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Long-term behavior of the Yashio dam, asphalt faced rockfill dam

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ABSTRACT: The 90.5 m high 15 year old Yashio dam, which was completed in 1995, is the upper dam of Tokyo Electric Power Company's Shiobara pumped storage power plant. There has been no leakage through the asphalt facing, and leakage through the foundation and exterior deformation of the dam body has been stable. We have measured the deformation of the asphalt facing utilizing a clinometer mounted on a vehicle towed from the crest of the dam. In addition, we have investigated the aging of the asphalt facing at the exposure test yard which was installed near the dam site on the same elevation level of the dam. We estimate that the asphalt facing was performed adequately after the aging.

1 INTRODUCTION

The Yashio dam, the 90.5 m high rockfill dam with aspahltic concrete facing was constructed by the Tokyo Electric Power Co., Inc. This dam is used as an upper dam for the Shiobara Pumped Storage Power Plant (900MW). The Yashio dam has been operating for 15 years, and we have confirmed that the behavior of the dam has been stable via many measurements and inspections. In addition, we have investigated the aging of the asphalt facing at the exposure test yard which was installed near the dam site on the same elevation level of the dam. We paved asphaltic concrete on the slope of the test yard with same material of the dam's facing. Thus, we can investigate the aging of the facing without having to directly analyze the facing of the dam itself. We estimate that the asphalt facing was performed adequately after aging. In this paper, the evaluation of the long-term behaviour of the exterior deformation and the leakage, and the aging of the asphalt facing of the Yashio dam will be described in detail.

2 OUTLINE OF THE YASHIO DAM

Given the tremendous water pressure, the facing of the Yashio dam was designed as a double-deck structure having an impermeable layer in each upper and lower portion. An intermediate drainage layer has been installed in order to clearly detect water leakage. The facing have a total of seven layers and 37 cm thickness. The surface of the facing has been covered with a thin layer of asphalt mastic so as to protect it from damage which can be caused by ultraviolet, frost and snowfall. Three types of grain sizes were used: a coarse one (max. size of aggregate is 20 mm) in the macadam and levelling layers; a fine one (max. size of aggregate is 13 mm) in the impermeable layers; and an open one (max. size of aggregate is 25 mm) in the intermediate drainage layer. An outline of the Yashio dam is given in Table 2.1, the plan of the dam is shown Figure 2.1, and the typical cross section is shown in Figure 2.2. The structure of the facing is shown in Figure 2.3, the standard mix proportion of the aspahltic concrete for facing is shown in Table 2.2.

Table 2.1. The outline of Yashio dam.

Name of dam	Yashio Dam
Name of river	Nabearisawa river, Naka river system
Purpose of dam	Hydropower generation (Pumped storage)
Type of dam	Rockfill dam with asphalt facing (AFRD)
Height of dam	90.5 m
Length of dam crest	263 m
Volume of dam	2,109,000 m^3
Catchment area	2.0 km^2
Reservoir area	0.47 km^2
Total storage volume	11,900,000 m^3
Year of completion	1995

