Annex No.2
Geological Condition

THE STUDY ON
COUNTERMEASURES FOR SEDIMENTATION
IN
THE WONOGIRI MULTIPURPOSE DAM RESERVOIR
IN
THE REPUBLIC OF INDONESIA

FINAL REPORT

SUPPORTING REPORT I

Annex No.2: Geological Condition

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CHAPTER 1 REVIEW OF EXISTING GEOLOGICAL INVESTIGATION

1.1 Data Collection

Geological investigations concerning to countermeasure works for sedimentation in the Wonogiri reservoir are summarized in Table 1.1.1. Two check dam sites of Keduang River were studied for countermeasure in 2002.

Table 1.1.1 Summary of Existing Geological Investigation Related to Countermeasures for the Wonogiri Multipurpose Dam

Year	Project	Investigation items	Output	Study Area
1975	Feasibility Report on the Wonogiri Multipurpose Dam Project	Core drilling: 23 holes, total length: 880m Seismic reflection Prospecting 3 lines, total length 2300 m Laboratory tests	Geology of dam site Left abutment: tuff, lapilli tuff, and andesite Right abutment: tuff, tuff breccia	Dam site and the reservoir etc.
1978	Map of Engineering Geology Wonogiri Multipurpose Dam Inundation Area	Ground mapping	Geological map of Wonogiri Multipurpose dam inundation area in scale of 1:1:10,000	Reservoir area
2002	The Basic Design Study on Urgent Countermeasure for Sedimentation in Wonogiri Multipurpose Dam Reservoir	Core Drilling: 8 holes, total length: 65 m Laboratory Test	Geology of proposed check dam The proposed check dam sites are underlain by Quaternary tuff breccia (unconfined compression strength: 12.5-89.8 MPa). Small terraces covered by very dense sandy gravels are scattered along the river. Thin Laterite soils cover the both abutments of the proposed dam.	Proposed check dam site of Keduang River
		Core drilling: 4 holes total length: 54.2 m Laboratory test	Sediment materials of the Wonogiri reservoir are mainly composed of very soft silt and clay (N values were almost zero).	Dam Intake site

Source: JICA Study Team

Sediments in Wonogiri reservoir are composed mainly of very soft silt-clay and remarkably contrast with riverbed materials of the Keduang River in grain size and compaction as shown in Table 1.1.2 and Table1.1.3. In addition, river deposits are not more than 2-3 meters in thickness and bedrocks of riverbed are exposed at many places along the Keduang River. This leads to the conclusion that sediments in Wonogiri reservoir are derived mainly from suspended load, and the suspended load would have been flushed out to the downstream if there had not been the dam.

Table 1.1.2 Summary of the Existing Data of Keduang Riverbed Deposit Materials and Wonogiri Reservoir Sediments

Location	Particle size	Properties
Riverbed of Keduang River	Gravel 80-90% Sand 10-20% Mud -	Dense to extremely dense Non plastic
Wonogiri reservoir	Gravel: – Sand: 5% and under Mud: (65)-95%	Very soft, N value: almost zero PL, LL, PI are approximately 30%, 70% and 40 respectively. Soil classification: CH

Source: JICA Study Team

Table 1.1.3 Summary of Laboratory Tests for Sediment in the Wonogiri Multipurpose Dam Reservoir Area

