the advance of slaking.

(4) Sketches of the surface observed during each test were made. When slaking was seen, the depth of crack was measured, and at the same time as the repulsion degree was also measured with a Schmidt hammer.

5.2. TEST CONDITIONS

Table 3 shows the curing conditions and verification frequency of the slaking confirmation test. At the test locations, because the confirmation test was reluctantly performed in the winter month of March, the test field was enclosed and heated to adjust weather conditions to match the dam body placing period (see Fig. 12).

5.3. TEST RESULTS

5.3.1. Slaking Confirmation Test Results of Foundation Bedrock

Test results are shown in Table 4.

・On *Shal strata* with BIIIb; when the exposed surface was left uncured, slaking caused hexagonal cracks 2.5 hours later, and drying was accompanied by advance of cracks (see Figs. 13 and 14 (1)).

・On *Shal strata* with BIIIc; when the exposed surface was left uncured, slaking caused hexagonal cracks 1 hour and 40 minutes later, and drying was accompanied by advance of cracks (see Fig. 14 (2)).

・On *Sh strata* with BIIIc; when the exposed surface was left uncured, slaking caused hexagonal cracking 1 hour after the start of drying, but this depended on the weather.

Table 3
Slaking confirmation test, curing condition and validation frequency

Test cases	Curing conditions	Verification frequency
Continuous water spraying	• Sprinkler + supplementary continuous water spraying, immediately after finishing excavation,	After 6 hours After 12 hours After 24 hours After 3 days After 7 days
Moisture mat curing	• Moisture mat curing, immediately after finishing excavation (spray curing until the mat is placed) • Moisture mat used is for curing concrete with 3mm of thickness, and spraying is done before the mat dries.	
No curing while leaving surface exposed	• The rock surface immediately after finishing excavation is left in exposed condition without curing by moisture mat or spraying. • Observation is done 1/hour, and the time until cracks by slaking occur is recorded.	

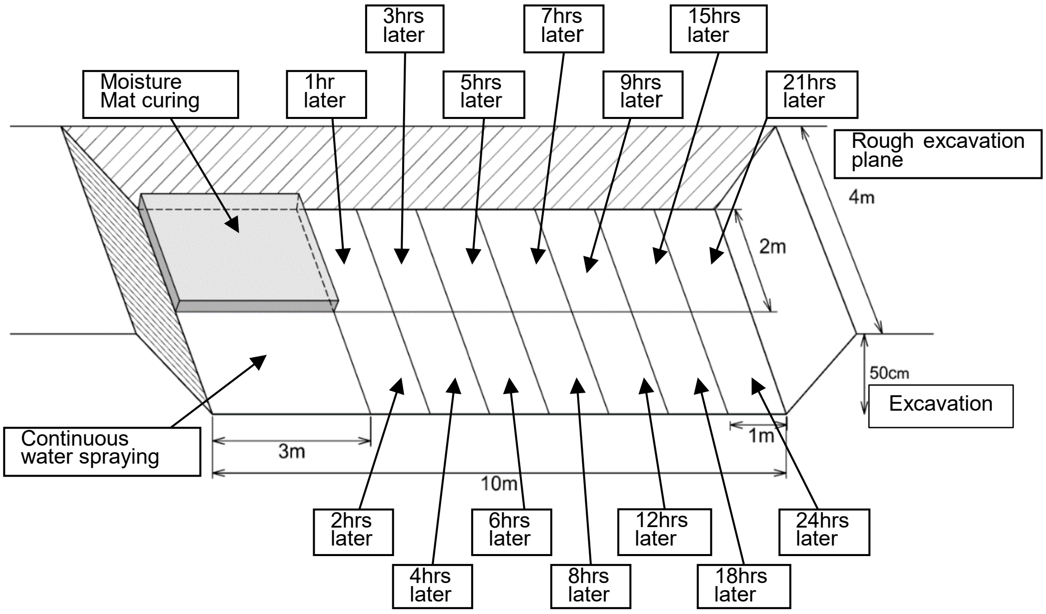


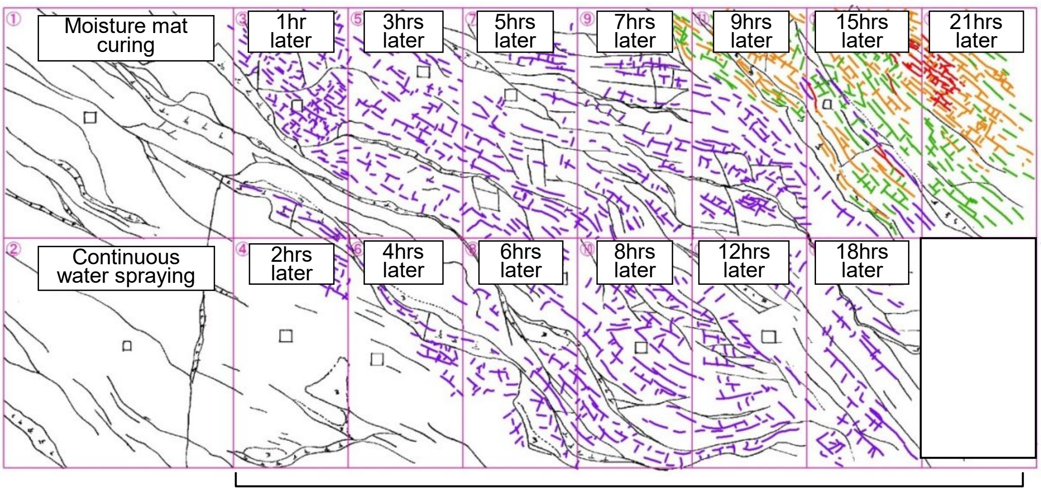
Fig. 11
The shape of the trench and division on test surface
La forme de la tranchée et la division de la surface de test

