MAINTENANCE OF TERAUCHI DAM SPILLWAY CONCRETE DEGRADED BY ALKALI AGGREGATE REACTION

Shigeki Ichikawa[1]
Satoshi Inoue[2]
Katsushi Nagata[3]

ABSTRACT

Terauchi Dam was completed in 1978. More than 10 years after completion, degradation phenomena such as cracks on concrete surfaces began to be observed in structures such as the flood spillway. To investigate the cause of this degradation phenomenon and the possibility of its future progression, we identified characteristics of degraded structures, microscopically observed thin specimens of concrete, determined the relation between concrete strength and modulus of elasticity, and conducted accelerated expansion testing of concrete specimens, and so on. As a result, the cause of the degradation was found to be Alkali Aggregate Reaction (commonly referred to as Alkali Silica Reaction (ASR)), since signature characteristics of ASR were confirmed, such as characteristics of cracks, kinds of aggregate used, minerals contained in aggregate and characteristic relation between compression strength, modulus of elasticity , and so on. Based on the classificatory evaluation of concrete's degradation in thin specimens observed microscopically and accelerated expansion testing of concrete samples, it was concluded that degradation was slight at the time of the investigation, and that concrete expansion would likely progress. On the basis of the above investigation, in 2010 a repair construction against degradation progression was carried out that comprised of coating of degrading parts and affixing of carbon fiber sheets. We are continuing to monitor the condition of the structure after repair.

INTRODUCTION

In Japan, there has been no instance of a dam's structural functionality being negatively impacted by ASR-caused degradation of the concrete in the dam's main concrete structures (Koga 2011). The reason for this is generally thought to be that the concrete used for dams contains less alkali than concrete used for general buildings, due to the following:

1) Cement content of concrete used for main dam structures is generally small in amount: 230 kg or less per $1m^3$.

2) Part of the cement in the concrete used for dams constructed during and after the 1980s was replaced with blast-furnace slag or fly ash.

However, the concrete have been used for spillway and water-intake facilities of rockfill dams is similar to those used for general civil structures. Therefore, there are cases of degradation due to ASR in these structures. As an example of such degradation, this

[1] Japan Water Agency, Saitama, Japan, Shigeki_Ichikawa@water.go.jp
[2] Japan Water Agency, Fukuoka, Japan, Satoshi_Inoue@water.go.jp
[3] Japan Water Agency, Ehime, Japan, Katsushi_Nagata@water.go.jp

paper discusses: the state of degradation of the spillway concrete; its cause identified by investigation and analysis; selected measures for repair work and to hold current degradation state; and a plan for future maintenance, in the rockfill dam.

OVERVIEW OF TERAUCHI DAM

Terauchi Dam, completed in April 1978 and managed by the Japan Water Agency, is a rockfill dam with 83 meter-high. As shown in Figure 1, the dam is located on the Sata river, part of the Chikugo River system in the northern part of the Kyushu region. A panoramic view of the dam is shown in Figure 2.

The Dam's spillway with a width of 22m and a length of 382.6m, was constructed on left bank side of the dam (Figure 3). The total amount of concrete cast, approximately 62,800 m^3, was prepared at a ready-mixed concrete plant some 30 minutes' drive from the dam site and transported by agitator trucks. The concrete was placed using concrete pumps, except for some blocks of the spillway, from August 1975 to January 1977. The cement content of the concrete was about 300 kg per $1m^3$. There is no detailed record of the cement's components but, presumably, no fly ash or blast-furnace slag was used, judging from the results of the polarization microscopic observation carried out as part of this research.