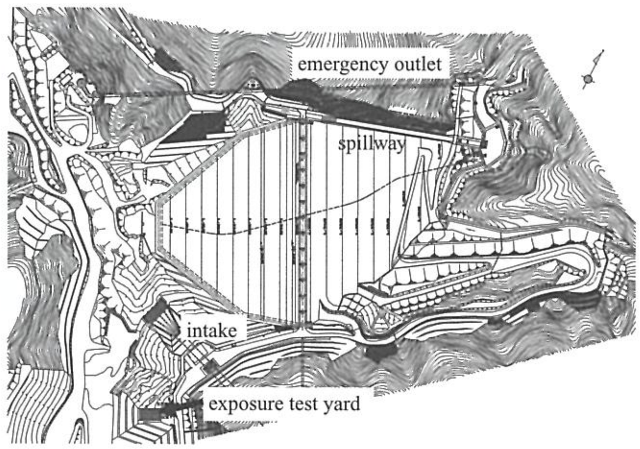
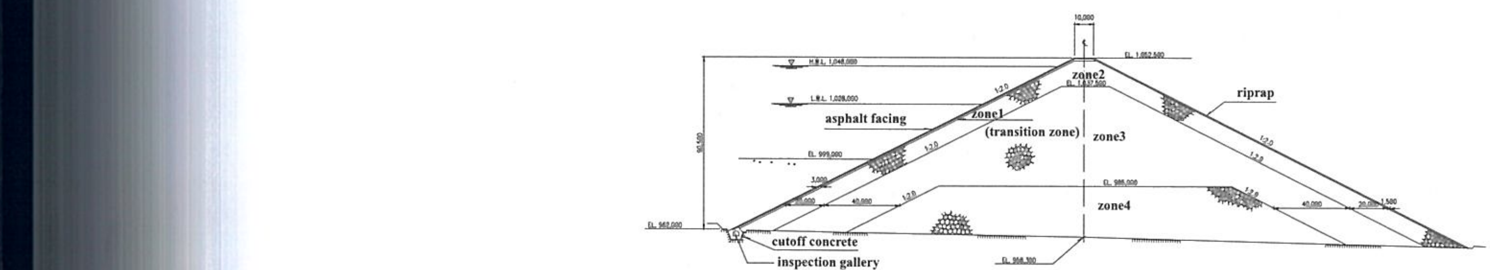


Figure 2.1. The plan of Yashio dam.



		Max. size (mm)	Density (g/cm^3)		Angle of internal friction	Cohesion
			Dry	Wet		
Zone 1	porphyrite	300	2.04	1.95	43	0
Zone 2	porphyrite	1,000	2.04	1.95	43	0
Zone 3	porphyrite	1,000	2.04	1.95	42	0
Zone 4	tuff	1,000	1.96	1.85	38	0

Figure 2.2. The standard cross section of Yashio dam.

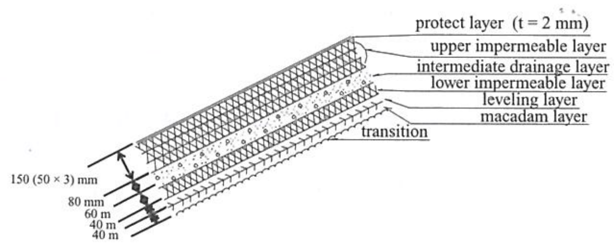


Figure 2.3. The structure of the facing.

Table 2.2(1). The standard mix proportion of the asphaltic concrete for facing.

Grade	Max size of aggregate (mm)	Content per unit weight (kg/ton)							
			Aggregate						
			Crushed stone			Crushed sand	Fine sand	Filler	
		Asphalt	20–13	13–5	5–2.5	2.5–0	2.5–0	Stone dust	Addition
Coarse	20	50	171	304	228	190	–	57	–
Open	25	40	399	292	197	–	48	24	–
Fine	13	85	–	166	267	275	83	115	8

Table 2.2(2). The standard mix proportion of the asphalt mastic for protect layer.

Content per unit weight (kg/ton)			
Asphalt		Filler	
Straight	Blown	Stone dust	Addition
185	185	580	50

3 THE RESULT OF THE MEASUREMENTS

3.1 *Leakage*

The leakage seeping through the facing and the bedrock are guided respectively to the inspection gallery. The drainage layer and the rock material of the dam body are connected with the inspection gallery with the drainpipes respectively. They are measured separately by the weir installed at eight points in the gallery. The flowing quantity is measured with the automatic measuring system. The leakage measurement equipment is shown in Figure 3.1. The leakage through the upper impermeable layer has been almost zero. Even though a slight amount of leakage through the seams and hair cracks of the inspection gallery concrete was measured for the period of the initial filling, it was stopped up. We installed drain pipes in the inspection gallery at the side of the dam body so that the backing pressure should not act on the facing. The amount of flowing quantity from these drain pipes was 10 liter/min. for the period of the initial filling, but it decreased and is about 5 liter/min. now. Moreover, it is judged that there is no danger of backing pressure or piping fracture occurring in the dam, because there has been no fine-grained fraction in the water. The flowing quantity from the dam body side drain in the inspection gallery is shown in Figure 3.2.

