A brief report of the bituminous concrete impervious facing of upper reservoir of the Zhanghewan Pumped Storage Power Station Project in Hebei Province, P.R. China

Y. Miura
TAISEI CORPORATION, Shinjuku-ku, Tokyo, Japan

M. Saruwatari
TAISEI ROTEC CORPORATION, Chuo-ku, Tokyo, Japan

ABSTRACT: Zhanghewan Pumped Storage Power Station is located on the main stream of Gantao River in Jingxing County, Shijiazhuang, Hebei Province. The installed capacity of the station is 1,000MW with 4 reversible pump-turbine units. Each unit has a capacity of 250MW. The project is composed of upper reservoir, waterway system, underground powerhouse, outgoing yard and lower reservoir. The upper reservoir is located at the top of Mt. Laoyemiao on the left bank of Gantao River. The work scope consists of rockfill dam, bituminous concrete lining, water drainage system, and reservoir bank foundation treatment. The dam level of upper reservoir is approx. at El. 812m a.s.l. with a reservoir perimeter of about 2843m, an upstream dam slope of 1:1.75, a downstream dam slope of 1:1.5 and a maximum dam height of 57m. The normal storage level is at El. 810m a.s.l. and the dead water level is at El. 779m a.s.l. The total storage capacity is 7,700,000m^3, the regulating storage 7,150,000m^3 and the dead storage 550,000m^3. The upper reservoir adopts the technology of full anti-seepage with 4 layers bituminous concrete lining impervious reservoir basin. The total impervious area is about 337,000m^2 with an area of 200,000m^2 for the reservoir slopes and an area of 137,000m^2 for the reservoir bottom. Taisei-CGGC JV was awarded the contract for the project in May, 2005 and completed it in July, 2007. This report describes the bituminous concrete impervious facing for the upper reservoir of the Zhanghewan Pumped Storage Power Station Project.

KEY WORDS: China, pumped storage power station, upper reservoir, bituminous concrete, impervious facing.

1 INTRODUCTION

1.1 Location

Zhanghewan Pumped Storage Power Station is located on the main stream of Gantao River within the territory of Jingxing County, Shijiazhuang, Hebei Province. It is situated at a distance of about 77km to the city of Shijiazhuang and about 45km to the Jingxing County. The installed capacity of the station is 1,000MW with 4 reversible pump-turbine units. Each unit has a capacity of 250MW. The project is composed of upper reservoir, waterway system, underground powerhouse, outgoing yard and lower reservoir.

1.2 Upper Reservoir

The upper reservoir is located at the top of Mt. Laoyemiao on the left bank of Gantao River. The work scope consists of rockfill dam, bituminous concrete lining, water drainage system, and reservoir bank foundation treatment.

The principal engineering features of upper reservoir are shown in Table-1.

Table 1: The principal engineering features of upper reservoir

Item	Unit	Quantity	Item	Unit	Quantity
Normal Storage Level	m a.s.l	810	Crest perimeter Length	m	2843
Dead Water Level	m a.s.l	779	Maximum Dam Height (at the dam axis)	m	57
Total Storage	m^3	7,700,000			
Regulation Storage	m^3	7,150,000	Upstream Dam Slope		1:1.75
Dead Storage	m^3	550,000	Downstream Dam Slope		1:1.5
Operating Depth	m	31	Impervious Area of Reservoir Slope	m^2	200,000
Crest EL.	m a.s.l	812	Impervious Area of Reservoir Bottom	m^2	137,000
Crest Width	m	7.25/8/9.25			

The annual extreme high and low temperature is 41.0°C and -24.0°C, and the annual mean ground temperature is 9.4°C.

Ichnography of the upper reservoir of Zhanghewan Pumped Storage Power Station is shown in Figure-1.