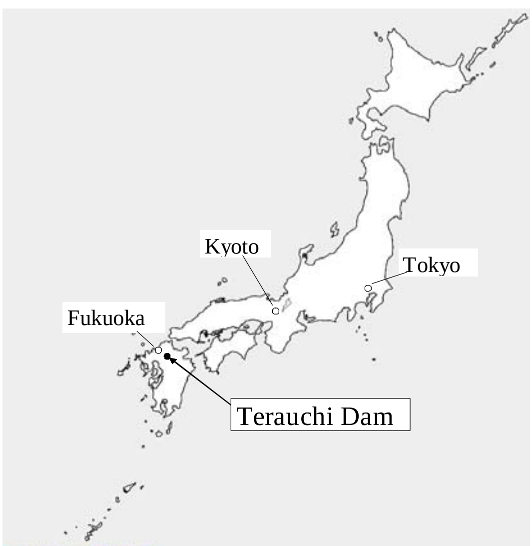


Figure 1. Location of Terauchi Dam.

Figure 2. Panoramic View of Terauchi Dam.

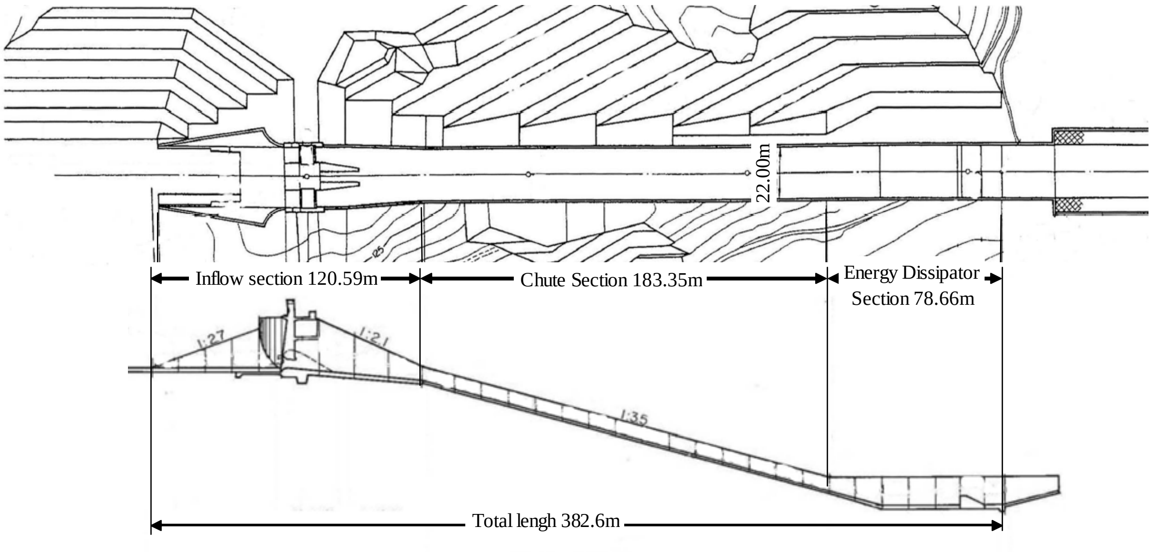


Figure 3. Plane Figure and Longitudinal Profile of Spillway.

DEGRADATION GENERATED IN SPILLWAY CONCRETE

History of Degradation

It is not clear when concrete in the spillway began to crack, but around 1997, some 20 years after the dam was completed, cracks up to 5 mm wide became apparent in places such as the top surfaces of training walls. The first investigation into the degradation phenomenon at the dam was carried out beginning in 1997 and lasting until 1999. In 2001, repair work of injecting the polymer cement grout into the crack at the top of the training wall of the spillway was made. The injected material was mainly composed of ultra-fine cement. A total length of the injection was 492.5m.

Thereafter, it was monitored continuously for the repaired portion, further cracking was observed. The detailed investigation, analysis and testing were therefore carried out from 2006 to 2007.