3.2 *Exterior deformation of the dam body*

The exterior deformation of the dam body is measured by external targets. The external targets set up at 15 points on the crest and the downstream side of the dam, and 26 points on the upstream of the dam. The 12 points under the LWL on the upstream were able to be measured only for the period of initial filling and 14 points were able to be measured in the event of a drawdown. The arrangement of the external targets is shown in Figure 3.3.

The maximum horizontal displacement towards the direction of the upstream was about 30 mm at No. 13 (near the center of the dam crest) and 25 mm at No. 3 (in the middle of the downstream at the left bank) towards the direction of the downstream. The maximum vertical displacement is about 150 mm at No. 12. We estimate that it has been stable because its increase has been 2 mm a year over the past five years. Further, we estimated that the vertical displacement near the center of the dam crest caused the horizontal displacement towards the direction of the upstream. The horizontal displacement towards the direction

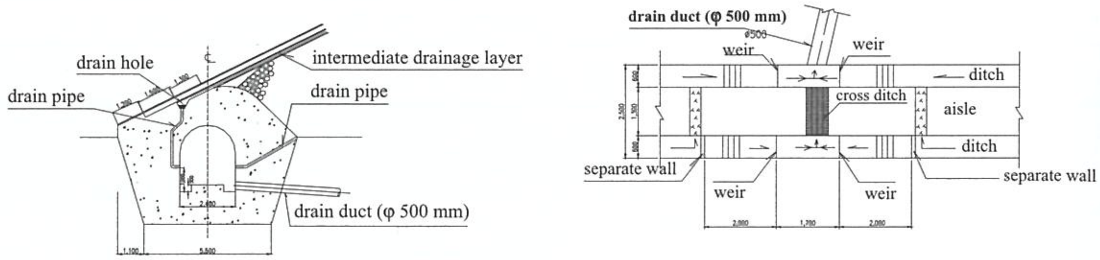


Figure 3.1. The leakage measurement equipment.

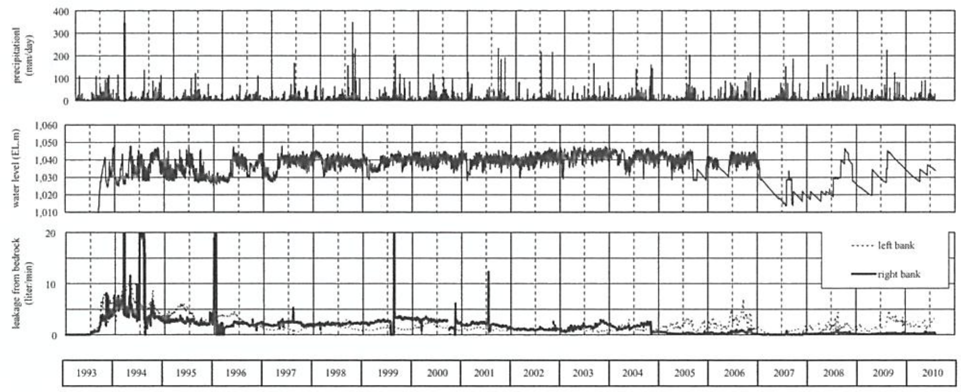


Figure 3.2. Flowing quantity from the dam body side drain.

