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Long−Term Field Exposure Tests of Dam Concrete Using Large-Scale Concrete Blocks

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ABSTRACT:
The Technical Committee on Research of Actual Frost Damage of Concrete of the Japan Commission on Large Dams has been conducting long-term exposure tests since 1961 aiming to “identify the relationship between the weathering resistance of dam concrete in cold areas and the results of durability tests using concrete specimens”. Fully mixed large concrete blocks, which are 1m cubic, and small specimens prepared by wet screening fresh concrete, which have under 40-mm of coarse aggregates, were installed at six locations in Japan that are exposure under severe weathering conditions, for annual measurements of ultrasonic wave propagation time and other parameters. The following conclusions were reached.

1) The measurements with elapse time vary according to the water-binder ratio of the exposed specimen. At a water-binder ratio of 45 to 49 %, similar to that of the dam, relative dynamic modulus of elasticity was kept at 80 % or higher after 41 to 49 years of exposure. Specimens thus remain in the sound state.

2) Replacing approximately 25 % of cement with fly-ash is effective for improving the freeze-thaw resistance of dam concrete.

Keywords: freeze-thaw, large concrete blocks, water-binder ratio, fly-ash, relative dynamic modulus of elasticity

1. INTRODUCTION

Concrete dams are typical civil engineering structures that require high safety level. Care should be taken in various phases of construction of a concrete dam such as detailed rock survey around the dam site, guarantee of adequate safety from seismic and other external forces expected during the service life of a dam, review of dam materials, strict construction control planning and construction. The deterioration of dam concrete due to freezing and thawing is an issue common to concrete dams constructed in cold areas. Preventing freeze-thaw-induced deterioration of concrete is important to maintenance.

Studies have long been conducted concerning the durability of dam concrete and provided valuable knowledge. Studies have, however, been made under predetermined conditions in terms of specimen size, minimum temperature and freeze-thaw speed. Few studies have been conducted for actual structures under natural environment. The durability of dam concrete is determined not only by meteorological effects and concrete exposure conditions but also concrete aggregate size and various other factors. Evaluating the durability of dam concrete under actual environment in accelerated tests using small specimens is not easy. In view of the above, the Technical Committee on Research of Actual Frost Damage of Concrete of the Japan Commission on Large Dams (JCOLD) has been conducting long-term exposure tests since 1961 to "identify the relationship between the weathering resistance of dam concrete in cold areas and the results of durability tests using concrete specimens". Fully mixed large concrete blocks, which are 1m cubic, and small specimens prepared by wet screening fresh concrete, which have under 40-mm of coarse aggregates, were installed at six locations in Japan that are exposure under severe weathering conditions, for annual measurements of ultrasonic wave propagation time and other parameters.

This paper is an update of the paper submitted to 2001 ICOLD 20th Conference in Beijing concerning Question 78 [Kokubu, M et al. (2000)] and describes changes of large blocks with time.

2. TEST OUTLINE

At the start of the test, meteorological and immersed conditions of specimens were carefully considered. As a result, specimens were exposed at seven locations as shown in Table 1. The specifications for dams and consisted materials of concrete are listed in Table 1. Air entrained concrete with a water-cement ratio of 40 to 50 % was used for surface concrete of dams.

