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Case study on engineering behaviors of the Simajiri mudstone for dam construction - slope reinforcement in dam reservoir

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ABSTRACT: "K"dam was constructed with large excavation of Shimajiri group mudstone (Shimajiri mudstone) deposited in Tertiary . This mudstone is low in strength (soft rock), weak consolidation and especially poor in slaking-durability, consequently it is easy to deteriorate and become muddy. The design and performance considering the characteristics of the mudstone were carefully studied for the dam construction and cut-slope in the dam reservoir. In this study, the rebound phenomenon accompanying with the excavation was observed by highly precise extensometer in the dam reservoir bed, and was related to the decrease of strength of the Shimajiri mudstone by laboratory tests. On the contrary, the decrease of strength was not observed in the cut slope countermeasured by concrete frame with a tie-back. These results indicate that this reinforcement method is highly effective to deterioration of Shimajiri mudstone and may be better consideration to solve the problems of the similar works in Shimajiri mudstone.

1 INTRODUCTION

1.1 *Outline of works*

"K"dam is a gravity type dam constructed for flood control. The scheme of the dam and the standard cross section of the dam are shown in Table1 and Figure 1 respectively.

1.2 *Geological aspects*

"K"dam was constructed in the middle of a typical urban river. The geological feature around the dam is shown in Figure 2. Yonabaru layer mudstone, which belongs to the Shimajiri group is mainly deposited, and Quaternary Ryukyu limestone partly covers this formation. This mudstone was sedimented in the ocean and the small faults are found obviously. Thin seams of the sandstone are often sandwitched in the mudstone layer. The slope failures and landslides occur in the mudstone slopes around the dam. The view plan around the dam reservoir is shown in Figure 3.

1.3 *Fundamental properties of mudstone*

Physical and mechanical properties of the mudstone are shown in Table 2. This mudstone consists of clay and silt, and is very homogeneous, weak-consolidated and low in strength. Potential swellingness is low, but it deteriorates easily by the repetition of wet-dry condition and results in strength decrease.

Table 1. Scheme of dam.

Dam	Type	Gravity	
	Dam height	19	m
	Dam length	120	m
	Dam crest level	E.L.52	m
	Dam volume	14,250	m^3
Reservoir	River basin area	1.7	km^2
	Reservoir area	0.04	km^2
	Total reservoir volume	510,000	m^3
	Effective reservoir volume	470,000	m^3
	Low water level	E.L.36.4	m
	Surcharge water level	E.L.49.5	m
	High water level	E.L.50.5	m

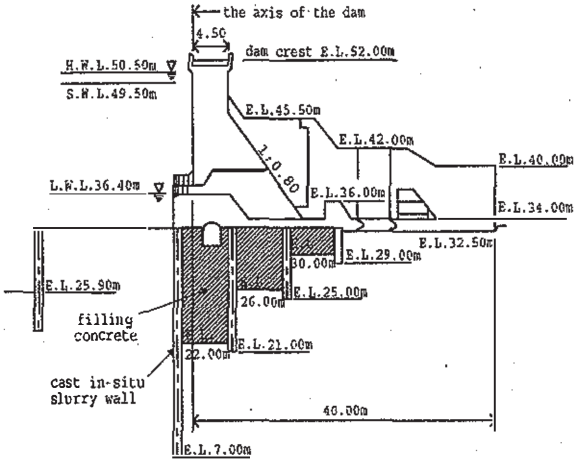

Figure 1. Standard cross section of "K"dam.

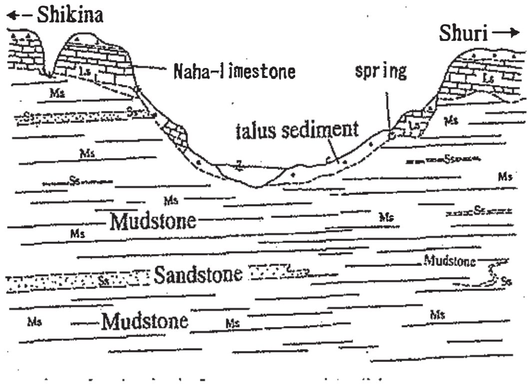

Figure 2. Geological feature around "K"dam.

