ROLLER COMPACTED CONCRETE DAM AND UTILIZATION OF FLY ASH IN JAPAN

Kimitaka UJI[1]

SUMMARY

RCC Dams have been constructed in order to reduce the construction period and construction cost due to the decrease of cementitious materials. Fly ash is important material for RCC Dam, and usually replaced from 20 to 30 % for cement. But, in other countries, replacement ratio more than 50 % is adopted. Also, it becomes difficult to use the fly ash with adequate qualities. In this paper, the properties of RCD in Japan is described compared with RCC Dam in other countries, and the standard specification of JIS for fly ash and the effect of fly ash out of standards on concrete properties is discussed.

Keywords: *Roller compacted concrete dam; RCD; fly ash; cementitious material; cement content; replacement ratio of fly ash; ignition loss; characteristics of fly ash concrete.*

INTRODUCTION

More than 250 RCC Dams have been constructed in 40 countries. And the dam volume becomes large steadily based on the actual results and the development of construction technique and mix proportions.

In Japan, a term of "RCD (Roller Compacted Dam)" is used for RCC (Roller Compacted Concrete) Dam. RCD have been expected almost same performance as the dam constructed by traditional method for permeability and so on. The purpose of use of RCC method is the reduction of construction period and the reduction of construction cost due to the decrease of cementitious materials. There are some differences between RCC method and RCD methods. For instance, the thickness of 1 lift is 300 mm for RCC Dam and 750-1,000 mm for RCD.

Fly ash is important material for RCC Dam, and usually replaced from 20 to 30 % for cement in Japan. But, replacement ratio more than 50 % is sometimes adopted in other countries. It becomes difficult to use the fly ash with adequate qualities. Therefore, it is necessary to clear the characteristics of concrete including fly ash out of standards.

14

[1] *Associate Professor, Civil & Environmental Engineering Course, Tokyo Metropolitan University, JAPAN 192-0397, e-mail: k.uji@ecomp.metro-u.ac.jp*

In this paper, the features of RCD in Japan are described, and the effects of the 4 fly ash classified to 4 types in Japan Industrial Standard (JIS) and the fly ash out of specification on concrete properties are discussed.

RCC Dam (RCD) in Japan

RCC Dam (in Japan, usually used "RCD") was firstly examined at Ohkawa Dam in 1976, and Shimajigawa Dam was actually constructed by RCD method in 1980, following Tamagawa Dam in 1987. At those times, the cement content was large compared with Dams of other countries.

Willow Creek Dam with 52m-hight was constructed in 1982 by RCC method in USA. Cement of 47 kg and fly ash of 19 kg, total cementitious materials: 66 kg, were used for 1 m^3. But, large leak of water occurred, so that cement grouting was adopted. Copperfield Dam with height of 40 m was constructed in Australia (1984). Binder of 110 kg (Cement: 80 kg, fly ash: 30 kg) was used for surface concrete, and a little leak was observed. On the other hand, Upper Stillwater Dam was constructed in 1987, using concrete with cement content of 252 kg/m^3.

Table 1 shows the volumes and heights of about 150 Dams constructed by RCC method from 1981 to 1999. Average volume of dam except the data of Japan is 200,000 m^3, average height is 46 m, and average volume of RCC is 150,000 m^3. Then, in USA having 23 Dams, those values are 140,000 m^3, 36 m, 130,000 m^3, respectively. From these data, it can be seen that RCC Dams in USA are comparatively small. Maximum RCC dam in USA is Upper Stillwater Dam, which has volume of 1,280,000 m^3, height of 91 m, and RCC volume of 1,130,000 m^3. And the volume of RCC Dams in Spain is similar to that in USA.

In Japan, average dam volume is 550,000 m^3, average height is 87 m, and average RCC volume is 350,000 m^3. The volume of RCD Dam is larger than the average volume of other countries. Maximum dam volume is 1,930,000 m^3 of Miyagase Dam (completion in 1997), and the height is 156 m of Urayama Dam (completion in 1999) and Miyagase Dam. Scale of RCC in China is similar to that of Japan.

Typical RCD Dams in Japan are mentioned in Table 2. Shimajigawa Dam of which height is 89 m has volume of 317,000 m^3 and RCC volume of 165,000 m^3. Tamagawa Dam has a height of 100 m, dam volume and RCC volume are 1,090,000 m3 and 750,000 m^3, respectively.

At the end of 2002 year, 251 RCC Dams were completed in 39 countries, the number of RCC Dams are China: 45, Japan: 42, USA: 36, Brazil: 29, Spain: 21. Average height in recent years is 80 m and dam volume is 600,000 m^3. Recently, RCC Dam becomes large compared with RCC Dam at the beginning. Also, Sankyo Dam has being constructed in China. This project started in 1993 and will be completed in 2009. The concrete volume will be 15,000,000 m^3.