Investigation, Analysis and Testing to Determine Degradation Status

Methods of Investigation and Analysis. Given the conditions of the degraded concrete and the manner in which the degradation developed, it was concluded that the cause was most likely ASR. Based on this conclusion, the following investigation, analysis and testing was carried out:
1) Survey of degradation statuses: visual inspections were conducted, focusing on presence of cracks, length of cracks and width of cracks.
2) Analysis of rocks used as aggregate and their constituent minerals. Core specimens were sampled from the concrete, and their cross-sections were observed with the naked eye. Also, thin specimens were cut from these core specimens and observed with a polarization microscope. The aggregate rocks and their constituent minerals were thereby

distinguished and identified; whether they contained substances that might affect ASR was assessed.
3) Measurement of unconfined compression strength and modulus of static elasticity: Sampled specimens were shaped to prescribed dimensions (100 mm diameter, 200 mm length) to measure unconfined compression strength and modulus of static elasticity; their correlation was also checked.
4) Measurement of residual expansion: Sampled specimens were shaped to prescribed dimensions (100 mm diameter, 250 mm length) to measure length changes after curing at the standard 20 degrees Celsius and 100% humidity condition and unrestrained expansion. The specimens were further subjected to accelerated curing at 40 degrees Celsius and 100% humidity to measure changes in length and calculate residual expansion rates. In this way, the concrete expansion potential was assessed.

Degradation Status Survey Results. The detailed investigation conducted over 2006 to 2007 confirmed the degraded conditions of concrete as described below. The function of the spillway was not decreased. However, the crack width was increased. Degradation of the spillway had proceeded to reliably compared it to 2001.
1) Many of the cracks on the top surfaces of the spillway training wall, which had been repaired in 2001, once again developed into cracks. In some places, new cracks were observed. These cracks were 1 to 5 mm in width (Figure 4 (a)).
2) On the side surface of the spillway training wall, ocher-colored, fine alligator cracks or non-directional cracks (map cracks) were newly generated near the top of the wall (Figure 4 (b)). Other than near those locations, cracks were also generated in places such as joints between cast concrete and cold joints that tended to increase the moisture (Figure 4 (c)).

Given these conditions, it was concluded that map crack were generated in places where there was little constraining force against deformation, such as the side surfaces of the training wall, and that cracks extending along a direction in which there was a constraining force were generated in places such as the top surfaces of the training wall. Also, cracks apparently tended to occur in places such as the top surfaces of the training wall and joints between cast concrete where standing water tended to accumulate.

(a) Cracks on Top Surface of Training Wall

(b) Micro Cracks near Top Surface of Training Wall

(c) Micro Cracks on Side Surface of Training Wall

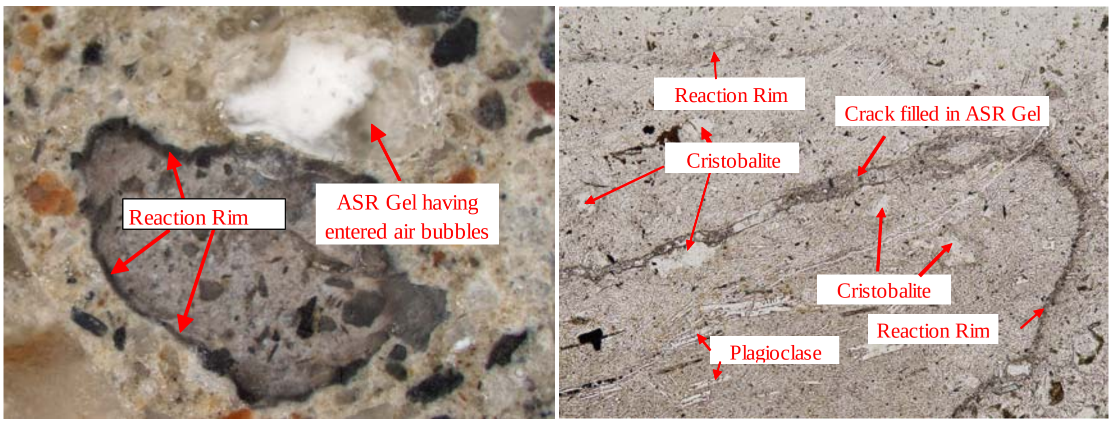
Figure 4. Degradation of Concrete in Flood Spillway.