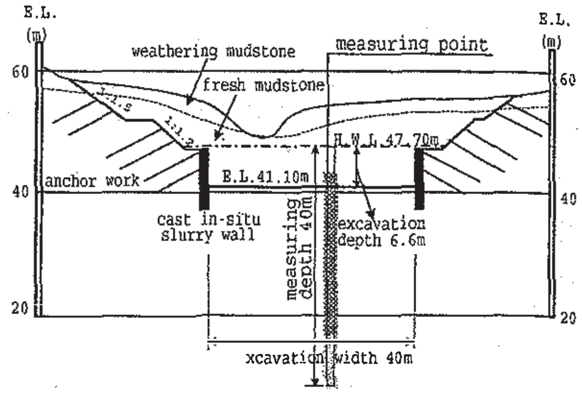

Figure 4. Standard cross section of slope protection.

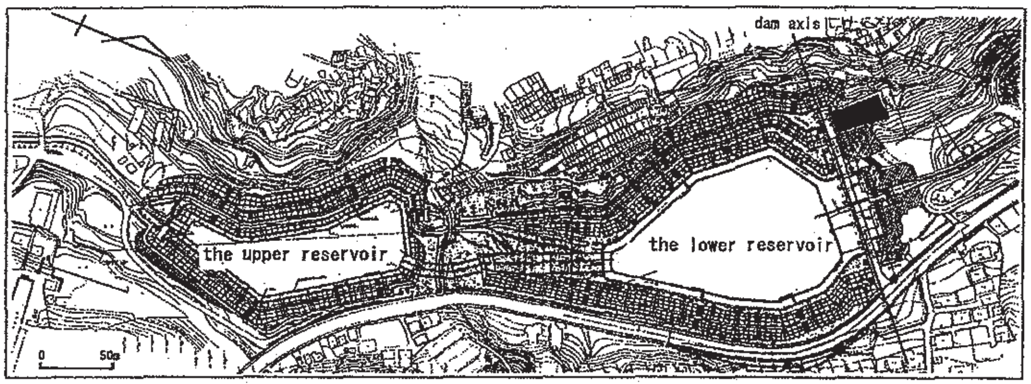

Figure 3. Dam reservoir plan of "K"dam.

Table 2. Basic property of mudstone.

properties	test data	
Grain size	Clay	50 %
	Silt	47 ~ 49 %
	Sand	1 ~ 3 %
Dry density		1.5 ~ 1.7 g/cm^3
Water content		22 ~ 31 %
Void ratio		0.55 ~ 0.87
Uniaxial strength		1 ~ 3 N/mm^2
Cohesion		0.25 ~ 0.53 N/mm^2
Angle of internal friction		23 ~ 35 °
Slaking index		3 ~ 4
Swellingness		0.6 %<

Table 3. Scheme of slope protection.

cast in-situ slurry wall	H = 11m
concrete frame	500mm× 500mm
	4,000mm×4,000mm
anchor	end-enlarged anchoring method
	1 type D220mm
	2 type D270mm

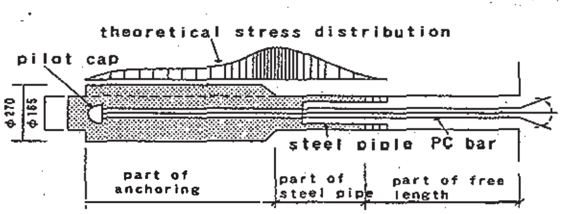

Figure 5. Stress distribution of end-enlarged type anchor.

2 DESIGN AND PERFORMANCE OF SLOPE PROTECTION

2.1 *Outline of design*

To ensure the capacity of the dam reservoir, the deep excavation in the riverbed was undertaken due to the topographic limitation.

Moreover, the dam reservoir was divided into two parts, that is, the upper reservoir and the lower reservoir in the consideration of environmental problems such as housing, traffic road, cemeteries and cultural assets. Consequently, a large-scale of cut slope, which consists of mudstone were constructed around the dam reservoir. Therefore, the slope failure and the landslide, which would accompany deterioration of mudstone, were discussed and the reviewing of the slope protection methods was examined. Finally, concrete frame with a tie-back and cast in-situ slurry wall with a tie-back were studied for the countermeasure, which could prevent from slope failures due to deterioration. As for a tie-back, "end-enlarged anchoring method" was adopted to secure the anchoring. In Figure 5, the stress distribution around the end-enlarged anchor is shown.

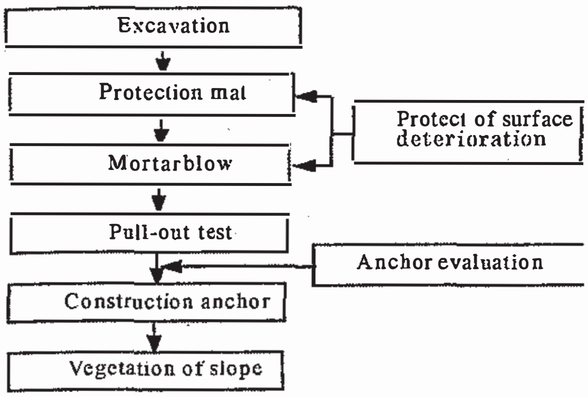

Figure 6. Procedure of slope protection.