The change of cementitious materials content for RCC Dam is shown in Fig. 1. At 1950', cementitious material content of 180 kg/m^3 was used for block construction method, i.e., traditional concrete gravity dam. Cementitious materials content decreases 100 kg/m^3 for 60 years due to the improvement of technique on quality control and construction machine. Consequently, in RCC Dam, total volume of cementitious materials became about 120 kg/m^3.

At the beginning of construction by RCC method, lean mixture was adopted, but at present, rich mixture becomes sometimes to be used. Table 3 shows the normal mix proportions. Rate of rich mixture RCC (binder: 150kg/m^3 <) is 47.4%, and the rate of fly ash to cement (F/C) is 0.53. Medium mixture (100-150 kg/m^3) and lean mixture (<100 kg/m^3) of RCC are 18.6% and 16.1 %, respectively. The rate of RCD is 15.4 % and F/C is 0.30. F/C of rich mixture RCC is high, and cement is 91 kg/m^3, fly ash is 103 kg/m^3. In RCD concrete, cement content is 86 kg/m^3, and fly ash is 37 kg/m^3. Both cement contents of rich mixture RCC and RCD concrete are similar each other.

The thickness of each lift for compaction of RCD concrete differs from that of RCC Dam. In Table 4 and Fig. 2, it is obvious that the 1 lift of RCC Dam is mainly 300 mm and that of RCD is from 750 to 1,000 mm. Mixed concrete are spread with bulldozer for 3 or 4 thin layers, then they are compacted about 10 times by vibratory roller. Shimajigawa Dam and others, which were constructed in 1980', have a thickness of 500 mm for 1 lift. The thickness of 1 lift becomes 750 mm in 1990' and recently 1,000 mm on the economical viewpoint.

Fig. 3 shows the relationship between the heights of RCD Dam and the rate of monthly average construction height. Rate of construction of RCD Dam, which is adopted in Japan, is slow in comparison with RCC Dam method. But, in cases of Dams having volume more than 190,000 m^3 in Fig. 4, the rate of construction by RCD method is similar to that of RCC method in USA or China.

The sloped layer method shown in Fig. 5 was developed, and employed on the construction of Tannur Dam and Lajeado Dam. This method was enabled to continuously place concrete by adjusting the slope degree in consideration of the capacity of placing machines and the concrete supply.

The purpose of use of RCC method is the reduction of construction period and the reduction of construction cost due to less cementitious materials content. Generally, it can be thought that RCD Dam actualizes the reduction of 9 % of construction cost and 13 % of construction period.

Fig. 6 shows the mix proportions and the position of segmentation for Kazunogawa Dam. For inner concrete, 3 mix proportions were adopted, and the replacement ratio of fly ash was 30 %. Mix proportions are shown in Table 5. The content of cement and fly ash for RCD were from 130 kg/m^3 to 110 kg/m^3. Maximum size of coarse aggregate was 120 mm. Consistency was examined by VC value (Vibrating Compaction Value) using the testing machine shown in Photo 1, and procedure was described below. The VC value was specified to 20 ± 10 sec.

Procedure of VC value;
i) Packing RCD screened by sieve of 40 mm into mold (diameter of 24 cm, height of 20 cm)
ii) Vibrating RCD concrete
iii) Measuring mortar rising time

Comparison of RCC Dam method and traditional method (for gravity dam) is shown in Table 6.

RCC construction process is shown as follows;