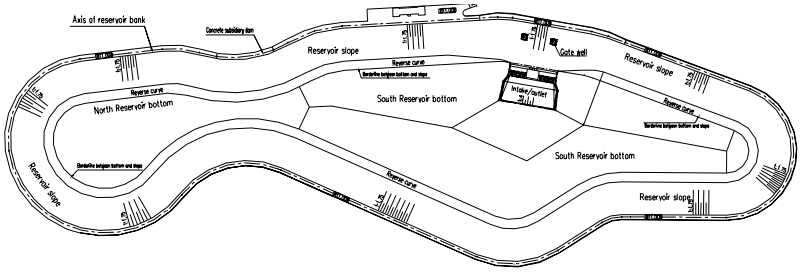


Figure1: Ichnography of the upper reservoir of Zhanghewan Pumped Storage Power Station

The full view of the upper reservoir is shown in Photograph 1.

Photograph 1: The full view from north of the upper reservoir

2 MAIN PROFILES OF BITUMEN CONCRETE LINING

The main profiles of bitumen concrete lining are shown in Table 2.

Table 2: The main profiles of bitumen concrete lining

Area	Structure Layer	Design Thickness (mm)		Type of Bitumen	Type of Bituminous Concrete
		Bottom	Slope		
Normal Areas	Seal Coat	2		Improved	Mastic
	Impervious	100		Straight-run	Dense-graded
	Drainage	100	80	Straight-run	Open-graded
	Leveling and Binder	80		Straight-run	Dense-graded
Additional Areas	Seal Coat	2		Improved	Mastic
	Impervious	100		Straight-run	Dense-graded
	Reinforced Mesh	—		—	—
	Additional Impervious	50		Straight-run	Dense-graded
	Drainage	100	80	Straight-run	Open-graded
	Leveling and Binder	80		Straight-run	Dense-graded
Boundary between the Excavation and Fill and the Arc Area at Dam Crest	Seal Coat	2		Improved	Mastic
	Impervious	100		Straight-run	Dense-graded
	Reinforced Mesh	—		—	—
	Drainage	100	80	Straight-run	Dense-graded
	Leveling and Binder	80		Straight-run	Dense-graded
Insulating Strip Area	Seal Coat	2		Improved	Mastic
	Impervious	100		Straight-run	Dense-graded
	Insulating Strip	100	80	Straight-run	Dense-graded
	Leveling and Binder	80		Straight-run	Dense-graded

3 MAIN RAW MATERIAL SOURCES

The main raw material sources used on this project are shown in Table 3.

Table 3: The main raw material sources

Material name	Name of Manufacture and Place	Remarks
Straight-run Bitumen	Petrochina Kelamayi Petrochemical Company	
	Petrochina Liaohe Petrochemical Company	
Improved Bitumen	Nichireki Co,Ltd.	
Semi-Finished Aggregate(20～40 mm)	Sinohydro Co,Ltd of Zhanghewan P/J Upper reservoir crushing plant	By Employer
Natural Sand	Hebeiruiji Co,Ltd.	
Filler	Shijiazhuangdongshenggaodengjilumianshiliao Co,Ltd.	

4 CHARACTERISTICS OF EMPLOYED MATERIAL

4.1 Straight-Run Bitumen

The bitumen utilized in this project is Kelamayi straight-run bitumen and Panjin shuangxiling brand hydraulic straight-run bitumen. The Kelamayi bitumen is mainly utilized for impervious layer (including additional impervious layer and insulating strip of drainage layer), and the Panjin bitumen is mainly utilized for drainage layer and leveling and binder layer.

Properties of employed straight-run bitumen are shown in Table 4.