Table 1. Specification of dams and consisted materials

			Kurobe	Okuniikappu	Ohtori	Okutabami	Senbiri	Kawamata	Midono
Dam	Type		Arch	Arch	Arch	Retaining wall	Gravity & earth fill	Arch	Arch
	Height	m	186.0	61.2	83.0	—	11.7	117.0	95.5
	Volume × 1000	m3	1,570	24	156	—	65	168	304
	Elevation	m	1,454.0	728.0	557.0	-	80.0	980.0	855.5
	temperatur	Maximum	29.4	33.5	36.7		35.0	31.4	33.0
		Minimam	−18.6	−30.5	−20.0		−31.0	−20.9	−17.0
Concrete materials	Type of cement		MHC	MHC	MHC	OPC	SC	MHC	MHC
	Fly ash	Gravity	—	2.1	2.2	—	—	—	2.2
		Ig.Loss	—	1.2	0.5	—	—	—	1.1
	Admixture	Water−reducing adimixture	Pozz.8	Pozz.8	—	—	—	Pozz.8	—
		Air−antraining admixture	No.202	No.202	Vinsol	Vinsol	Vinsol	—	Vinsol
Specifications and mix proportions	Max size	mm	180.0	100.0	150.0	40.0	60.0	150.0	150.0
	Slump	cm	3.0	4.0	2.5	10.0	3.0	5.0	3.0
	Air content	%	3.0	4.5	4.0	3.5	3.0	4.0	3.0
	W/(C+F)	%	47.0	43.0	47.0	61.4	45.0	45.0	49.0
	F/(C+F)	%	0.0	0.0	30.0	0.0	0.0	0.0	25.0
	C+F	kg/m3	190.0	245.0	210.0	220.0	250.0	265.0	200.0
	W	kg/m3	89.0	105.0	99.0	135.0	112.0	120.0	100.0

Tables 2 and 3 show the number of concrete blocks installed at respective sites, and concrete mix proportions and exposure conditions, respectively. Concrete blocks were installed and measurement was commenced in 1961

Table 2. Blocks number and beginning period at each site

Dam Site	Organization	Number	Initial observation
Kurobe	Kansai Electric Power Co., Inc.	22	1962
Okuniikappu	Hokkaido electric Power Co., Inc.	8	1963
Ohtori	Electric Power Development Co., Ltd.	8 (1)1)	1963
Okutadami	Electric Power Development Co., Ltd.	(1)2)	1963
Senbiri	Hokkaido electric Power Co., Inc Electric Power Development Co., Ltd.3)	7	1961
Kawamata	Ministry of Land, Infrastrure, Transport and Tourism	6	1967
Midono	Tokyo Electric Power Company	24	1969

1) Measurement hole was made on the retaining wall of tailrace of the power plant.
2) Measurement hole was made on the upstream face of the dam.
3) The company took over the responsibility for measurement.

Table 3. Concrete recipe and exposure conditions at sites

Dam	Concrete Mix					Exporsure Conditions				
	Max size mm	W/(C+F) %	F/(C+F) %	C+F kg/m3	Air %	El m	Water depth m	Repeated freezing times	Snow fall manths	Submerging months
Kurobe	180	47	0	190	3.0	1430	18	7	4.5～7.5	2.0～8.0
					3.1	1430	In the air	10		−
Okuniikappu	100	43	0	245	5.3	720	3	61	3.5～5.5	2.5～5.5
					5.7	722.3	0.7	85		0.5～5.0
Senbiri	60	45	0	250	3.0	79.5	1.4	51	3.5～6.0	12
					3.5	80	0.9	91		12
					3.7	81.7	In the air	94		−
Okutadami	150	44	25	211	3.3	745	In the air	15	4.2～7.0	−
Ohtori	150	47	30	210	3.0	554.6	2.4	46		0～2.5
Kawamata	150	45	0	233	3.3	980	In the air	99	2.5～6.0	−
Midono	150	49～110	0～25	80～200	1.1～3.0	850	3.5	94	2.0～4.5	4.5

through 1964 at five sites and in 1969 in one site.

The objective of the test was to identify the relationship between the durability of dam concrete and the results of free-thaw lab-tests using small specimens. It was therefore preferable that the specimens to be exposed had similar mix proportions as the main body of the dams and were as large as possible. Concrete blocks in the form of a 1 m cubic were used to facilitate measurement of changes with time. Concrete blocks were placed under varying conditions. For example, some were placed in locations where immersed in water and air exposure alternately occurred ("in inundated state" below) while others in locations where they were constantly exposed in the air ("in the air" below).