Spreading RCC by Bulldozer

Compacting by Vibrating Roller

Making Joint by Vibrating Cutter
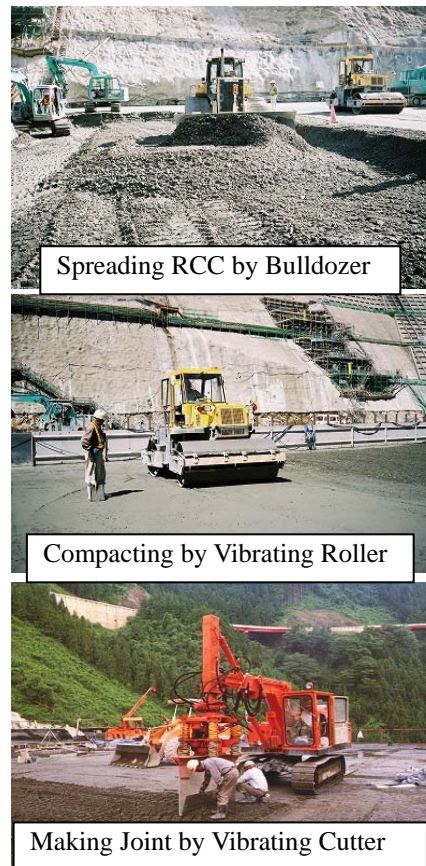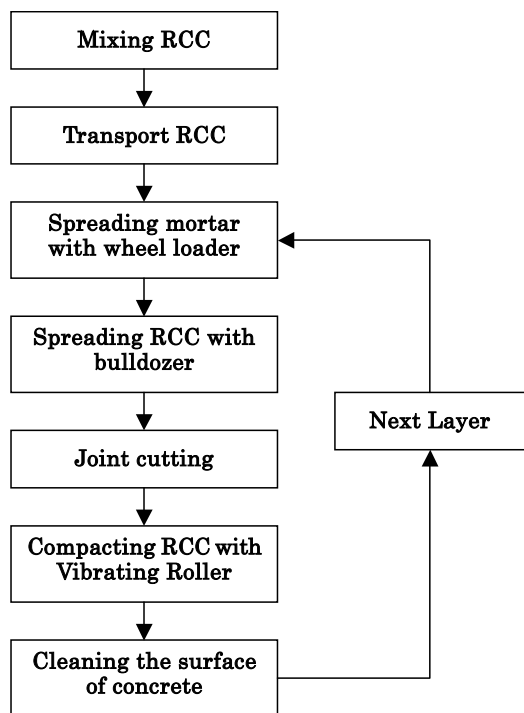
Chubetsu Dam is a combination of a concrete gravity dam and rockfill dam of 86.0 m and 78.5 m dam height respectively, as shown in Photo-2 and Figs. 7 and 8. The riverbed around the dam site is very wide at about 600 m, and unconsolidated river deposits are distributed there thickly. As a result of a comparative study on various types of dam and combinations, it was determined to adopt a concrete gravity dam for the foundation with bedrock in a 290 m portion of crest length on the left bank where the thickness of the gravel deposits was as shallow as 5-10 m. A rockfill dam with a center core was chosen for the foundation based on the low permeability of the fully consolidated lower river deposits in the 595 m of crest length on the right bank. Mix proportions for concrete gravity dam constructed by RCD method is shown in Table 7. Maximum size of coarse aggregate was 150 mm. The content of the cement and fly ash for RCD was 120 kg/m3, and replacement ratio of fly ash was 0.30. The VC value of 10±5 sec was specified.

Utilization of fly ash

Japan Industrial Standard for fly ash was revised in 1999, and 4 types of fly ash was classified in JIS A 6201-1999 for the utilization of coal ash. Table 8 shows the quality of 4 types of fly ash (F I, II, III, IV). Generally, F II is used for cementitious material. F I is used for high quality concrete because of high specific surface and low ignition loss. Quality of F III and F IV is low, but these are specified for environmental protection and effectively use of resource. 4 types of fly ash are classified due to maximum ignition loss and specific surface. Ignition loss of F II is specified to be less than 5%, and minimum specific surface is 2,500 g/cm^2. Maximum of ignition loss of F III is 8.0 %, and minimum specific surface of F IV is 1,500 g/m^2. Chemical ingredients of fly ash are shown in Table 9. Also, the ignition loss of fly ash

ranges from less than 1% to 17%.

As shown in Fig. 9, the generation capacity by coal-fired power in Japan is 13 %, and 30 million kw are generated by 37 power plants. As shown in Tables 10-12, production of fly ash in 2003 was 9.9 million tons, including 7.5 million tons from electric power industry and 2.4 million tons from general industry. And 6.1 million tons (81.7%) and 2.3 million tons (95.1%) were used, respectively. Fly ash is used for cement and concrete, civil engineering, building construction, agriculture/forestry and others. 6.33 million tons (76%) were used for cementitious materials.

Because of its spherical particles and pozzolanic effect, fly ash improved from coal ash has the following characteristics for use in concrete.
(a) Long-term strength increase
(b) Low dry shrinkage
(c) Control alkali aggregate reaction
(d) Low heat from hydration
(e) Water-tightness

The properties of concrete including F II type of fly ash are well known. But, there is little data for other types of fly ash. In this paper, the effect of ignition loss on the properties of concrete using fly ash. The values of ignition loss range to the extent of 17%. The relationship between pozzolanic activity index and ignition loss is shown in Fig. 10. Strength development of mortar containing the fly ash with high ignition loss does not differ from mortar using F II type fly ash. On the other hand, as shown in Fig. 11, flow value ratios decrease with increasing of ignition loss, therefore, workability of concrete with high ignition loss may lower. Fig. 12 shows the relationship between ignition loss and the required content of chemical admixture. Increase of ignition loss affects the quantity of chemical admixture for adequate workability.