No.		1	2	3	4	5	6	7	8	9	10
Location		Keduang Bridge	Proposed check dam No.1	Proposed check dam No.2	5 km upstream of No.2 site	River bed in vicinity of Wonogiri Multipurpose dam	Upstream end of the reservoir	Boring BH-1 Intake site Probable old surface soil before construction	Boring BH-2 Intake site	Boring BH-2 Intake site	Boring BH-4 Intake site Probable old surface soil before construction
Year		Sep.2001	Sep.2001	Sep.2001	Sep.2001	1975?		May 2002	May 2002	May 2002	May 2002
Distance from Wonogiri Multipurpose Dam (km)		8	12	19	24	0.5~2	6-8	Intake	Intake	Intake	Intake
Sampling point GL(- m)		0.5	0.5	0.5	0.5	1.0	-	1.2-1.5	4.45-5.0	9.45-10.5	11.0-11.4
Specific gravity (g/cm3)		2.507	2.735	2.649	2.611	2.74~3.30		2.5478	2.5774	2.5897	2.5786
Natural water content (%)		52.2	13.1	10.8	22.7			43.750	77.950	70.780	62.240
Particle Size	Gravel (%)	2	92	78	82	80~97	0				
	Sand (%)	19	8	22	18	3~15	5	2	35	4	2
	Silt (%)	75	<0.2	<0.2	<0.2	0~5	56	95	60	92	93
	Clay (%)	4					39	3	5	4	5
Consistency	Liquid Limit (%)	64.6						77.20	66.20	71.30	71.75
	Plastic Limit (%)	28.4						32.68	28.27	32.26	30.26
	Plastic Index Ip	36.2						44.52	37.93	39.04	41.49
	Consistency Index Ic	0.3						0.75	-0.31	0.01	0.23
Soil Classification		(MH)	(GW)	(GW)	(GW)	(GW)	F	(CH)	(CH)	(CH)	(CH)

References:

No.1-4: The Basic Design Study on Urgent Countermeasure for Sedimentation in Wonogiri Multipurpose Dam Reservoir (2002)
No.5: Engineering Report, Soil and Rock Material Investigation for Consulting Engineering Services on Wonogiri Multipurpose Dam Project
No.7-10: The Detail Design Study on Urgent Countermeasures for Sedimentation in Wonogiri Multipurpose Dam Reservoir in the Republic of Indonesia
No.8 and No.9 are new sediments after construction of Wonogiri Multipurpose Dam

CHAPTER 2 REGIONAL GEOLOGY

2.1 Topography

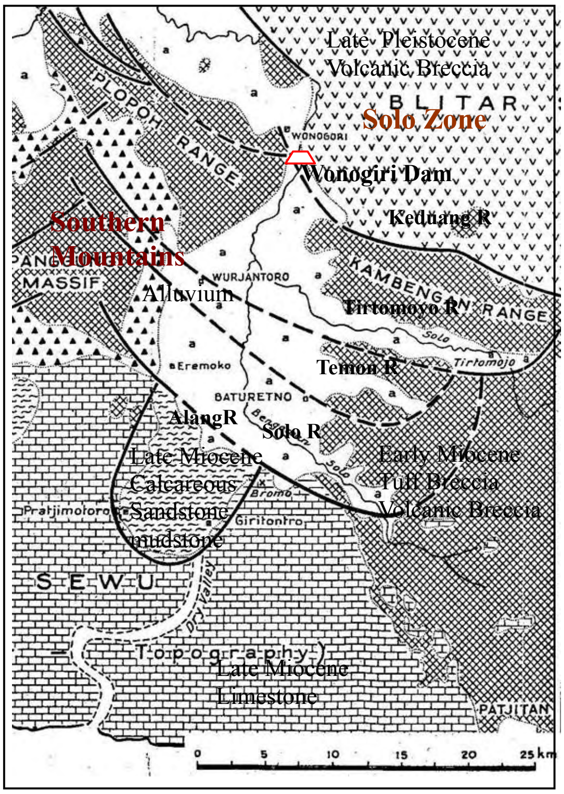
The Bengawan Solo River rises on southwest slope of G. Rahtawu in Tertiary Volcanic mountains area, and flows westward along the mountains series. The Solo River runs northward receiving Alang River, Temon River, Tirutomoyo River and Keduang River immediately upstream of the Multipurpose Wonogiri Dam. After the confluence, the Solo River clockwise flows around Mt. Lawu throw alluvial basin of Surakarta City and Sragen City, and runs eastward to Nagawai City. After the confluence with the Maddiun River the Solo River flows northward to Cepu City and changes the direction to the east northeast and flows into the Jawa Sea about 30 kilometers to the northwest of Surabaya City.

2.2 Regional Geology

The geomorphic and geotectonic zones of Java Island form belts of the east to west direction as follows from south to north.