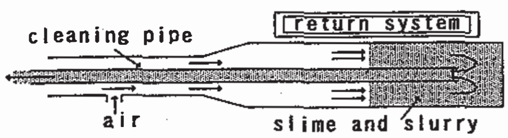

Figure 7. Excluding method of borehole slime.

2.2 *Outline of slope protection*

The performance procedure of the slope protection is shown in Figure 6.

Pull-out test was performed to confirm the bond capacity of the anchor. As a result, it was indicated that the conventional anchoring method could not secure the prescribed pull-out force, and so the method of excluding the borehole slime as shown in Figure 7, was adopted.

3 GROUND DEFORMATION AND CHANGE OF SOIL PROPERTIES

3.1 *Ground deformation behavior due to excavation*

Field measurements were performed at the central part of the dam reservoir to observe the deformation behavior caused by the excavation. The results obtained by using highly precise extensometer (sliding micrometer) are shown in Figure 8.

The upheaval deformation of the ground occurred from the ground surface to the depth of 30m. Especially, the deformation in the surface of excavation site is larger, and it occurs immediately after excavation and continues for a long time. But at the part of the cut slope reinforced by a tie-back and cast in-situ slurry wall, obvious deformation was not observed.

3.2 *Changes of ground soil properties*

The changes of soil properties due to the excavation were studied by laboratory tests. Test specimens were sampled from boring cores in the dam reservoir bed and the cut slope, and specific direct shear test was adopted to know the mechanical properties. Laboratory tests were carried out at three depths

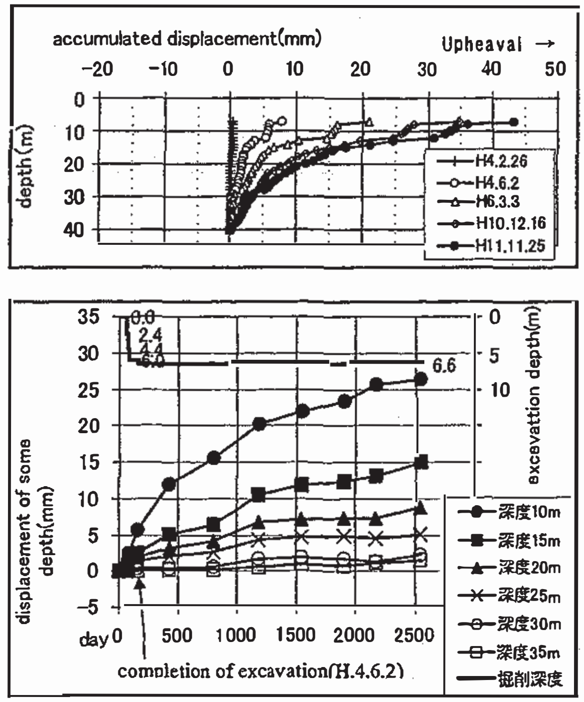

Figure 8. Measurement result of dam reservoir bed.

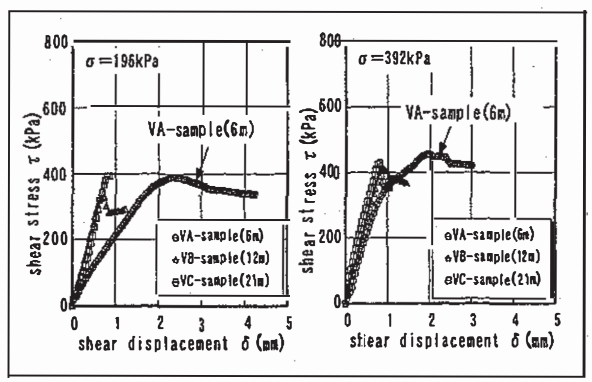

Figure 9. Deformation properties of dam reservoir.

(6m, 12m, 21m) with boring core specimens of the dam reservoir bed to compare the rebound quantities with excavation depths. On the other hand, boring core specimens of the 5m depth in the cut slope were tested. The results of the specimens in the dam reservoir bed are shown in Figure 9 and Figure 10 respectively. The shear modulus of the specimen at the 6m depth is much smaller than the others, but it recovers easily, as the confining pressure gets larger.

Peak strength of the shallow depth specimen (6m) is much smaller than that of the deeper points (12m, 21m). From the above mentions, it was cleared out that the strength and deformation properties of the Shimajiri mudstone must be strongly influenced by the rebound behavior due to excavation.