Relationship between compressive strength and Young's modulus is shown in Fig. 13. Concrete has 9 kinds of fly ash with different ignition loss and replacement ratio from 0 to 45 %. Compressive strength has a proper relation with Young's modulus. Fig. 14 shows the relation between compressive strength and tensile strength under the conditions of 5 kinds of fly ash and replacement of ratio from 0 to 30 %. It can be thought that the ignition loss rarely affect the properties of hardened concrete.

CONCLUDING REMARKS

RCC Dam method was adopted from 1980, and the number of RCC Dams is increasing steadily. The reduction of construction cost can be achieved by RCC method, because of the shortening of construction period and the reduction of cementitious materials content. Cementitious materials content in RCC method decreases 100 kg/m3 compared with traditional method due to improvement of technique on quality control and construction machine. Also, the reduction of cement content is effective for prevention of thermal cracking. Thickness and velocity of lift for RCD differ from RCC Dam method. For instance, thickness

of lift is 750-1,000mm for RCD, and that of RCC Dam is 300mm. Rational and economical construction method must be further investigated.

Utilization of fly ash is very important for effective use of resource. Fly ash with high ignition loss rarely affects the properties of hardened concrete, but the increase of chemical admixture for the adequate workability of fresh concrete. More investigation is desirable for fly ash with low quality.

REFERENCES

Technical Committee of Japan Commission on Large Dams, "Report for shortening of construction period in RCD method," Large Dams, No.179, pp.5-37, 2002.4

Haga, T, "Construction Plan of Chubetsu Dam," Dam Nippon, No.648, pp.15-32, 1999

Japan Society of Civil Engineers, "Recommendation for the construction of concrete incorporating fly ash," 2003.

Center for Coal Utilization, "Investigation report on actual production of coal ash in Japan," 2005.3

Japan Fly Ash Association, "Technical report for Coal Ash (Fly-Ash, Clinker-Ash)," 2004.4

Table 1　Volume and height and RCC Dams (1981-1999)

National	Number of Data		Volume of Dam(m^3)	Volume of RCC(m^3)	Height of Dam (m)	Crest Length (m)
USA	23	Ave.	142,130	128,304	36	295
		Max.	1,281,000 (Upper Stillwater Dam,1987)	1,125,000 (Upper Stillwater Dam,1987)	91	815
		Min.	3,000	3,000	17	46
China	34	Ave.	468,088	303,353	71	345
		Max.	1,970,000 (Guanyinge Dam,1995)	1,240,000 (Guanyinge Dam,1990)	128	1,040
		Min.	23,000	17,000	25	93
Spain	21	Ave.	165,571	148,000	47	273
		Max.	1,016,000	980,000	99	835
		Min.	5,000	4,000	16	75
Average	116	Ave.	204,972	151,960	46	285
Japan	30	Ave.	552,490	345,000	87	304
		Max.	1,927,300 (Miyagase Dam,1997)	1,341,515 (Urayama Dam,1995)	156	445
		Min.	193,579	97,255	48	218

Table 2　Typical RCC Dam (RCD) in Japan

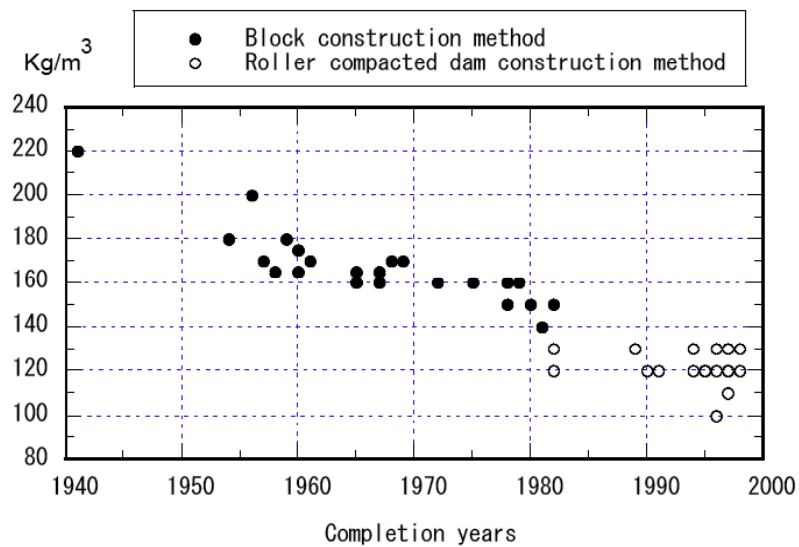| Dam	Volume of Dam (m^3)	Volume of RCC (m^3)	Height of Dam (m)	Completion Year
Shimajigawa	317,000	165,000	89	1981.3
Tamagawa	1,092,000	754,450	100	1990.12
Miyagase	1,927,300	1,303,844	156	1997.3
Urayama	1,709,387	1,341,515	156	199.3
Kazunogawa	622,000	315,000	105	2001.3
Chubetsu	777,000	336,000	86	2005