- The Southern Mountains
- The Solo zone
- The Kendeng zone
- The Randublatung zone
- The Rambang zone

The Wonogiri Dam is located in the southwestern foothill of Mt. Lawu near the boundary between Solo Zone and Southern Mountains. (See Figure 2.2.1)



(References: R.W. Van Bemmelem,1949)

Figure 2.2.1 Geological Map of the Study Area

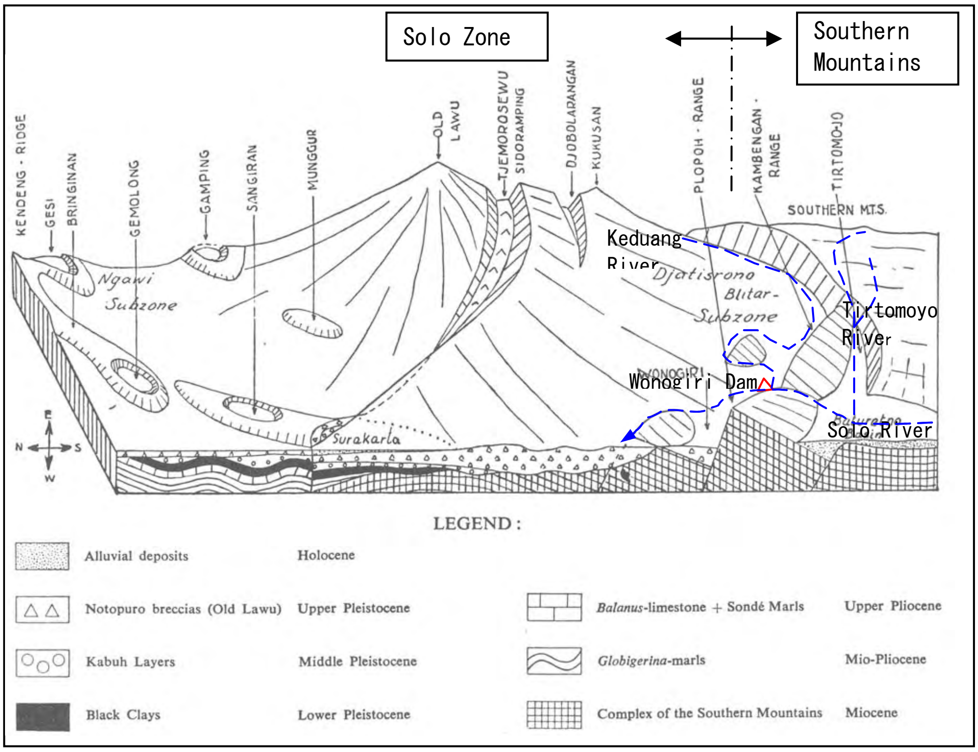
The Southern Mountains

This zone is divided into a southern part, the karst plateau of Late Miocene limestone, and a northern mountainous part of Early Miocene tuff breccia or volcanic breccia.

The Solo Zone

In the Solo zone, the Tertiary formations are covered by a number of Quaternary volcanic products.

The Southern Mountains, forming the southern flank of the anticline, were elevated and tilted southward in Quaternary. At first a consequent, southward drainage pattern developed on the surface of the Southern Mountains. A dry valley running southward shows an old river course at the time. Thereafter, in the Upper Pleistocene, a further warping of this tiled surface has taken place and a basin of Baturetno was formed. Due to this later warping the drainage took a reversed course (towards the North) and became part of the catchment basins of Solo River. During the uplift the crest of the anticline, step faults sliding northwards are supposed to have been developed (See Figure 2.2.2).