Table 4: Properties of employed straight-run bitumen

Test Items			Test Result		Technical index	Test Standard	Remarks
			Kelamayi	Panjin			
Features before heating (TFOT)	Penetration (25℃,1/10 mm)		78	81	70～90	*JTJ T 0604-2000	100g, 5s
	Softening point (℃)		51	46.1	45～52	JTJ T 0606-2000	
	Brittle point (℃)		-10	-13	≦ -10	JTJ T 0613-1993	
	Ductility (cm)	15℃(5cm/min)	＞150	＞150	≧ 150	JTJ T 0605-1993	
		4℃(1cm/min)	28	＞80	≧ 15		
	Paraffins contents (%)		1.75	1.9	≦ 2.0	JTJ T 0615-2000	
	Density (25℃,g/cm^3)		0.9803	1.0103	Actual survey	JTJ T 0603-1993	
	Solubility (%)		99.7	99.9	≧ 99	JTJ T 0607-1993	
	Ash content (%)		0.19	＜0.2	≦ 0.5	JTJ T 0614-1993	
	Flash point (℃)		297	289	＞ 230	JTJ T 0611-1993	
Features after heating (TFOT)	Quantity loss (%)		0.14	0.1	≦ 1.0	JTJ T 0610-1993	Rolling Thin Film Oven Test, 163℃, 5h
	Softening point rise (℃)		3.1	4.1	≦ 5	JTJ T 0606-2000	
	Penetration rate (%)		78	68.4	≧ 65	JTJ T 0604-2000	
	Brittle point (℃)		-8	-10	≦ -8	JTJ T 0613-1993	
	Ductility (cm)	15℃(5cm/min)	＞150	＞150	≧ 100	JTJ T 0605-1993	
		4℃(1cm/min)	10	9	≧ 8		

Remark: *JTJ = Technical Standard of Highway Engineering, Ministry of Communications, China

4.2 Improved Bitumen

Improved bitumen is material designed by us and utilized for seal coat only.

Properties of employed improved bitumen are shown in Table 5.

Table 5: Properties of employed improved bitumen

Test Items			Test Result	Technical index	Test Standard	Remarks
Features before heating (TFOT)	Penetration(25℃,1/10 mm)		80	—	JTJ T 0604-2000	100g, 5s
	Softening point (℃)		75.7	—	JTJ T 0606-2000	
	Brittle point (℃)		-21.1	≦ -8	JTJ T 0613-1993	
	Ductility (cm)	15℃(5cm/min)	119.6	≧ 50	JTJ T 0605-1993	
		4℃(1cm/min)	69.4	≧ 5		
	Paraffins contents (%)		1.959	≦ 2.0	JTJ T 0615-2000	
	Density (25℃,g/cm^3)		1.007	Actual survey	JTJ T 0603-1993	
	Solubility (%)		99.31	≧ 99	JTJ T 0607-1993	
	Ash content (%)		0.22	≦ 0.5	JTJ T 0614-1993	
	Flash point (℃)		262	＞ 230	JTJ T 0611-1993	
Features after heating (TFOT)	Quantity loss (%)		-0.24	≦ 0.6	JTJ T 0610-1993	Rolling Thin Film Oven Test, 163℃, 5h
	Softening point rise (℃)		-10.6	≦ 5	JTJ T 0606-2000	
	Penetration rate (%)		78.8	≧ 65	JTJ T 0604-2000	
	Brittle point (℃)		-20.1	≦ -6	JTJ T 0613-1993	
	Ductility (cm)	15℃(5cm/min)	57	≧ 10	JTJ T 0605-1993	
		4℃(1cm/min)	41.7	-		

4.3 Aggregate

The Employer provided artificial semi-finished aggregate of oolitic limestone with size from 20mm to 40mm. From the semi-finished aggregate, four kinds of grading range aggregates needed in the project, namely 0~2.36mm, 2.36~4.75mm, 4.75~13.2mm and 13.2~19.0mm, have been processed.

The grading ranges of finished coarse aggregate are 2.36~4.75mm, 4.75~13.2mm and 13.2~19.0mm. The aggregate of 13.2~19.0mm were utilized for the drainage layer only.

Properties of employed coarse aggregate are shown in Table 6.