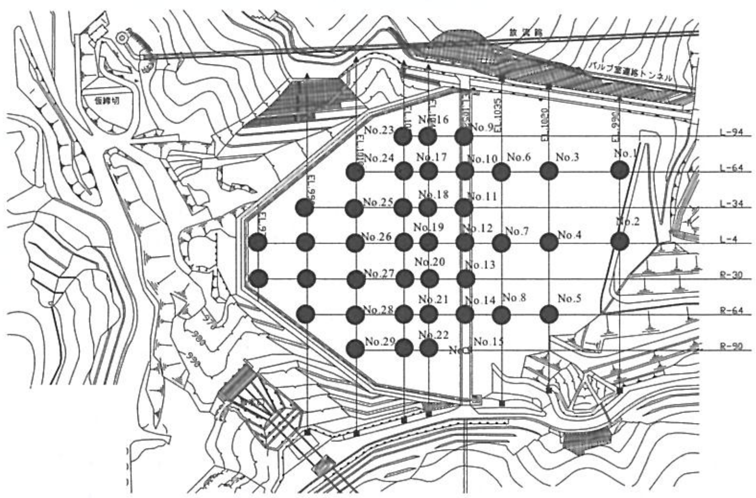


Figure 3.3. The arrangement of the external targets.

of the upstream of No. 13 increased along with the water level rising in the period of the initial filling. Further, it had decreased gradually for 10 years since five or six years after the water level reached the HWL. Now that the horizontal displacement toward the direction of the upstream of No. 13 is 20 mm. Similar behavior has been shown at other points on the dam crest, and it has been evaluated that the displacement towards the direction of the upstream was caused mainly by the influence of the vertical displacement of the upstream side of the dam by hydraulic pressure. The horizontal and vertical displacements are shown in Figures 3.4 and 3.5. Further, the distribution of the horizontal displacement and the vertical displacements in the dam central cross section is shown in Figure 3.6.

3.3 *Deformation distribution of the facing*

The deformation of the facing has been measured utilizing a clinometer mounted on a vehicle towed from the crest of the dam. We have measured the deformation of the facing at the center line of the upstream of the dam. The outline of the clinometer mounted on a vehicle is shown in Figure 3.7.

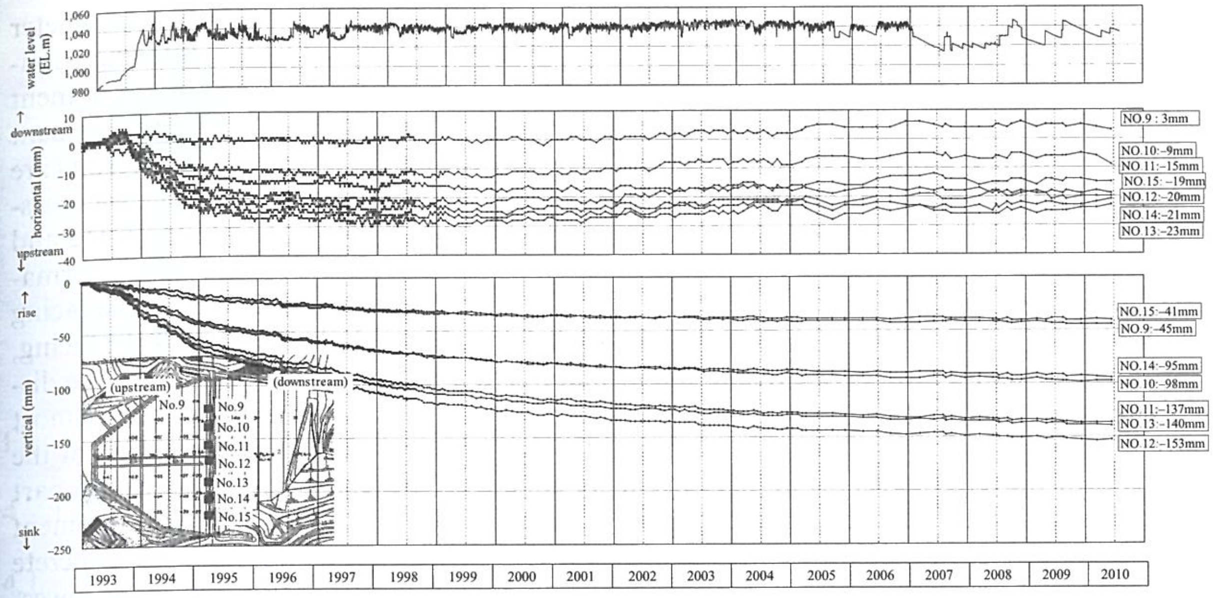


Figure 3.4. The exterior deformation measurement results (dam crest).