(References: R.W. Van Bemmelem,1949)

Figure 2.2.2 Schematic Profile of the Study Area

CHAPTER 3 SITE CONDITION

3.1 Topography

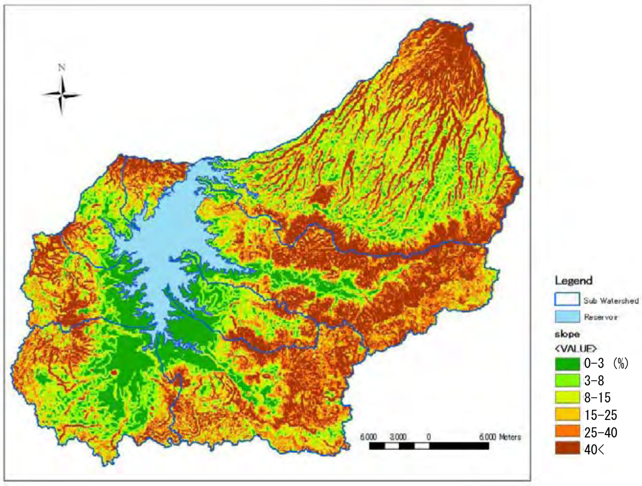
The catchment area of Wonogiri Dam is topographically divided into the following three mountain regions extending east and west, and one plain area surrounding Wonogiri reservoir (Figure 3.1.1 and Figure 3.1.2).

Southern area forms karst tableland with many small mountains of about 400 m in elevation. Almost of rainfall on the tableland infiltrate into underground, and there is no obvious runoff. There are some springs along the foot of the tableland.

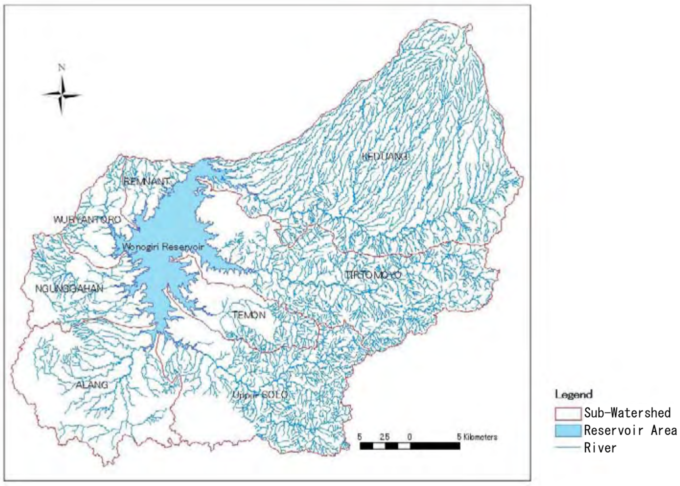
Middle area is characterized by EL.500 m-EL.1200 m ranging mountains and steep valleys extending east-west with dendritic drainage feature.

Northern area, G. Semilir (EL. 2,023 m) on the south slope of Mt Lawu is the highest of the catchment area, forms a volcanic corn with deep V-shape valleys running radially.

Relatively wide plains spread around the confluence of Bengawan Solo River and Alang River, and downstream region of along Tirutomoyo River.



Source: JICA Study Team
Figure 3.1.1 Inclination Map of Wonogiri Catchment Area



Source: JICA Study Team
Table 3.1.2 Watershed of Wonogiri Dam Catchment Area

3.2 Site Geology

3.2.1 Geologic Component

(1) Semilier Formation/ Nglanggran Formation*[*]

Distribution: Forming east-west mountain area of 500-1200 m in elevation between left bank of Keduang R. and Bengawan Solo River

[*] According to Map of Engineering Geology Wonogiri Multipurpose Dam Inundation Area (1978), Semilier Formation and Nglanggran Formation are mainly composed of volcanic breccia and lapilli tuff respectively. However, the boundary of the both formations is unclear in the study area.

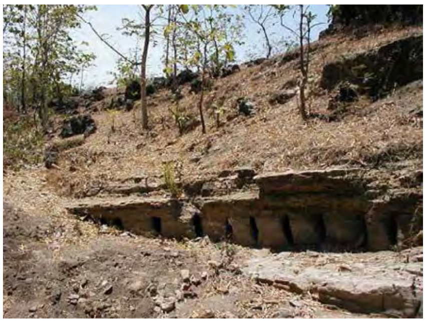
Lithology: Early Miocene volcanic breccia, tuff breccia and lapilli tuff composed of hard andesitic fragments and relatively soft sandy matrix.