Petro-logical Investigation and State of Concrete Micro Structure. Observed by visual observations and polarizing microscope, were as follows (Figure 5):

1) Crushed amphibolites were used as coarse aggregate. Nothing found within this aggregate or its periphery was suggestive of concrete degradation.

2) Fine aggregate was sand whose main ingredient was clastics derived from volcanic rocks (mainly andesite and welded tuff of rhyolite) and granite. Substances that can cause ASR, such as cristobalite, tridymite and volcanic rocks, including volcanic glass, comprised around 30 to 40% of the mineral.

3) In all concrete specimens, including those sampled from locations with no cracks, ASR gel was seeping out or ASR reaction rim was observed. However, there was no instance of ASR gel occurring widely in cement paste, or intruding into air bubbles. These conditions correspond to degree 2 or 3 of the Severity of ASR Classification by Katayama (2008) as shown in Table 1.



(a) Reaction Rim around Fine Aggregate

(b) Crack and ASR Gel (Observed by Polarizing Microscope)

Figure 5. ASR-Caused Degradation Confirmed in Concrete Micro Structure.

Table 1. Severity of ASR Classification by Katayama (2008)

ASR severity	Condition
1	Reaction rim observable on aggregate; Gel seep in cement paste around aggregate
2	Cracks filled with ASR gel observable within aggregate
3	Cracks filled with ASR gel continuous from inside of aggregate to cement paste
4	Many air bubbles in cement paste filled with ASR gel

Relation between Compression Strength and Modulus of Static Elasticity. Concrete that has been degraded by ASR exhibits a modulus of elasticity that generally tends to be lower relative to its compression strength than sound concrete. The relation between unconfined compression strength and modulus of elasticity for the concrete core samples in this study is shown in Figure 6, together with the relation generally observed in sound concrete provided as Japan Society of Civil Engineers (JSCE) –Standard (JSCE 2008a). As shown, for concrete sampled from the spillway the modulus of elasticity is low relative to the compression strength in comparison to sound concrete, suggesting ASR-caused degradation.

<u>Residual Expansion.</u> The residual expansion test results, shown in Figure 7, are generally 0.03 to 0.05%, suggesting the possibility of progressing expansion.

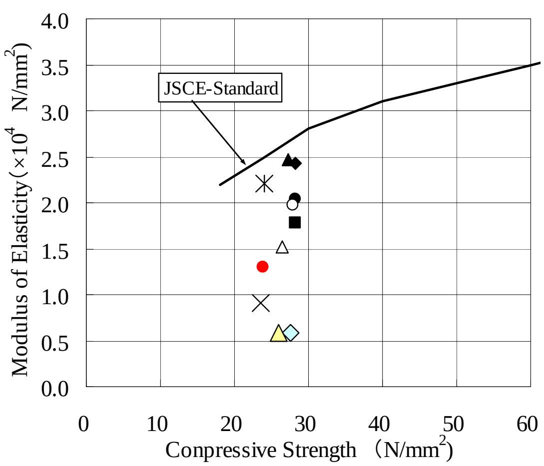


Figure 6. Compression Strength and Modulus of Elasticity.

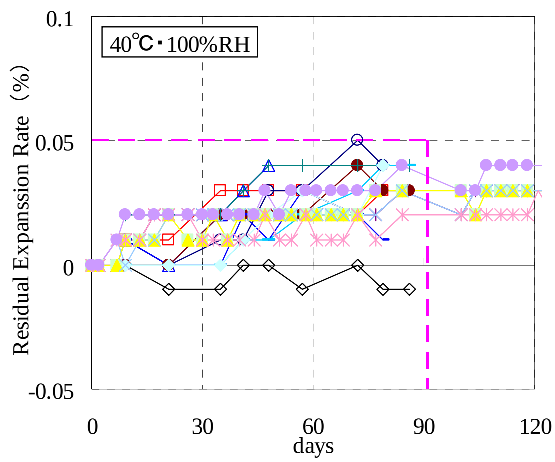


Figure 7. Result of Residual Expansion Test.