Table 6: Properties of employed coarse aggregate

Test Items	Sieve Size	Test Result			Technical Index	Test Standard	Remarks
		19~13.2	13.2~4.75	4.75~2.36			
Gradation [percent of passing](%)	26.5mm	100.0	100.0	100.0	Oversize≦10% Undersize≦10%		
	19mm	97.3	100.0	100.0			
	16mm	58.2	100.0	100.0			
	13.2mm	2.0	98.5	100.0			
	9.5mm	0.1	60.7	100.0			
	4.75mm	—	2.0	98.6			
	2.36mm	—	0.2	3.3			
	1.18mm	—	—	1.1			
Bulk specific gravity (g/cm^3)		2.699	2.700	2.665			
Water absorption (%)		0.30	0.28	0.85	≦2.0	JTJ T 0308-2000	
Sediment percentage (%)		0.04	0.10	0.10	≦0.5	JTJ T 0310-2000	
Bitumen adhesiveness		Pass	—	—	≧grade 4	JTJ T 0616-1993	Bitumen-binding percent ≧90%
Los Angeles test (%)	500revs.	17.4	—	—	≦40	JTJ T 0317-2000	
	100revs.	5.9	—	—	≦8		
Soundness [weight loss] (%)		0.9	6.9	0.96	≦10	JTJ T 0314-2000	Sodium sulphate method, five times of wetting and drying cycle
Heat resistance		—	Pass	—	No characteristics change in heating		
Flat and elongated particles content (%)		9.3	14.6	—	≦20	JTJ T 0312-2000	Ratio of max. and min. dimension in a particle ≧3:1

The finished fine aggregate is consisted from artificial crushed sand, which is processed by our aggregate plant, and natural sand with a proportion of about 1:1. The grading range is 0.075~2.36mm.

Properties of employed fine aggregate are shown in Table 7.

Table 7: Properties of employed fine aggregate

Test Items	Sieve Size	Test Result		Technical Index	Test Standard	Remarks
		Crushed Sand	Natural Sand			
Gradation [percent of passing](%)	4.75mm	100.0	100.0			
	2.36mm	98.4	96.0	≧95		
	1.18mm	78.1	82.8			
	0.6mm	58.3	46.2			
	0.3mm	25.7	11.2			
	0.15mm	13.7	2.8			
	0.075mm	9.1	0.7	≦5		
Apparent density (g/cm^3)		2.711	2.669			
Water absorption (%)		1.03	1.00	≦2.0	JTJ T 0330-2000	
Sediment percentage (%)		—	0.9	≦1.0	JTJ T 0333-2000	
Soundness [weight loss] (%)		2.3	1.6	≦10	JTJ T 0340-1994	Sodium sulphate method, five times of wetting and drying cycle
Heat resistance		Pass	Pass	No characteristics chang in heating		
Organic matter content (natural sand)		—	Pass	Lighter than the standard color	JTJ T 0336-1994	
Sand equivalent (%)		—	93	≧90	JTJ T 0334-1994	For natural sand

4.4 Filler

The main composition of filler is limestone.

Properties of employed filler are shown in Table 8.

Table 8: Properties of employed filler

Test Items	Sieve Size	Test Result	Technical Index	Test Standard	Remarks
Gradation [percent of passing](%)	0.6mm	100	100	JTJ T 0351-2000	Water method, all grain size of filler
	0.3mm	100			
	0.15mm	98.9	＞95		
	0.075mm	88.5	≧80		
	0.075mm	100	100	ISO 13320-1:2000	Laser diffraction methods grain size under 0.075mm
	0.050mm	90.8	＞ 80		
	0.030mm	77.7	＞ 60		
	0.020 mm	62.7	＞ 20		
Water content (%)		0.4	≦0.5		
Apparent density (g/cm^3)		2.701	≧2.60	JTJ T 0352-2000	Specific weight
Hydrophilic coefficient (cm^2/g)		0.734	≦1	JTJ T 0353-2000	
Iithofacies identification		Pass CaO content = 53%	Limestone, no impurities like organic matter and mud, no accretions and congregated grains		CaO%＞50%
Fineness [specific surface] (%)		4280	≧3500	ASTM C 204-2000	Grain size under 0.075mm

5 CHARACTERISTICS OF BITUMINOUS MIXTURE

5.1 Leveling and Binder Layer

As a foundation for the upper layer of the bituminous concrete structure, the leveling and binder layer provide a solid and leveling working face. It also acts as a bituminous concrete layer that is well water-resistant with a sufficient density.