Structure: massive, partially sediment facies.

Weathering/Soil runoff: Weathered rocks and its residual soils exposed in the cultivated area spread in the dam catchment area are assumed to be a major source of reservoir sediment materials due to their easily erosive character.

(2) Ojo Formation

Distribution: Forming gently inclined plane upstream of Wonogiri reservoir area, widely developed upstream to middle-stream area of Alang River.



Lithology: Late Miocene calcareous mudstone and sandstone with thin bedded of approximately 50 cm in thickness.

Structure: gently dipping southward, and grading downward into tuffaceous stone.

Weathering/Soil runoff: Moderately hard to moderately soft. Little potential of tractional load.

(3) Wonosari Formation

Distribution: Forming many small **mountains of 300 m-400 m in elevation from** to the southern of the Wonogiri reservoir, called "Gunung Sewu" meaning one thousand mountains.

Lithology: Kalstaric limestone of late Miocene age

Structure: gently dipping southward, partially massive.

Weathering/Soil runoff: Mainly subsurface runoff, probably little tractional load.

(4) Nitopuro Formation

Distribution: The upstream area of the Keduang River and on right bank of the downstream area of the Keduang River.

Lithology: Volcanic breccia, partially lahar facies including andestic and/or basaltic fragments, and tuffaceous sand-silt, tuff breccia of late Pleistocene age.

Structure: Gently inclined southward in general

Weathering/Soil runoff: Moderately soft to soft. Completely weathered rocks and residual soils exposed in the cultivated area of the middle stream of the Keduang River are assumed to be a major source of sediment materials in the reservoir, although upstream natural forests area and downstream area widely distributed by paddy fields probably have little potential for erosion.

(5) Lacustrine Deposit

Distribution: Upstream area of Wonogiri reservoir except for Keduang River, forming terraces or plain fields below 200 m in elevation

Soil Condition: Black to dark grey relatively soft sediment, sometimes including limestone pebbles. Deposited in a basin surrounding Wonogiri Reservoir.

Consistency/Soil runoff: Relatively soft to soft and erosible, a major source of sediment materials from Alang River, Tirutomoyo River, and partly Solo River.

(6) Terrace Deposit

Distribution: Small terraces of approximate 5 meters in height are scattered along the river.

Soil condition: extremely dense sand and gravels, and top thin layers of moderately soft sandy silt.

Consistency/Soil runoff: Terrace deposits of Kuduang River are very dense and the riverbed and banks seem to be stable recently. There would not be a considerable source of the sediment materials of the reservoir. Whereas, some terraces of lower stream area of Solo River and Tirutomoyo River covered by loose sand-silt of 2-3 m in thickness. These loose materials are suffered by riverbank erosion.

(7) Recent River Deposit

Distribution: Bedrock is exposed at many places along the river. Thickness of river deposits is inferred to be less than 2-3 meters in general.

Soil condition: Mainly distributed along the Tirutomoyo River.

Consistency/Soil runoff: Recent river deposits are relatively stiff and are composed mainly of sandy gravels. River deposits differ from sediment in the dam reservoir in containing little fine component in general.