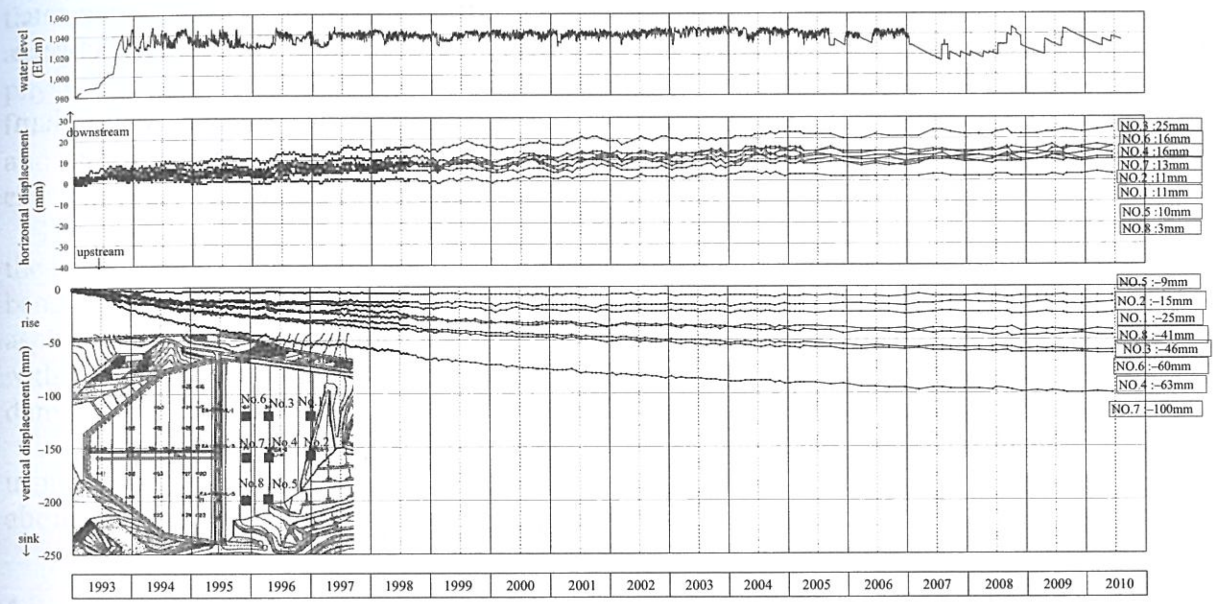


Figure 3.5. The exterior deformation measurement results (downstream surface).