Fig. 12
Slaking confirmation test in field
Test de validation de relâchement sur le terrain

It was confirmed that on both the *Shal* and *Sh strata*, hexagonal cracks caused by slaking occurred between 1 hour and 2.5 hours from the start of drying after the excavation. It was also confirmed that as a result of performing continuous water spraying or moisture mat curing for 7 days, the hexagonal cracks by slaking and a decline of the repulsion degree of a Schmidt hammer did not occur, confirming that they restrict the advance of cracks. But on bedrock with BIIIc, in addition to the advance of slaking, conspicuous looseness caused by the stress release after the excavation was seen [4].

Table 4
Slaking confirmation test results

Test yard	Foundation bedrock geology	Test results
1	*Shal layer,* Rock-mass classification BIIIb	(1) The surfaces not cured remained moist and did not show cracks until 1.5 hours after start of the test because of cloudy. But about 2.5 hours later (4 hours after start of test), when the sky had cleared drying the test surfaces, hexagonal cracking occurred and the cracks extended as drying continued. (2) If continuous spraying or moisture mat curing was done, no cracking and no looseness of the bedrock surface occurred until about 1 week after test start.
2	*Shal layer,* Rock-mass classification BIIIc	(1) It was confirmed that continuous spraying or moisture mat curing restrained cracks until about 1 week after test start. (2) The surfaces not cured (Nos. 3 to 7) were dry since the test start because of clear sky, then 1 hour and 40 minutes after the test start, cracks appeared at right angles to the bedding plane. (3) Even if continuous spraying or moisture mat curing was done, looseness occurred on the entire bedrock surface because of the stress release, and it was judged that if this situation continued, placing would be impossible.
3	*Sh layer,* Rock-mass classification BIIIc	(1) On surfaces not cured (Nos. 3 to 14), from the test start until 9:00 the next day, the surfaces remained wet and no cracking occurred because of cloudy. The sky cleared at about 9:00 the day following the test start, so about 1.0 hour later when the test surfaces had dried, hexagonal cracking occurred. (2) Even if continuous spraying or moisture mat curing was done, looseness occurred on the entire bedrock surface because of the stress release, and it was judged that if this situation continued, placing would be impossible.



No-curing, Observation; every 1hr (0-9hr), every 3hr (9-24hr)

Fig. 13
Test results at Yard 1 (alternation strata of shale and sand stone, BIIIb grade)
Résultats du test au chantier 1 (alternance couche de schiste et sable, classe BIIIb)

(1) BⅢb grade (2) BⅢc grade

Fig 14

Crack occurrence at alternation strata of shale and sand stone

Apparition de fissure sur l'alternance couche de schiste et de sable

5.3.2. *Looseness Confirmation Test Results Of Foundation Bedrock*

On bedrock of *Shal* and *Sh strata* with BIIIc, in addition to the advance of slaking, conspicuous looseness caused by the stress release was found, so supplementary excavation of about 50 to 80cm was executed. Therefore the bedrock of BIIIb without looseness was finally exposed and continuous water spraying or moisture mat curing was performed, confirming the advancement of bedrock looseness. As a result, the *Shal* and *Sh strata* were excavated to the bedrock with BIIIb and the excavation surface was continually cured by water spraying and moisture mat curing, confirming that neither slaking nor looseness occurred for 7 days (see Table 5).

5.3.3. *Correspondence To Slaking At The Stage Before Construction*

It is possible to decrease the advance of hexagonal cracks by slaking by performing continuous water spraying or moisture mat curing. But, in a case where the bedrock surface is rock-mass classification BⅢc, the bedrock looseness will advance according to the passage in time without treatment. On the other hand, in a case where rock-mass classification BIIIb has also been exposed, performing continuous water spraying or moisture mat curing prevents looseness of the bedrock surface up to 7 days after the test start.

For this reason, secondary (finishing) excavation exposes the bedrock with classification BIIIb. Then after excavation, moisture mat curing starts within 1 hour, and the mortar is laid and placing starts within 6 days (see Fig. 15).