Properties of leveling and binder layer are shown in Table 9.

Table 9: Properties of leveling and binder layer

Test Items	Sieve Size	Test Result	Technical index	Test Standard	Remarks
Gradation [percent of passing] (%)		(Combined)	(Target)		
	16mm	100	100		
	13.2mm	99.5	97		
	9.5mm	88	85		
	4.75mm	69.9	70		
	2.36mm	53.8	54		
	1.18mm	45.8	43		
	0.6mm	32.8	29		
	0.3mm	17.4	20		
	0.15mm	12.6	14		
	0.075mm	10.2	10		
Bitumen Cotent (%)		5			
Apparent Density (g/cm^3)		2.397	＞2.20	JTJ T 0705-2000	Saturated Surface Dry Method
Voids Content (%)		3.5	≦5.0		
Slope Floe Value (mm)		0	≦1.5	Van Asbeck	Marshall Sample, 1:1.75,70℃, 48h
Permeability Coefficient (cm/s)		7.59×10^{-8}	$\leqq5\times10^{-5}$	Van Asbeck	Pressurization type, 0.49Mpa, 2h
Immersion Stability (%)		97.7	≧85	ASTM D 1075-2000	Samples with about 6% of Voids Content

5.2 Drainage Layer

The drainage layer with higher voids content after the roller compaction is able to collect the seepage water from the impervious layer and drain the seepage water immediately to the drain gallery.

Properties of drainage layer are shown in Table10.

Table 10: Properties of drainage layer

Test Items	Sieve Size	Test Result	Technical index	Test Standard	Remarks
Gradation [percent of passing] (%)		(Combined)	(Target)		
	26.5mm	100			
	19mm	98.6	100		
	16mm	78.5	75		
	13.2mm	49	49		
	9.5mm	34.2	33		
	4.75mm	12.7	16		
	2.36mm	11.8	12		
	1.18mm	10.2	10		
	0.6mm	7.7	8		
	0.3mm	4.7	6		
	0.15mm	3.7	4		
	0.075mm	3.1	3		
Bitumen Cotent (%)		3.5			
Apparent Density (g/cm^3)		1.972	＞1.90	JTJ T 0708-2000	Volume Method
Voids Content (%)		22.7	≧16.0		
Permeability Coefficient (cm/s)		2.81×10^{-1}	$\geqq1\times10^{-1}$	Van Asbeck	Constant Head
Heat stability factor		3.69	≦4.5	JTJ T 0713-2000	

5.3 Impervious Layer

The impervious layer must fulfill non-permeability, as well as providing slope stability and flexibility for the water pressure and thermal stress. The impervious layer require high density (voids content <3%) after the roller compaction.

Properties of impervious layer are shown in Table 11.