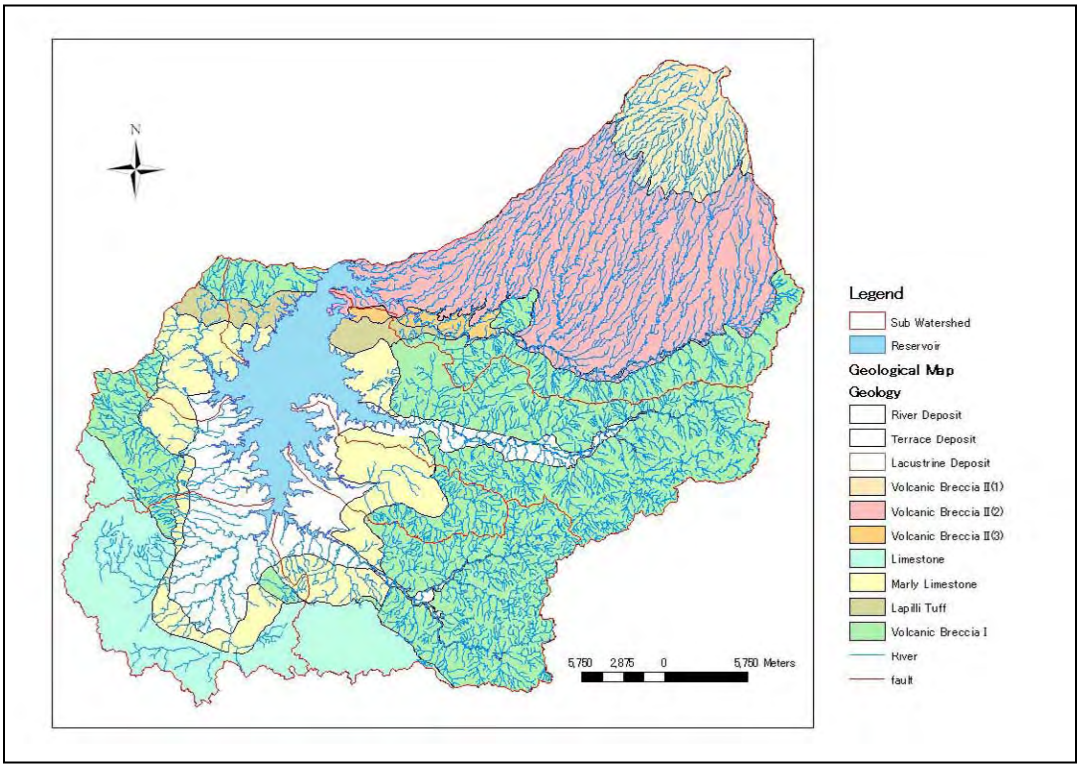
3.2.2 Stratigraphy

Stratigraphy of the study area is show in Table 3.2.1, and geological map is shown in Figure 3.2.1.

Table 3.2.1 Stratigraphy of the Study Area

Geological Age (Ma)	Formation	Rock Unit		Description	Thick -ness (m)	Physical Properties
Holocene (0.00-0.01)		Recent river deposit		Upper: light brownish grey sandy clay to silty sand of 50 cm in thickness Lower: light brownish grey, sandy gravels 5-10 cm, consisted of cobbles (max 10 cm in diameter) to fine sand.	0-2	Upper: Loose Lower: relatively dense
Holocene-Pleistocene		Terrace deposit		Brown gravel to sandy loam,	5	very dense, permeable, well drainage
		Lacustrine deposit		Black to dark brown clay, including limestone pebbles	10-20	Loose to weakly cemented, permeable, well drainage to poor drainage.
Pleistocene (0.01-2.0)	Notopuro F. (Duyfjess,1933)	Volcanic breccia II	(1)	Grey, brownish grey, purple, volcanic breccia, bedrocks of Keduang R., sometimes exposed.	-?	Easily weathering, remained hard fragments of andesite. Loose to strongly cemented, poorly jointed, and impermeable in general.
			(2)	Grey, brown, volcanic breccia, lahar sediments		Easily weathering, soften and erosible.
			(3)	White to grey, tuffaceous sand, tuffaceous silt, thin bedded, intercalated thin silty conglomerate layers		Easily weathering, slaking. Impermeable in general.
Miocene (5.3-23.5)	Wonosari F. (Bothe, 1929)	Limestone		White to grey, limestone, thin bedded clayly limestone.	>650	Hard in general including intercalated thin weak layers. Karstic limestone in some places, strongly jointed in the shear area.
	Ojo F. (Bothe, 1929)	Tuffaceous sand/Marly limestone		Light grey to brownish grey, thin bedded, tuffaceous sandstone, including relatively hard clay stone layers of 20-50 cm in thickness.		Moderately to strongly cemented, porous and good drainage at some places.
	Nglanggran F. (Bothe, 1929)	Lapilli tuff		Grey, lapilli tuff, tuff breccia tuff, good layering. Component: pumice and andestic rocks.	>1500	Relatively hard, poorly jointed, impervious in general. well graded.
	Semilir F/ Old Andesite (Bothe, 1929)	Volcanic breccia (I)		Grey, volcanic breccia with intercalate lapilli tuff layers, good layering.	>650	Moderately to well graded, relatively hard, and impermeable in general except thin bedded layers or strongly jointed zone.