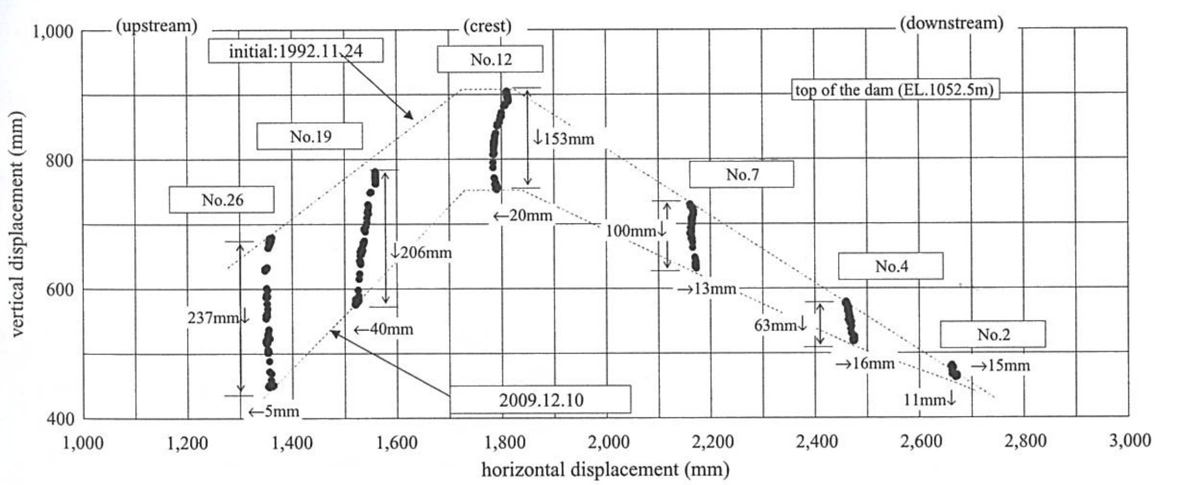


Figure 3.6. The distribution of the horizontal displacement and the vertical displacement in the dam central cross section.

The deformation of the facing is calculated by measuring the tilt angle with a clinometer and the distance between the measurements (1 m). We have observed it by the difference, converted to a perpendicular displacement of the upstream slope, between the each measurement and the initial value that was measured before the initial filling. The maximum displacement is about 400 mm at about 80 m from the bottom of the facing. The measurement results are shown in Figure 3.8. The deformation of the facing had increased according to the water rising in the initial filling, and have showed little elastic behavior according to water rising and the descent and creep deformation since the water level reached HWL. However, the deformation has been stable in recent years. The increase of the maximum displacement of the facing has gradually decreased. We evaluated that there is no problem with the stability of the facing, because the increase ratio of the maximum displacement is small and the increase of the displacement of the joint part of the facing with the inspection gallery concrete has been almost zero in recent years because the maximum tensile strain by hydraulic pressure occurs at the joint part of the facing with the inspection gallery concrete. The tensile strain at the joint part of the facing with the inspection gallery which is calculated by the deformation measurement result is about 0.5% or less, it is small enough for the yield strain of the asphaltic concrete of about 5% at the temperature of 5°C and the strain rate of 5×10^{-5} 1/sec. 5°C is the lowest water temperature of the reservoir, and the strain rate of 5×10^{-5} 1/sec is the lowest strain rate of the test machine(actual strain rate during the initial filling was about 1×10^{-10} 1/sec).

The yield strain of the asphaltic concrete depends on the temperature and the strain rate. The larger the strain rate becomes, the smaller the yield strain becomes. The relation between the yield strain and the temperature and the strain rate is shown in Figure 3.9.

We estimated that the facing is stable because the calculated tensile strain is smaller than the yield strain under the test conditions of a larger strain rate at the same temperature.

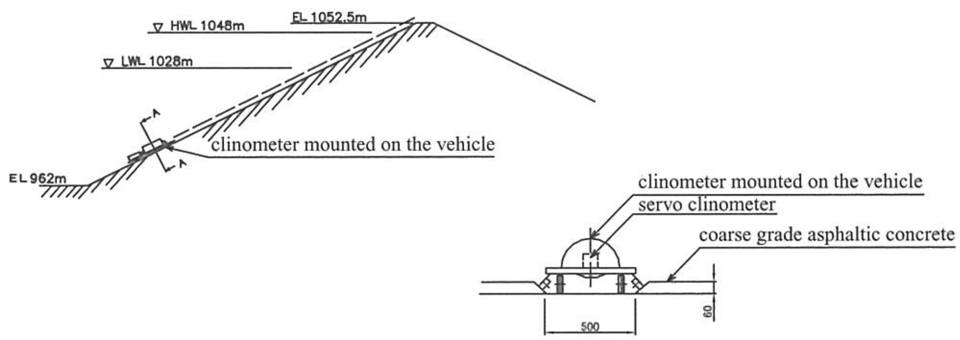


Figure 3.7. The outline of the clinometer mounted on a vehicle.