The basic type of concrete mix proportion was same as dam concrete. At the site of Midono dam, the following two types of concrete mix proportions were also adoped.

i) Water-binder ratio was higher than used in the dam.

ii) No admixtures were used such as fly-ash and air-entraining (AE) agent.

In the Ohtori Dam, measurement holes were set up on upstream of the dam for measurement. Ultrasonic wave propagation time was measured by owner and operator of each dam approximately once a year in principle in concrete blocks. Based on the measurements, propagation speed and dynamic modulus of elasticity were calculated. The method for measuring ultrasonic wave propagation time is shown in Fig.1. Location of each dams is given in Fig.2. An example of the state of exposure is given in Fig.3.

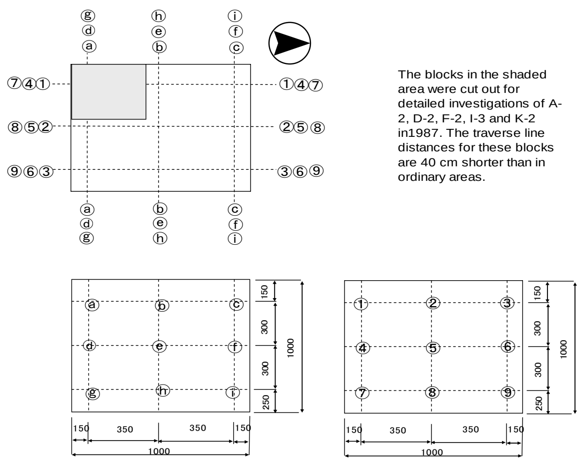


Figure 1. Measuring points of a block for ultrasonic

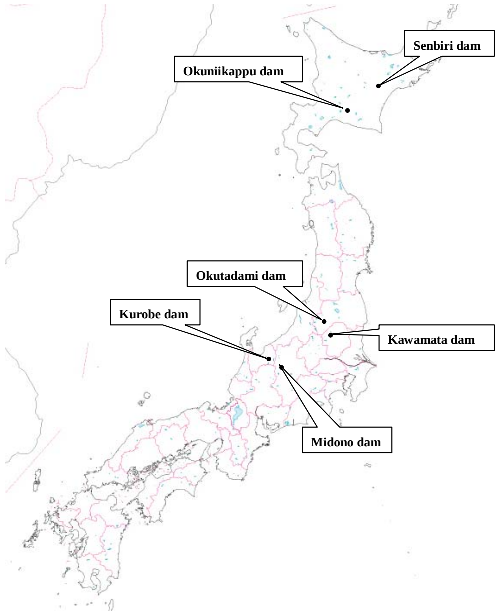


Figure 2. Dam sites

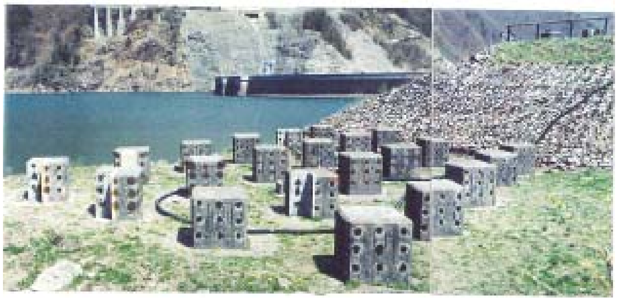


Figure 3. Site of exposure (at the site of Midono

3. OUTLINE OF MEASUREMENT RESULTS

3.1 Effects of Exposure Condition on Relative Dynamic Modulus of Elasticity

It is 41 to 49 years as of October 2010 since the beginning of the test. Table 4 lists the exposure conditions and estimated frequencies of freeze and thaw.