Fig. 1　Change of cementitious materials content

Table 3   Mix proportions for RCC Dam

Mix Proportion	Binder	Rate of use	C(kg)	F(kg)	W(kg)	F/(C+F)	W/B
Rich mixture RCC	150kg<	47.4%	91	103	107	0.53	0.55
Medium mixture RCC	100-150kg	18.6%	72	44	116	0.38	1.00
Lean mixture RCC	<100kg	16.1%	69	11	123	0.14	1.54
RCD		15.4%	86	37	94	0.30	0.76
Others		1.4%					

Table 4   Height of lift for RCC Dam

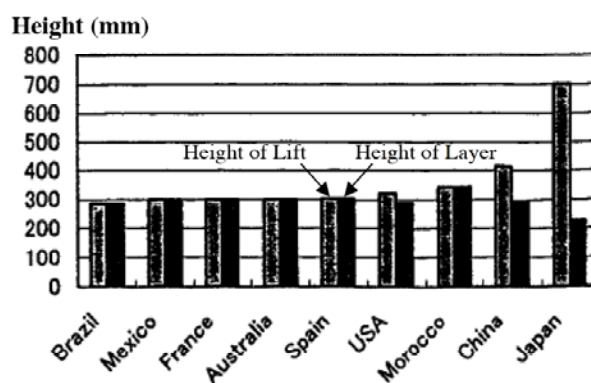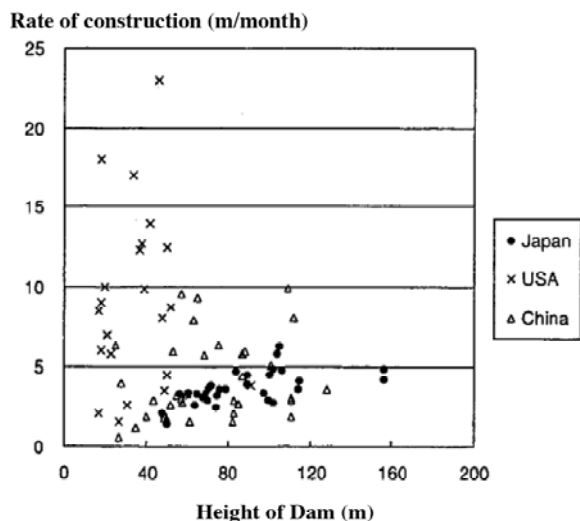| Mixer	Revolving-paddle	40.5%
	Tilting	20.7%
	Continuous	26.5%
Height of Lift	<250mm	5.3%
	300mm(Normal)	64.4%
	350-500mm	5.3%
	500-1000mm(RCD)	18.1%
	1000mm<	6.8%

Fig. 2   Height of lift and layer

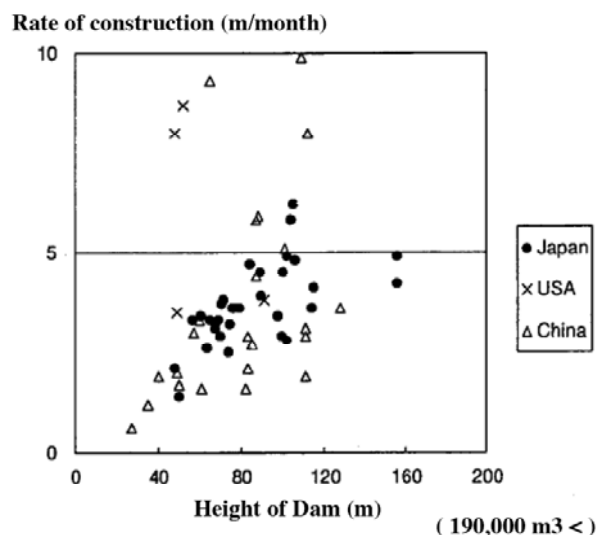Fig. 3   Relation between the rate of construction and height of dam