Soundness Evaluation of Structures

Characteristics indicative of ASR were confirmed by three types of observations: crack generation pattern, types of rocks used as aggregate and their mineral content, and the relation between compression strength and modulus of elasticity. We therefore concluded that ASR was the cause of the degraded concrete indications, such as the cracks observed in the spillway. ASR severity was judged to be degree 2 or 3 on a scale of 4 based on the Severity of ASR Classification by Katayama (2008), indicating that the observed degradation was slight as degradation by ASR, based on polarization microscopic observation and other results. The result of the residual expansion test, 0.3 to 0.5%, did not meet the criterion of 0.5% or greater residual expansion for concrete cured at 40 degrees Celsius and 100% relative humidity for 13 weeks, which is the general index value for deleterious degradation potential. However, future generation of cracks, and continued expansion of existing cracks, could not be ruled out.

Applying the criteria for the ASR-caused Degradation Process (Table 2) in Standard Specifications for Concrete Structures (JSCE 2008b), the concrete degradation was evaluated as follows:
1) Top surfaces of training wall where cracks were generated: Grade II or III
2) Sides of training wall and invert, where no cracks were generated: Grade I or II

Table 2. Definition of ASR-caused Degradation Process
(Descriptions Added to JSCE Concrete Standard Specifications)

Degradation process	Definition
Grade I (latency period)	Period in which ASR progresses, but expansion and cracking of concrete are not yet generated.
Grade II (progression period)	Period in which expansion progresses continuously with supply of water and alkaline substances, and cracks are generated. No steel member corrosion yet, however.
Grade III (acceleration period)	Stage at which ASR-caused expansion speed becomes greatest. Period in which cracks develop; steel member corrosion may occur.
Grade IV (deterioration period)	Period in which crack width and concentration increase, diminishing concrete integrity; load-bearing capacity decreases become apparent due to loss of cross-sectional area and corrosion of steel members.

IMPLEMENTATION OF COUNTERMEASURES

Selection of Countermeasure

Our basic policy in implementing conservatory measures against ASR-caused degradation is to select measures commensurate with the concrete structure's evaluated degradation stage; the selected measures were:
1) For structures with grade I (latency period) degradation, strengthen inspections and repair the structures for purposes of preventive maintenance.
2) For structures with grade II (progression period) or grade III (acceleration period) degradation, strengthen inspections and repairs.

Based on our examinations, it was decided to implement repair measures for the top surfaces of the training wall of the spillway, where degradation such as cracking was advancing, and the structural soundness evaluation grade was either II or III. As to the type of repair work, it was decided to coat the concrete surface with a material that would restrict the absorption of water, which is a factor in the progression of ASR-caused degradation. For the blocks where there were already cracks along the length of the training wall, it was decided to introduce constraint by applying a pre-stressing force together with the measure taken against the cracks. This was for the reason that the deformation of concrete due to temperature changes and the possibility of future expansion of concrete due to ASR had to be taken into consideration. Pre-stressing was achieved by affixing carbon fiber sheets. The countermeasure against cracking comprised filling cracks with a cement-type grouting material. For the side surface of the training wall, whose degradation was rated at either I or II, only strengthened checks were used as countermeasure, since the cracks were generally narrower than those on the top surfaces, and shielding that portion with surface covering was not very effective, given the ground-water coming from the back.

Repair Construction

The repair constructions were carried out during the period from April 2010 to March 2011. Areas where repairs were implemented are shown in Figure 8. Shown in Figure 9 is the breakdown of surface coating in places where only this coating was applied. Figure 10 shows the breakdown of surface coating applied together with concrete constraints realized by affixing carbon fiber sheets. As surface coating, organic surface-coating materials superior in water-resistance were used. The surface coating consists of a substrate coat of epoxy-based materials for shutting out water and a finish coat of polyurethane-based materials for securing weather-proof performance. Bidirectional carbon fiber sheets were used in consideration of possible concrete expansion due to ASR. Photos taken during construction work are shown in Figure 11; photos taken after work completion are shown in Figure 12.