Table 4. Exposure conditions and freeze- thaw frequencies at each site

	Kurobe		Okuniikappu		Senbiri			Okutadami	Ohtori	kawamata	Midono
Immersion conditions	Inundate	In the air	Inundated		Inundated		In the air	In the air	Inundated	In the air	Inundated
Maximum water depth	18	0	3	0.7	1.4	0.9	0	0	2.4	0	3.5
Present age	48		47		49			47	47	43	41
Estimated freez-thaw frequency at present	337	480	2873	4000	2504	4750	4600	705	2208	4340	3785
Relative dynamic modulus of elasticity (mean value for specimens with the same mix proportions as the dam)	128	128	129	125	130	128	117	90	104	80	103

Fig. 4 shows the relationship between the estimated frequency of freezing and thawing and the relative dynamic modulus of elasticity for the concrete blocks with the same mix proportions as the dam. For the estimated frequency of freezing and thawing, the mean annual frequency of a case was obtained of the fall of the temperature at the nearby weather observation point below 0℃ followed by temperature rise above 0℃ and multiplied by the duration of exposure. In reality, there is a possibility that specimens are buried in snow during winter and subjected to temperature changes different from the changes of outside air temperature. The total frequency of freezing and thawing was, however, estimated here based on the changes of the nearby weather observation point air temperature because no data was available on the snow depth and temperature changes at the location of the specimen. In the case where the specimen was buried in snow, little temperature change was assumed on ground of the insulation effect. There is therefore a possibility that the freezing and thawing frequency was calculated higher than actual frequency.

The specimens shown in Table 4 and Figure 3 have a water-binder ratio of 45 to 47 % and an air content of 3.0 % or higher (Table 3). Figure 3 shows that in the case of immersion, the relative dynamic modulus of elasticity of specimens was kept at 100 % or higher regardless of the estimated freeze-thaw frequency. The specimens are undegrade at present. In the specimens exposed in the air, relative dynamic modulus of elasticity was dropped compared to the specimens immersed in water. The relative dynamic modulus is kept at 80 % or higher and the specimens are in a sound state.

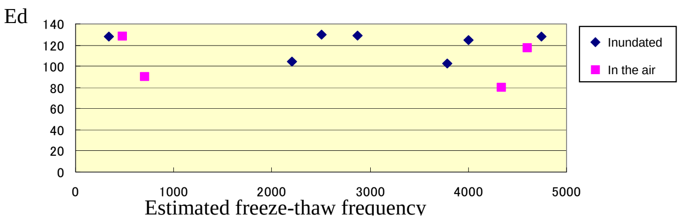


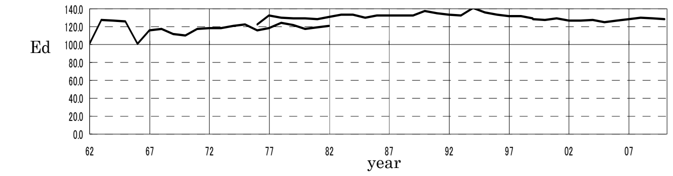
Figure 4. Observed relative dynamic elastic modulus v.s. estimated freeze-thaw frequencies

3.2 Changes in Relative Dynamic Modulus of Elasticity of The Block with The Same Mix Proportion as The Dam

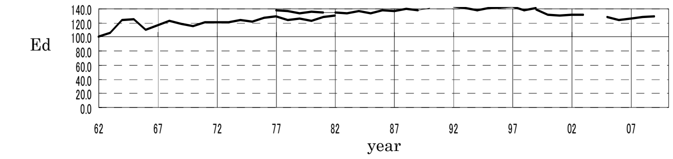
Fig.5 show changes in relative dynamic modulus of elasticity with time calculated based on the ultrasonic wave propagation time for concrete blocks with the same mix proportions as the dam at each site.

The age of one year was used as a basis for the relative dynamic modulus of elasticity, so the effect of subsequent strength development was found. Relative dynamic modulus of elasticity varied due to freeze-thaw actions.