Also, the decrease of strength by change of water content was studied, using the specimens at the 21m depth as shown in Figure 10. It was clarified that the slight change of water content could influence the strength of the mudstone.

4 EFFECT OF SLOPE PROTECTION

The strength of the mudstone at the shallow depth (5m) in the cut slope was the same as that at the 12m depth in the dam reservior bed as shown in Figure 11. If the deterioration progresses at the same speed in both the cut slope and the dam reservoir bed, the strength in the cut slope might decrease more. However, the decrease of strength in the shallow part reinforced by a tie-back was of strength restrained, and this phenomenon is evaluated as the effectiveness of the slope protection.

5 CONCLUSIONS

The results obtained by the research this time are as follows:

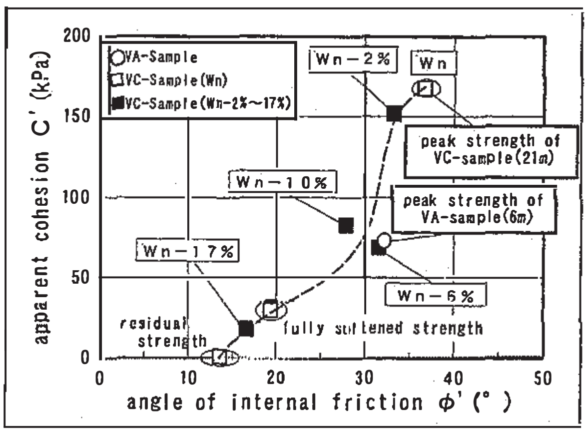

Figure 10. Strength decrease by change of water content.

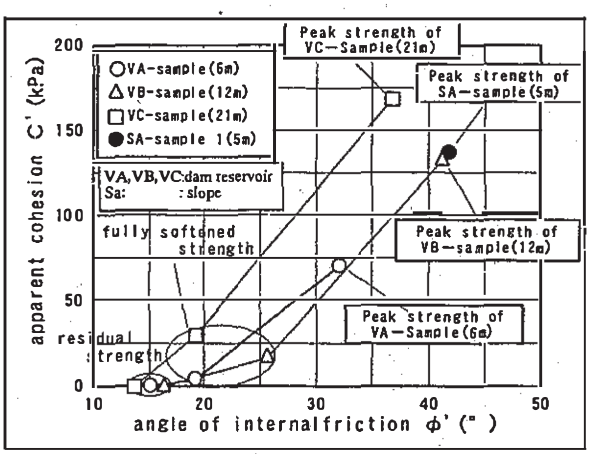

Figure 11. Comparison of strength in dam reservoir bed and cut slope.

1. "K" dam was based on the Shimajiri formation clay stone which was easy to cause slaking, Therefore, the concrete frame with a tie-back and cast in-situ slurry wall with a tie-back were applied for its construction in order to prevent slope failure due to the deterioration of mudstone layer excavated.
2. Field measurement at the dam site showed deterioration at the dam reservoir bed where the countermeasure was not applied, while no deterioration was found at the cut slope where the countermeasure was applied.
3. According to the results from the laboratory tests, the excavation bed surface with larger deterioration had larger deformation and smaller strength.
4. The slight variance in the moisture content was correlated with the significant decrease in shear strength, and the effect of repeated dry and wet was evaluated by moisture content changes.
5. The decrease in shear strength of the mudstone at the cut slope is much smaller, compared to that of the mudstone at the upper part of the dam reservoir bed. This is considered to be the effect of the slope protection with a tie-back.
6. Judging from the above mentions, it is important to take measures to prevent repeated dry and wet action or slaking as excavating the mudstone ground, In this case, cured protection mat and mortar blow were effective countermeasures. Also slope protective works such as anchor works were very effective to restrain the decrease of strength of the mudstone and to prevent slope failure in the mudstone layer.

6 CLOSING REMARKS AND ACKNOWLEDGEMENT

Shimajiri Formation clay stone forms the ground basis of the southern area of the Okinawa Main Island, which many civil engineers are familiar with. It is also known that it has geotechnical characteristics of slope failure and landslides. However, investigative study where we observed the deformation behavior at the site of large-scale excavation, revealed the strength characteristics in relation with deformation of the mudstone and the effect of the countermeasures against deterioration by slaking. It is our pleasure if the present study could be useful for the design and construction method of the dams and foundations problems in the Shimajiri formation clay. Finally, the authors appreciate greatly to the Okinawa Prefectural Dam office and all those who took part in the construction of "K"dam.

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