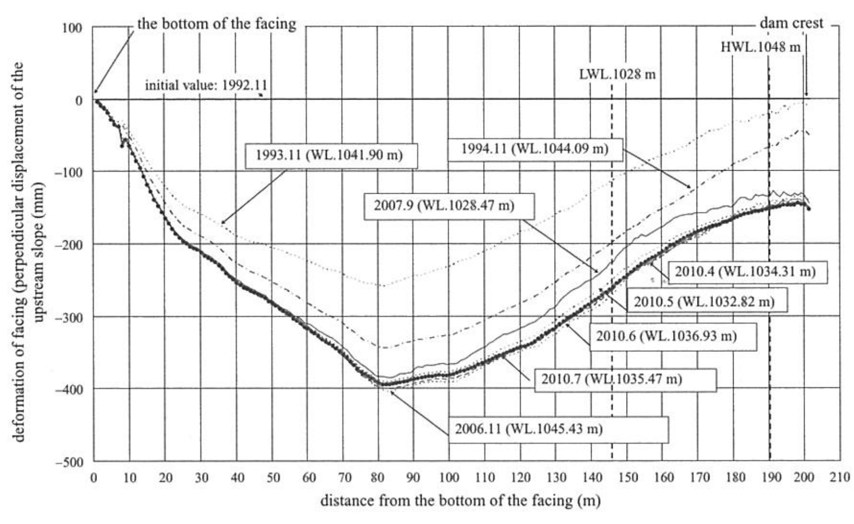


Figure 3.8. The deformation of the facing.

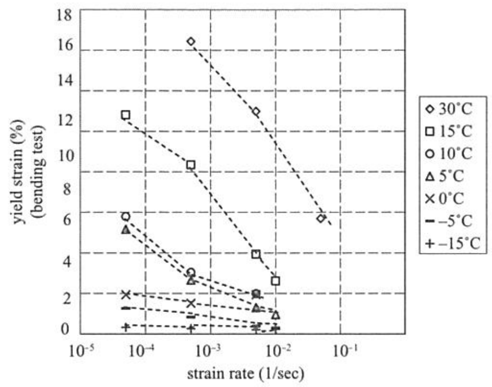


Figure 3.9. The relation between yield strain and temperature and strain rate.

4 THE AGING OF THE ASPHALTIC CONCRETE FACING

4.1 *The feature of the aging of the asphaltic concrete facing*

The asphaltic concrete is influenced by such factors as ultraviolet rays in the passing age which changes its mechanical properties. We set the exposure test pieces near the dam site before the construction of the dam, and investigated the asphaltic concrete's property changes after aging. The test pieces were exposed for five years, the mechanical examination, and the basic physical properties test (such as the penetration and softening point) of the asphalt extracted from the test piece were executed. We made test pieces of fine grade asphaltic concrete with and without the protective layer made out of asphalt mastic. The results of the physical properties tests are shown in Figures 4.1 to 4.3.

The property changes of the test pieces with the protective layer were comparatively large for the first few years. The penetration became small and the softening point rose up and the yield bending tensile strain became small, but after that they didn't change that much. In other words, asphaltic concrete hardens after few years, but after that, there are no changes, if it was coated with a protective layer. The bending test condition of −15°C is the lowest temperature of the dam site and the strain rate of 1×10^{-2} 1/sec is the one during the earthquake in Figure 4.3.

The amount of the tensile strain occuring on the facing during earthquakes was calculated using the two-dimensional dynamic response by means of the finite element method was about 0.1%, it is enough smaller than yield tensile strain.

4.2 *The exposure test yard*

At the Yashio dam, test paving was conducted before the construction of the facing of the dam. We planned to use this test yard as an exposure test yard for the investigation of the changes of the asphaltic concrete facing after aging in the future. We installed an exposure test yard near the dam site on the same elevation level of the dam. We paved asphaltic concrete on the slope of the test yard with the same material of the dam's facing. The slope inclination and direction of the test yard are the same as the dam's one. Thus, we can investigate the aging of the facing without having to directly analyze the facing of the dam itself. We have extracted a sampling from the exposure test yard and executed an investigation 0, 1, 2, 5, 10 years after the paving. The location of the exposure test yard is shown in Figure 2.1.

4.3 *The results of the investigation of the aging of the asphalt facing at the exposure test yard*

We have conducted various investigations and tests shown as follows by using the test piece samples taken from the exposure test yard.