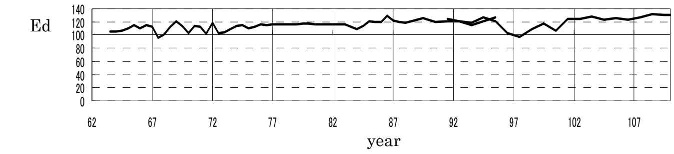
As described earlier, in all concrete blocks relative dynamic modulus of elasticity is kept at 80 % or higher and the specimens are undegrade. At the site of the Kawamata dam where concrete blocks are constantly in the air, unlike at the sites of Sembiri and Okutadami



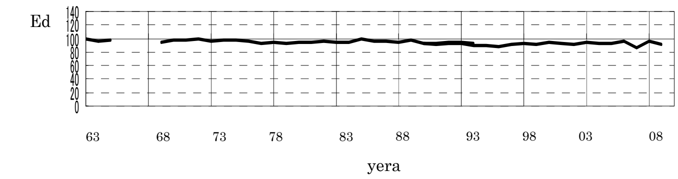
Kurobe (exposed in the air)



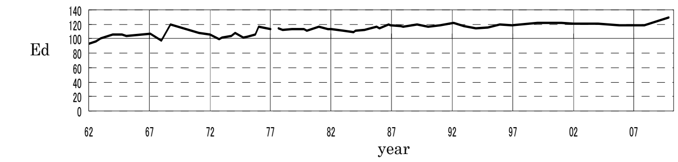
Kurobe (water depth of 18m in inundated state)



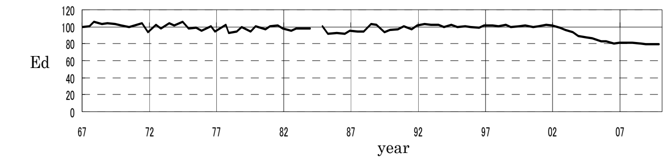
Senbiri (water depth of 0.7m in inundated state)



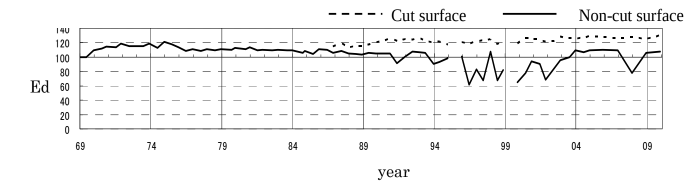
Okutadami (water depth of 3.0m in inundated state)



Okuniikappu (water depth of 3.0m in inundated state)



Kawamata (exposed in the air)

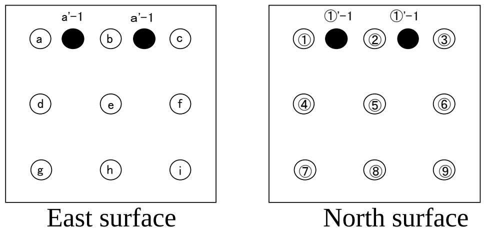


Midono (water depth of 3.5m in inundated state)

Figure 5. Observed relative dynamic elastic modulus v.s. exposure period

dams where blocks are under the same condition, relative dynamic modulus of elasticity has been falling remarkably in recent years. Reasons for the falling trend will be examined in the future.

At the Midono dam, relative dynamic modulus of elasticity fluctuated considerably during a certain period. In order to track down the cause, ultrasonic wave propagation time was measured at points other than regular measurement points shown in Fig.6. Then, concrete surface was chipped and propagation time was measured again. The results were shown in Fig.7.



ⓐ ①: Regular measurement points
● : New measurement points

Figure 6. New measurement points

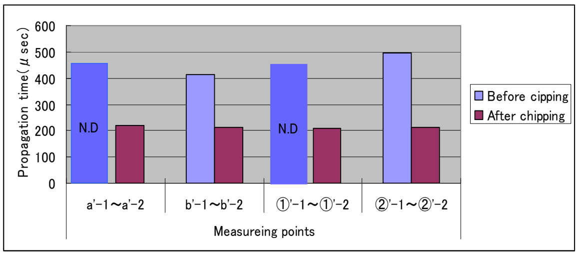


Figure 7. Measuring result

In Fig.7, the propagation time of the chipped surface is shorter than that of unchipped surface. Furthermore, although measurement of a' and ①' points could not be carried out under the condition that the surface is unchipped, it became possible by chipping.