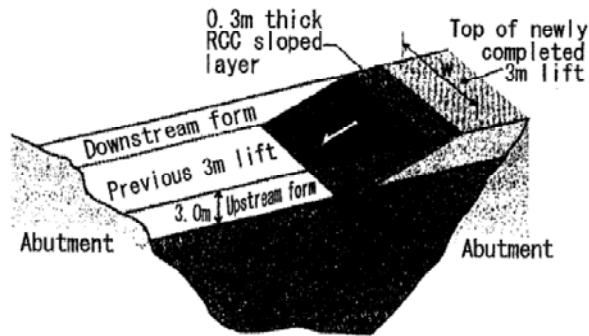Fig. 4   Relation between the rate of construction and height of dam (more than 190,000 m^3)
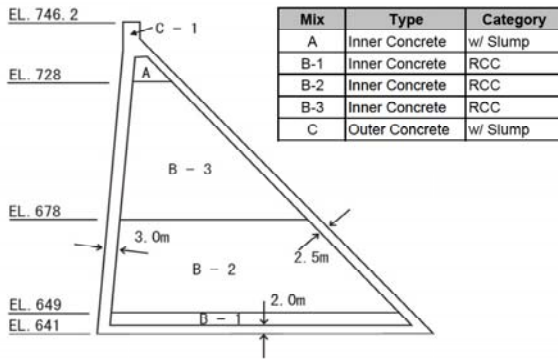
Fig. 5　Sloped layer method

Fig. 6　Segmention of Kazunogawa Dam

Mix	Type	Category
A	Inner Concrete	w/ Slump
B-1	Inner Concrete	RCC
B-2	Inner Concrete	RCC
B-3	Inner Concrete	RCC
C	Outer Concrete	w/ Slump

Table 5　Mix proportion for Kazunogawa Dam

Type of Concrete	Mix No.	Max Size of Coarse Aggregate (mm)	VC-Value (sec) Slump Value (cm)	Air (%)	W/(C+F) (%)	FA Replacement F/(C+F) (%)	Fine Percent s/a (%)
RCC	B-1				69.2		
	B-2	120	20±10	1.5±1	75.0	30	28
	B-3				82.7		
Slump	A	120	3±1	3±1	71.4	30	25
Concrete	C-1				49.0		22

	Unit Weight(kg/m^3)						
	W	C	F	C+F	S	G	Ad(%)
B-1	90	91	39	130	629	1648	0.325
B-2	90	84	36	120	632	1652	0.300
B-3	91	77	33	110	634	1660	0.275
A	100	98	42	140	546	1683	0.350
C-1	98	140	60	200	469	1707	0.500

Photo 1 VC value testing machine

Table 6　Comparison of traditional method and RCC method

Items	Traditional Method	RCC Method
Concrete Proportion	$C=160kg/m^3$ Slump=4cm	$C=120kg/m^3$ Slump=0cm VC value=20±10sec
Transport	Crane	Crane, Dump Truck
Placing	Block Placing Lift Height=1.5m Width=15m	Layer Placing Lift Height=0.75m The area is around $3,000m^2$
Spreading	Direct Flow Out	Bulldozer
Compacting	Stick Vibrator	Vibrating Roller
Placing interval	6 days	3 days

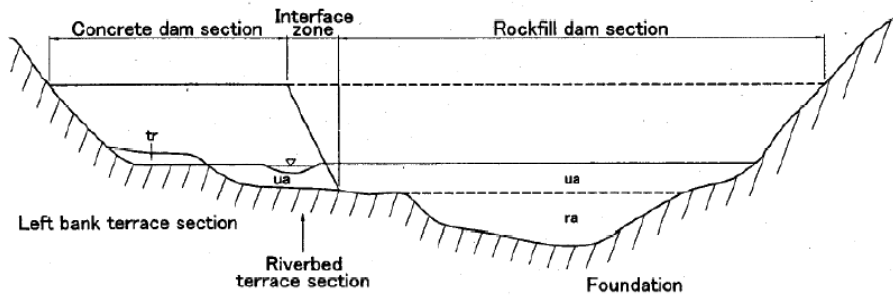
Photo 2　Chubetsu Dam

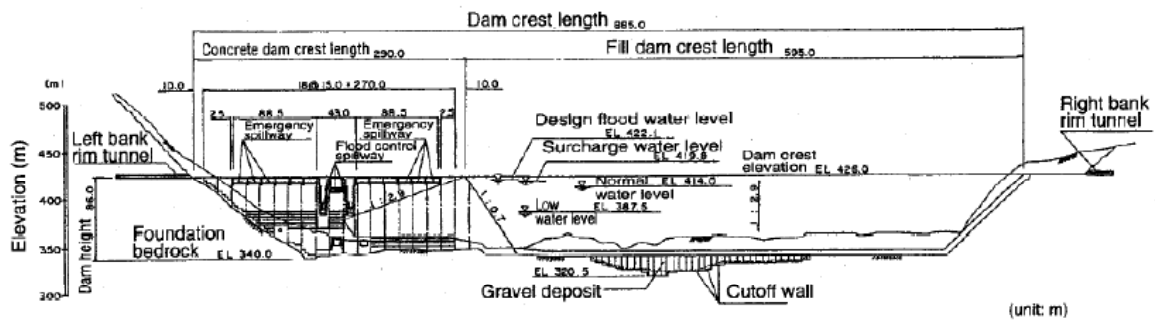Fig. 7   Conceptual arrangement of composite type dam