(1) Density test, (2) Penetration test, (3) Softening point test, (4) Chemical composition analysis, (5) Bending test, (6) Permeability test.

The results of the investigations are almost similar to the aforementioned former exposure tests results. The results of the bending test from this test yard are shown in Figure 4.4 as one

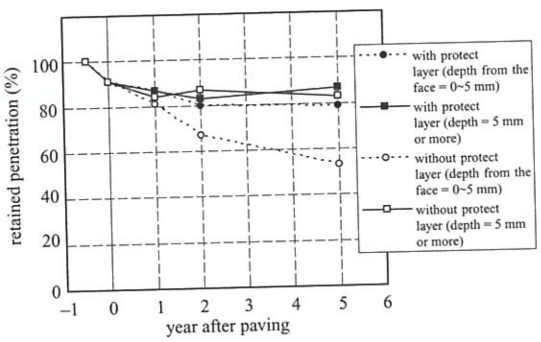


Figure 4.1. The retained penetration after aging.

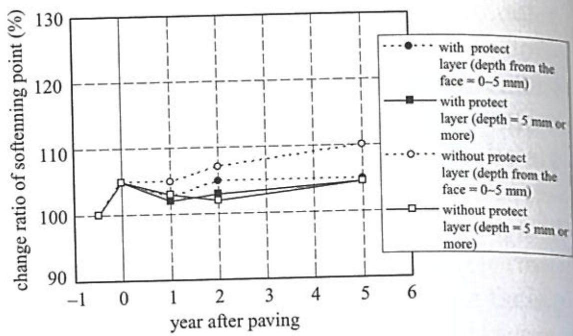


Figure 4.2. The change of softning point.

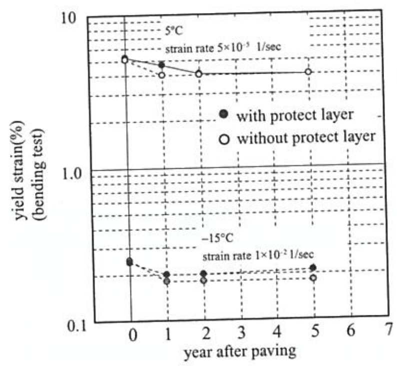


Figure 4.3. The change of yield strain.

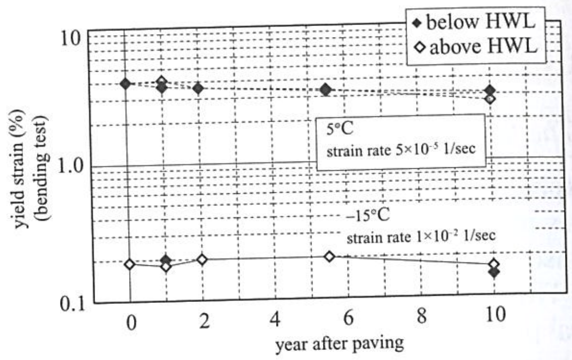


Figure 4.4. The change of yield strain after exposure.

of the examples. We have confirmed that the decrease of the yield bending tensile strain of the asphaltic concrete was small and that it had enough deformation performance about ten years after paving because we estimate that the tensile strain which occur during the earthquake is 0.06%. And we will continue investigating the change of the properties of the facing in the future, because they have tended to be a little hardened by aging.

5 CONCLUSION

We estimate that the asphalt facing is performing adequately after aging as follows.

a. The leakage through the upper impermeable layer has been almost zero.
b. The amount flowing from these drain pipes was 10 liter/min. for the period of the initial filling, but it decreased and is about 5 liter/min. now. Moreover, it has been judged that there is no danger of backing pressure or piping fracture in the dam, because there has been no fine-grained fraction in the water.
c. We estimate that it has been stable because its increase has been 2 mm a year over the past five years.
d. We evaluated that there is no problem with the stability of the facing, because the increase ratio of the maximum displacement is small and the increase of the displacement of the joint part of the facing with the inspection gallery concrete has been almost zero in recent years. Further, there were not large changes observed in the asphaltic concrete with a protective layer after a few years.

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