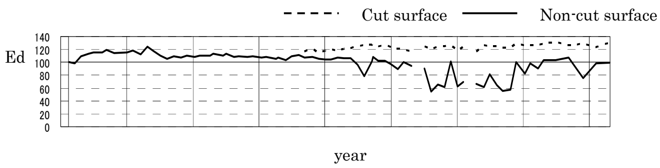
As the results, propagation time greatly improved after the concrete was chipped. It was determined that the surface of concrete block scaled substantially at the Midono dam and that the contact of the ultrasonic wave measurement equipment with concrete surface affected the measurements.

The phenomenon was also found during the measurement in the cut surface of the same block. Measurements were made in the case where one side of the block was cut and removed leaving the internal concrete exposed on one side. As a result, dynamic modulus of elasticity was greatly improved (Fig.5). Thus, the effects of scaling of concrete surface should be eliminated during ultrasonic wave measurement.

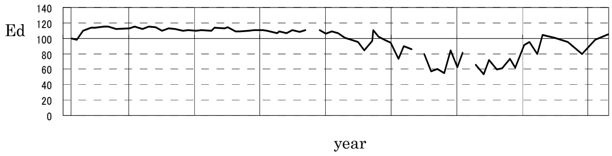
3.3 Effects of Water-Binder Ratio

Fig.8 shows changes in relative dynamic modulus of elasticity in blocks with varying water-binder ratios (W/(C+F)) at the site of Midono dam. The blocks are mixtures of AE agent and fly-ash (25 % of cement). Fig.5 shows that the measurements varied with time but that blocks with a mixture of AE agent and fly-ash had a relative dynamic modulus of elasticity of 80 % or higher even at a water-binder ratio of approximately 91 %.

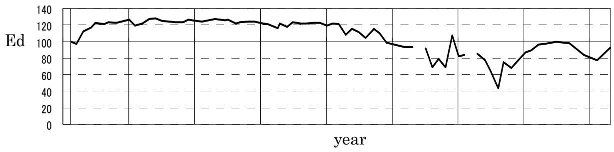
Relative dynamic modulus of elasticity fluctuated during the period of change with time probably because of surface deterioration as described earlier.



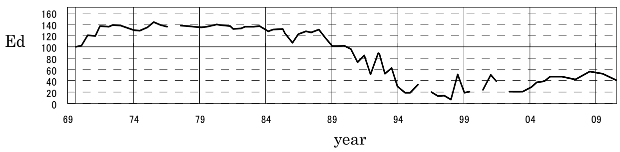
a) W/(C+F)=49% AE concrete



b) W/(C+F)=71% AE concrete



c) W/(C+F)=91 % AE concrete)



d) W/(C+F)=110 % AE concrete

Figure 8. Relative dynamic elastic modulus v.s. exposure period with varied water-binder ratio at Midono site

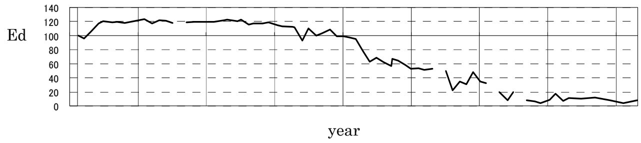
3.4 Effects of Air-Entraining Agent

Fig.9 shows changes in relative dynamic modulus of elasticity of blocks with and without AE agent with a nearly same water-binder ratio and with a fly-ash/cement ratio of 25 %.