Fig. 8   Upstream face of the dam

Table 7   Mix proportions for Chubetsu dam

	Gmax	Slump VC	Air (%)	W/(C+F) (%)	s/a (%)	Unit weight(kg/m^3)				
						W	C+F	S	G	Ad
Outside	150	3±1 cm	3±1	43.2	24	95	220	499	1575	0.55
RCD	150	10±5sec	1.5±1	63.3	28	76	120	632	1625	0.30
RC	40	8±2.5 cm	5±1	50.7	43	142	280	793	1056	0.70

Table 8   Specifications for fly ash

Properties	FA I	FA II	FA III	FA IV
Min Silicon Dioxide(%)	45			
Max Moisture Content(%)	1.0			
Max Ignition Loss(%)	3.0	5.0	8.0	5.0
Min Density(g/cm^3)	1.95			
Fineness				
Passing 45 μ m(%)	10	40	40	70
Specific Surface(g/cm^2)	5,000	2,500	2,500	1,500
Flow Value Ratio	105	95	85	75
Pozzolanic Activity Index				
28days(%)	90	80	80	60
91days(%)	100	90	90	70

Table 9   Chemical ingredients of fly ash

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO
Fly Ash	40.1 - 74.4	15.7 - 35.2	1.4 - 17.5	0.2 - 7.4	0.3 - 10.1
Crinker Ash	51.6 - 64.0	17.3 - 26.9	4.2 - 10.9	1.0 - 2.6	2.3 - 8.8
Cement	22.2	5.1	3.2	1.2	65.3
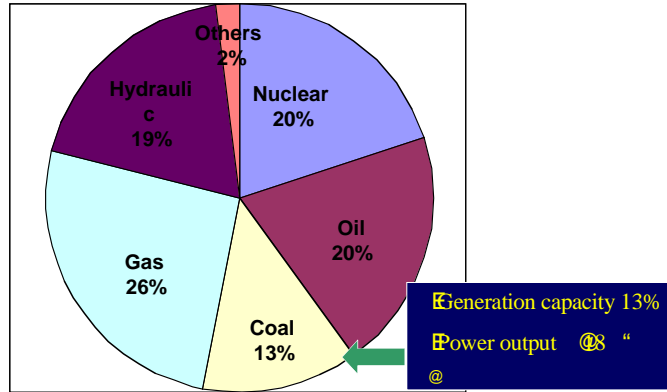
Fig. 9   Generation capacity by coal-fired power

Table 10   Production of fly ash

Year		Production		
		Total	Used	Landfilled
2003	Electric power industry	7.5 million tons (75.8%)	6.1 million tons (81.7%)	1.4 million tons (18.3%)
	General industry	2.4 million tons (24.2%)	2.3 million tons (95.1%)	0.1 million tons (4.9%)
	Total	9.9 million tons (100%)	8.4 million tons (84.9%)	1.5 million tons (15.1%)

Table 11   Utilization of fly ash   (unit: million tons)

Year	Situation of Utilization	Electric power industry		General industry		Total	
		Quantity	%	Quantity	%	Quantity	%
2003	Cement&concrete	4.60	75	1.73	76	6.33	76*
	Civil engineering	0.58	10	0.24	11	0.82	10
	Building construction	0.23	4	0.17	7	0.40	5
	Agriculture/forestry&fisheries	0.06	1	0.11	5	0.17	2
	Others	0.63	10	0.03	2	0.66	8
	Total	6.11	100	2.28	100	8.38	100