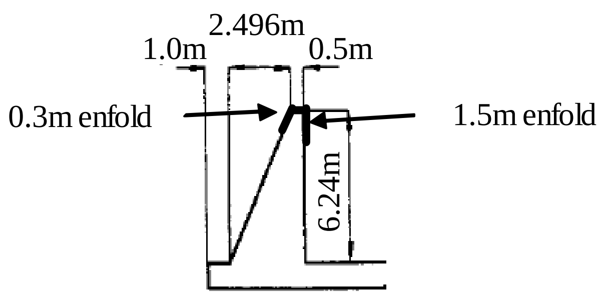


Figure 8. Repair-applied Portions

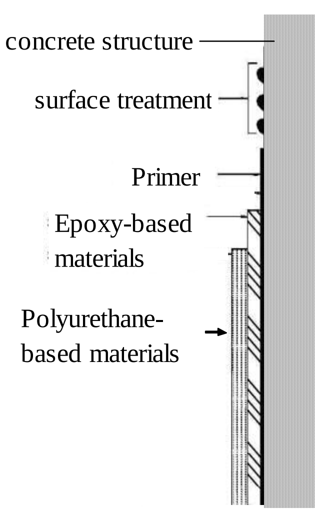


Figure 9. Breakdown of Surface-Coating-Only. surface

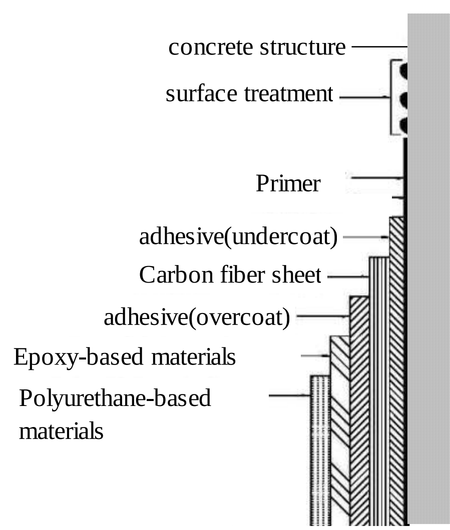


Figure 10. Breakdown of Surface Coating, Plus Affixing of Carbon Fiber Sheet.

(a) Crack-Repair Work (b) Carbon Fiber Sheet-Affixing Work

Figure 11. Photos of Repair Construction.

(a) Spillway Seen from Downstream (b) Spillway Seen from Upstream

Figure 12. Photos of Spillway with Repair Construction Completed.

MONITORING

Countermeasures against concrete degradation in Terauchi Dam flood spillway were implemented by 2011 for the top surfaces of the training wall. However, since the cause of the degradation, ASR, is progressive, continued monitoring is important.

For this purpose, the dam is checked once every 3 months by visual inspection. These checks focus on the following three points, in consideration of ASR characteristics and the repair work that has been carried out.

1) Condition of concrete near borders between areas where carbon fiber sheets were affixed and areas where no measures were taken

2) Condition of concrete near cold joints on side surface of training wall where no measures were taken

3) Degraded condition of coating materials

Since these measures were implemented not long ago, the conditions of the structures have shown no significant change. We intend to continue to monitor them as per a schedule for periodic checks, and to carry out appropriate maintenance to prolong the service life of the dam facilities.

CONCLUSION

The cause of the concrete degradation, such as cracks observed on the concrete of the flood spillway of Terauchi Dam and other structures, was determined to be ASR based on the results of our investigations, such as characteristics of generated cracks, minerals contained in aggregate used, microscopic observation of concrete specimens and static elasticity modulus testing. Since future progression of degradation was deemed likely, countermeasures were implemented that focused on restraining this progression, with emphasis on the affixing of carbon fiber sheets. At present, flood spillway functionality is not affected. However, we will continue to monitor of the spillway; degradation status will be evaluated appropriately at each monitoring, with suitable measures implemented so as to maintain the spillway functionality over the long term. We will improve our monitoring method as necessary, so as to get as accurate an understanding of the concrete condition as possible.

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