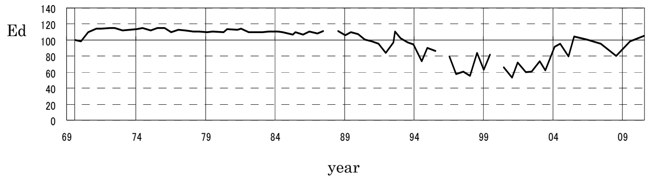
In the case with AE agent, modulus of elasticity is 100 % at present. In the case without AE agent, modulus of elasticity started falling in approximately 15 years of exposure. Deterioration has progressed so as to make measurement impossible. The improvement of freeze-thaw resistance owing to the mixing of AE agent has been reported in numerous existing works. Similar effects have been found in large blocks with the same mix proportions as the dam.

3.5 Effects of Fly-Ash

Fig.10 shows changes in relative dynamic modulus of



a) W/(C+F)=78 % nonAE concrete

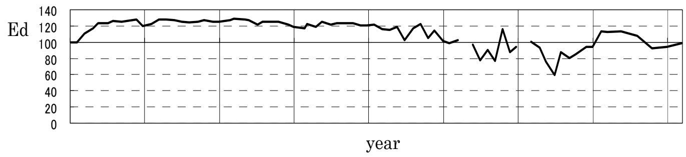


b) W/(C+F)=71 % AE concrete

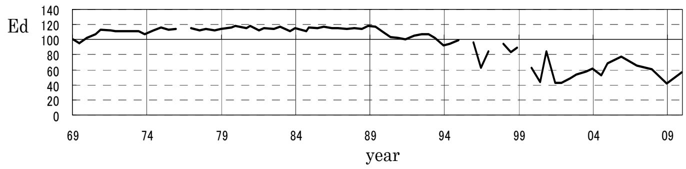
Figure 9. Relative dynamic elastic modulus v.s. exposure period with or without AE agent at Midono site

elasticity of blocks with and without fly-ash with a nearly same water-binder ratio. Both blocks were mixed with AE agent.

In the case with fly-ash, modulus of elasticity is 100 % at present. In the case without fly-ash, modulus of started falling in approximately 20 years of exposure and has fallen to approximately 60 % in recent years. No existing works provide cases of improvement of freeze-thaw resistance owing to the mixing of fly-ash for concrete blocks with the same mix proportions as the dam. The results of the measurement made in this study show that mixing fly-ash with dam concrete is effective not only for improving workability, developed long-term strength and controlling the heat of hydration as conventionally recognized but also for improving freeze-thaw resistance.



a) W/(C+F)=91 % AE concrete



b) W/C=71 % AE concrete

Figure 10. Relative dynamic elastic modulus v.s. exposure period with or without fly-ash at Midono site

4. CONCLUSIONS

In order to identify the relationship between the durability of dam concrete and the results of accelerated freezing and thawing tests, concrete block specimens, cubes with 1 m on side, with the same mix proportions as the dam and small specimens were placed under severe freezing and thawing conditions and changes with time were measured over a long period of 41 to 49 years.

This paper describes the results of measurement for large blocks. The following conclusions were reached.

1) The change with time varies according to the water-binder ratio of the exposed specimen. At a water-binder ratio of 45 to 49 %, similar to that of the dam, relative dynamic modulus of elasticity was kept at 80 % or higher after 41 to 49 years of exposure. Specimens thus remain in the sound state.
2) Air entraining by using AE agent is highly effective for improving the freeze-thaw resistance of dam concrete.
3) Replacing approximately 25 % of cement with fly-ash is effective for improving the freeze-thaw resistance of dam concrete.

The long-term exposure tests for nearly half a century have been handed down by numerous predecessors and provided valuable data for evaluating the freeze-thaw resistance of dam concrete. The results of the tests suggest the long-term soundness of dams. Tests will be continued to achieve the initial goal of identifying the relationship between the durability of dam concrete and the results of accelerated freezing and thawing tests through the comparison with the results of measurement of small specimens and of accelerated tests.

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