*Cement material 70%, Cement additive 4%, Concrete admixture 2%

Table 12   Applications of fly ash

Category	Applications	Used in 2003 (million tons)
Cement&concrete	Cement materials, materials to be blended with cement, concrete admixtures, etc.	6.33
Civil engineering	Groud-improving materials, road base course materials, asphalt filler materials, concrete products for civil engineering applications, coal mine restoration, etc.	0.82
Building construction	Building boards, artificial lightweight aggregate, concrete products for building applications, etc.	0.40
Agriculture/forestry&fisheries	Fertilizer, soil conditioners, deicing agents, etc.	0.17
Others	Wastewater treatment chemicals, iron manufacture, etc.	0.66
	Total	8.38
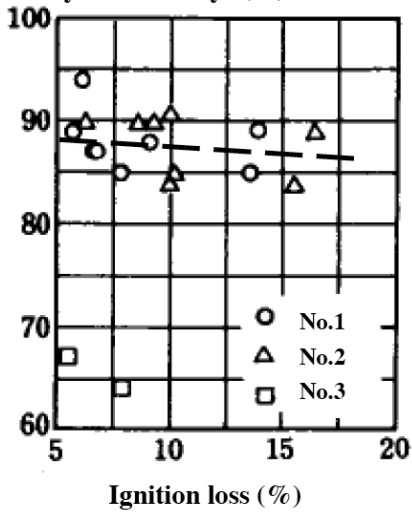
Fig. 10 Relationship between activity index and ignition loss
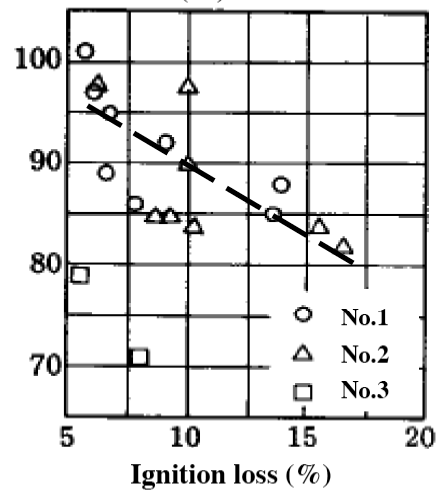
Fig. 11   Relationship between flow value ratio and ignition loss

Fig. 12   Relationship between rate of addition of admixture and ignition loss

Young's Modulus ($*10^4$ N/mm^2)
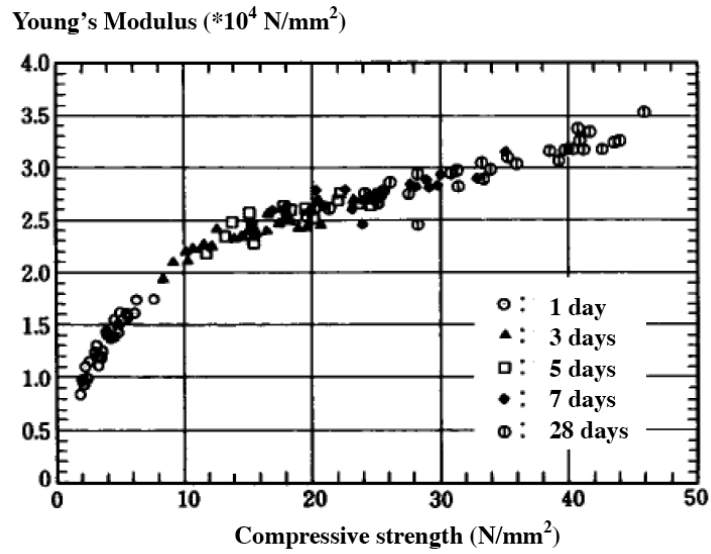

Fig. 13　Relationship between compressive strength
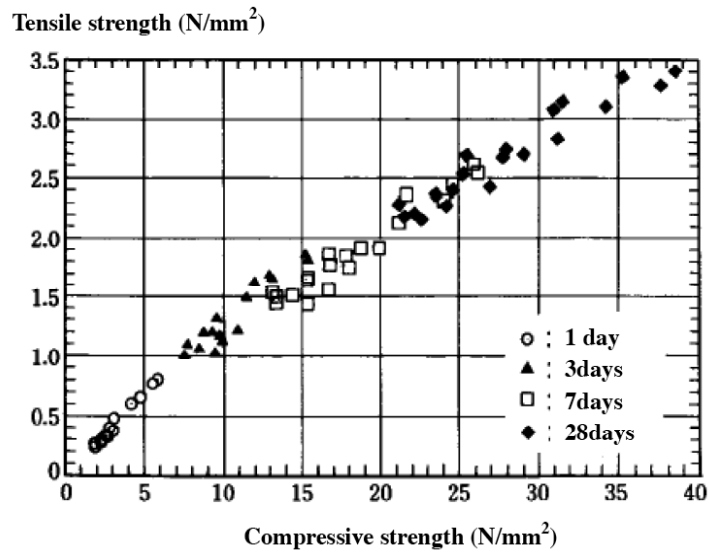and Young's modulus

Tensile strength (N/mm^2)

Fig. 14　Relationship between compressive
strength and tensile strength