Table 11: Properties of impervious layer

Test Items	Sieve Size	Test Result	Technical index	Test Standard	Remarks
Gradation [percent of passing] (%)		(Combined)	(Target)		After Aggregate combined, fiber is added. Take bitumen mixture as 100% and add 0.2% vegetable fiber into it.
	16mm	100			
	13.2mm	99.5	100		
	9.5mm	87.4	92.38		
	4.75mm	68.5	68.72		
	2.36mm	58	58.19		
	1.18mm	49.7	46.34		
	0.6mm	36.1	26.4		
	0.3mm	19.9	18.8		
	0.15mm	14.8	15.15		
	0.075mm	12.1	11.94		
Bitumen Cotent (%)		7.7			
Apparent Density (g/cm^3)		2.333	＞2.30	JTJ T 0705-2000	Saturated Surface Dry Method
Voids Content (%)		1.7	≦3.0		
Slope Flow Value (mm)		1.11	≦2.0	Van Asbeck	Marshall Sample, 1:1.75,70℃, 48h
Permeability Coefficient (cm/s)		$\leqq1\times10^{-8}$	$\leqq1\times10^{-8}$	Van Asbeck	Pressurization type 0.49Mpa, 2h
Susceptibility to moisture (%)		98.1	≧90	ASTM D 1075-2000	Samples with about 3% of voids content
Flexibility (%) [deflection of Van Asbeck's disk test]		≧12	No cracks for a strain of 10 %	Van Asbeck	25℃
		≧5	No cracks for a strain of 2.5 %		2℃
Freezing break temperature (℃)		-38.76	≦－35		
Direct tension strain (%)		1.416	≧0.8		2℃, tension speed 0.34 mm/min
Bending strain (%)		3.7558	≧2.0	JTJ T 0715-2000	2℃, test speed 0.5mm/min
Expansion (%) [Unit volume]		0.379	≦1.0	DIN 1996-9:1981	

5.4 Seal Coat

Seal coat is a thin layer of bituminous mastic (mixture of bitumen and filler) painted or sprayed on the surface of the impervious layer that can fill in the surface pores. It is used for isolating ultraviolet in the sunbeam and for retarding the bitumen ageing in the impervious layer. Properties of seal coat are shown in Table 12.

Table 12: Properties of Seal Coat

Test Items	Test Result	Technical Index	Remarks
Mix proportion	Filler : Bitumen = 70 : 30	Filler: 60%～70% Bitumen: 40%～30%	
Slope flow value (mm)	0	No-flow	Thickness : 2mm, 1:1.75, 70℃, 48h
Freezing break Temperature (℃)	＜-40	≦-35	Start : 0℃, Speed : -35℃/h

6 EQUIPMENT COMPOSITIONS

The equipment used in the production and construction is shown in Table-13.