Table 5
Looseness confirmation test results of foundation bedrock

Test yard	Foundation bedrock geology	Test results
2	*Shal layer* Supplementary excavation to Rock mass classification BIIIb	(1) It was confirmed that curing by spraying + moisture mat restrained the occurrence of cracking and looseness of the excavation surface for 7 days.
3	*Sh layer* Supplementary excavation to rock mass classification BIIIb	(2) When the excavation of test yard was temporarily stopped, clear skies dried the test surface, and hexagonal cracking occurred one hour later. (3) It was confirmed that the test surface lowered by 10cm from the cracked surface (exposing C_M grade) and cured by spraying+ moisture mat, showed neither cracking nor looseness for 7 days.

Fig. 15
Moisture mat curing of dam foundation
Maturation par l'humidité de la fondation du barrage

6. CONCLUSION

Apporo dam was constructed on the soft rock foundation. Properties of the soft rock in area of Apporo dam showed slaking caused by cyclic wetting and drying. Additionally, it is known that its foundation is dominated by cracks which extend at an angle of about 20° on the upstream side of left abutment parallel to the bedding plane, and that unevenness along the cracks tends to be formed on its excavated surface. So, the in-situ tests were performed to investigate the slaking characteristic of soft rocks at the preliminary survey and just before construction work. Finally, the proper construction flow of rock contact at the foundation was obtained.

The construction work of dam body began in October 2014, concrete placing started on April 30, 2015, and CSG placing started on June 12, 2015. The rock contact of Apporo dam was executed by overcoming the geological problems - deterioration of bedrock by slaking - then completing CSG placing at dam body on July 4, 2016. Concrete placing was completed on September 20, 2016. After construction works of appurtenant structures such as downstream energy dissipation, water intake facility and discharge systems, and the crest bridge etc. have been completed, the initial impoundment started in October 2017

REFERENCES

[1] OKABE, Y., TAKASUGI, S. and KONNO, M. Design and construction of Apporo trapezoidal CSG dam (part 1), *Engineering for dams, Japan dam Engineering Center*, No.351, pp.45-77, 2015 (in Japanese).

[2] JAPAN DAM ENGINEERING CENTER. Engineering manual for design, Construction and Quality control of Trapezoidal CSG Dam, *Japan Dam Engineering Center,* 2012.

[3] FUJISAWA, T. (2014): CSG note (Part 4) －Design and Construction at the rock contact, *Engineering for dams*, No.330, pp.3-16, 2014 (in Japanese).

[4] YOSHIMURA, S., TAKASUGI, S., KONNO, M., FUJISAWA, T., YOSHIDA H. and YASUDA, N. Construction of Apporo Trapezoidal CSG Dam, *4th APG Symposium and 9th EADC on Innovation technologies for dams and reservoirs toward the future generations*, 2016.

SUMMARY

Apporo dam is a multi-purpose dam now under construction at the Azuma river in Horonai frontage of Atsuma town, Yufutsu district of Hokkaido prefecture as part of comprehensive development of the Azuma river. The dam is a trapezoidal CSG dam with of 47.2m in height, 47,400,000m^3 in total reservoir capacity, and 43,100,000m^3.in effective reservoir capacity. Apporo dam uses soft rock as the CSG material of dam body, and its dam foundation is also soft rock. Properties of the soft rock surrounding Apporo dam include slaking caused by cyclic wetting and drying, so various technical studies were conducted in order to use soft rock as the foundation bedrock. The dam foundation is extremely uneven so the excavation procedure was also studied. Slaking tests during the survey and slaking confirmation tests before construction works showed clearly the slaking characteristic of this bedrock and leads to the effective countermeasures. The construction works were completed and the first impoundment started in October 2017.

RÉSUMÉ

Le barrage d'Apporo est un barrage polyvalent actuellement en construction surà la rivière d'Azuma à Horonai, en front de la ville d'Atsuma, préfecture de Yufutsu, district de Hokkaido, dans le cadre du développement global de la rivière d'Azuma. Le barrage est un barrage trapézoïdal de type CSG d'une hauteur de 47.2 m, d'une capacité totale de réservoir de 47,400,000 m^3, et d'une capacité de réservoir efficace de 43,100,000m^3. Le barrage d'Apporo utilise des roches tendres comme matériau CSG pour le corps du barrage, et sa fondation est également en roche tendre. Les spécificités de la roche tendre autour du barrage d'Apporo incluent le relâchement causé par mouillage et séchage cyclique, ainsi de diverses études techniques ont été menées afin d'utiliser la roche tendre comme fondation. La fondation du barrage est extrêmement inégale donc la procédure d'excavation a également été étudiée. Les tests de relâchement au cours de l'enquête et les tests de validation de relâchement avant le travail de construction ont clairement montré des caractéristiques de relâchement de cette fondation et ont conduit à des contre-mesures efficaces. Les travaux de construction ont été achevés et la première mise en eau a débuté en octobre 2017.

Key words; Foundation treatment, Geological investigation