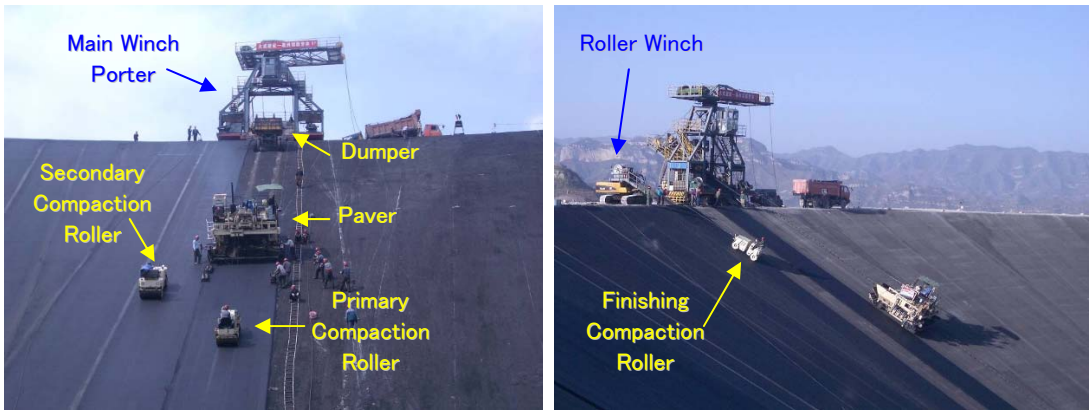
Table 13: Equipment list

Description		Type	Capacity	qt.	Purpose
Aggregate Final Processing System					
	・Cone crusher	GP200	110 t/h	1	
	・Impact crusher	PLF-750	15 t/h	1	
Bituminous Concrete Mixing Plant					[Manufacturer]
	・No.1	LB3250	180～240 t/h	1	No.1: Jilin Highway Machinery Co. Ltd.
	・No.2	NP2400CA	120～160 t/h	1	No.2: NIIGATA Tekkou Co. Ltd.
Reservoir Bottom	Paver	ABG TITAN423		2	Placing
	Vibration Roller	SW-330	2.945t, 31.4kN	1	Primary Compaction
	Vibration Roller	SW-500	4.00t, 24.5kN	1	Secondary Compaction
Reservoir Slope	Main Winch Porter		Length:12500mm Width:10800mm Heigth:12200mm Weight:162t	2	Pulling Paver, Pulling Dumper, Pulling Vibration Roller with SW-350 variant
	Roller Winch	SY230C1 Variant		2	Pulling Vibration Roller with SW-350 variant
	Paver	ABG TITAN273 variant		2	Placing, Pulling Vibration Roller with SW-250 variant
	Vibration Roller	SW-250 variant	1.55t, 9.2×2kN	2	Primary Compaction
	Vibration Roller	SW-350 variant	2.75t, 21×2kN	4	Primary Compaction, Secondary Compaction, Finishing Compaction
	Dumper		3.6m^3	2	Transportation of Mixture
Common Equipment	Mastic Squeezer	TS-2070-01	0.5 m^3	1	Painting Seal Coat
	Mastic Squeezer Winch	DH280 Valiant		1	Pulling Mastic Squeezer
	Cooking truck	Vertical mixing	4 m^3	2	Mixing and Transportation of Seal Coat
	Seal Coat hopper		0.25 m^3	1	Reloading of Seal Coat
	Truck Crane		8t	1	Loading Seal Coat hopper
	Plate Compactor	VP1135R	2.6kW		Hand placing
	Plate Compactor	VP1550AW	4.1kW		Hand placing
	Heater for Joint				

The construction machine formation in the reservoir bottom is shown in Photograph 2.

Photograph 2: The construction machine formation in the reservoir bottom

The construction machine formation in the reservoir slope is shown in Photograph 3.



Photograph 3: The construction machine formation in the reservoir slope

The construction machine formation for the seal coat is shown in Photograph 4.

Photograph 4: The construction machine formation for the seal coat

7. CONSTRUCTION PROGRESS

For this project, the pavement works have been started formally at April. 14th 2006, the completion circumstance of each location construction and unit construction and the quantity is shown in Table 14.

Table 14: Unit Work and Main Quantity

Location	Unit work	Name of Unit work	Commencement and completion time	Quantity		Location	Unit work	Name of Unit work	Commencement and completion time	Quantity	
Bottom	Leveling and binder	Drainage strip	'06.6.1～'07.4.1	1,349	m^3	Slope	Leveling and Binder	Leveling and binder layer	'06.6.6～'07.4.1	15,903	m^3
		Leveling and binder layer	'06.3.17～'06.8.13	10,627	m^3						
	Drainage	Insulating strip	'06.6.25～'06.9.13	799	m^3		Drainage	Insulating strip	'06.8.26～'07.4.18	691	m^3
		Drainage layer	'06.5.4～'06.8.19	13,252	m^3			Drainage layer	'06.8.2～'06.4.19	15,079	m^3
	Impervious	Additional impervious layer	'06.8.5～'06.10.22	795	m^3		Impervious	Additional impervious layer	'06.9.1～'07.5.20	2,214	m^3
		Reinforced mesh	'06.9.5～'06.10.22	23,148	m^2			Reinforced mesh	'06.9.16～'07.6.7	62,726	m^2
		Impervious layer	'06.7.21～'06.10.23	13,376	m^3			Impervious layer	'06.9.17～'07.6.8	19,786	m^3
		Seal coat	'06.9.19～'06.12.2	132,475	m^2			Seal coat	'06.10.23～'07.6.21	197,256	m^2

8. CONCLUSION

Since the commencement of the project, a department of construction special quality management had been set up to ensure proper project management for quality control. We optimized the resource arrangement and the bituminous facing procedure and continually applied best combination of available resources to ensure sequential progress and optimal resource flow with best results. The entire project has been completed safely on June 21st, 2007, and the construction quality and quantity met the requirement of the contract.

The completed upper reservoir under impound water condition is shown in Photograph 5.

Photograph 5: The completed upper reservoir under impound water condition

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