References: *Laporan Pemetaan Geologi Teknik Genangan Waduk Wonogiri* (1978)
Report: Mapping of Technical Geology, Inundated Area of Wonogiri Dam.



Source: JICA Study Team

Figure 3.2.1 Geological Map of the Study Area

3.2.3 Fault

North-slip normal fault system is supposed as previously mentioned, although no obvious fractures were observed along Keduang River and Tirtomoyo River, because these areas are covered by young volcanic deposits or thick soils.

Some minor faults extending N-S or WNW-ESE occur near the boundary between volcanic breccia I and limestone to the south of the Wonogiri Reservoir.

CHAPTER 4 GEOLOGICAL INVESTIGATION

4.1 Quantities

Geological Investigations composed of core drilling with testing, test pits and sampling of river bed materials and laboratory tests were carried out for the purpose of obtaining geological data about the sub-surface conditions to formulate the master plan for Wonogiri Multipurpose Dam.

Table 4.1.1 Quantities of Geological Investigation

Fiscal Year	Investigation Site	Items	Quantities
2004	Wonogiri Multipurpose Dam Reservoir	Core drilling	12 holes total length: 179 m
		Standard penetration test	84 nos.
		Laboratory tests	Particle size analysis: 84 nos. Specific gravity: 84 nos. Bulk density: 36 nos. Natural water content: 84 nos. Atterberg limit: 84 nos.
	Five tributaries in the Wonogiri dam catchment area	Laboratory tests	Particle size analysis: 31 nos. Specific gravity: 31 nos. Natural water content: 15 nos.
	Downstream of the Wonogiri dam	Laboratory tests	Particle size analysis: 30 nos. Specific gravity: 30 nos.
	Proposed spillway site for the Wonogiri Dam	Core drilling	5 holes, total length 150 m
		Standard penetration tests	61 nos.
		Permeability test	30 nos.
		Laboratory tests	Bulk density: 5 nos. Water absorption: 5 nos. Unconfined compression: 5 nos.
2005	Five tributaries in the Wonogiri dam catchment area	Ground mapping	1 set
2006	Proposed spillway site, closure dike site, and overflow weir site	Core drilling	11 holes total length: 223 m
		Standard penetration test	66 nos.
		Laboratory test	For foundation Particle size analysis: Specific gravity: Natural water content: Bulk density: Unconfined compression test: Consolidation test: For material source Particle size analysis: 4 nos. Atterverg limits: 4 nos. Specific gravity: 4 nos. Natural water content: 4 nos. Balk density: 4 nos. Tri-axial (UU, CU): 4 nos.

Source: JICA Study Team

Table 4.1.2 Quantities of Drilling Works

Boring	Location	Coordinates		Elevation (m)	Length (m)	Site Test (nos.)		
		N	E			SPT	Constant Head Test	Lugeon test
2004								
BH-1	Wonogiri Reservoir	488,285	9,118,215	134.6	12	4	-	-
BH-2		488,472	9,119,615	133.0	16	5	-	-
BH-3		488,566	9,123,113	127.4	9	5	-	-
BH-4		488,901	9,126,102	123.4	12	7	-	-
BH-5		491,672	9,126,235	130.0	12	7	-	-
BH-6		494,063	9,123,155	134.0	13	8	-	-
BH-7		489,276	9,128,498	126.0	13	8	-	-
BH-8		490,624	9,130,630	118.5	14	8	-	-
BH-9		491,253	9,132,558	118.9	13	8	-	-
BH-10		492,360	9,133,703	130.1	23	5	-	-
BH-11		492,725	9,133,217	131.4	25	16	-	-
BH-12		495,158	9,131,612	134.5	17	3	-	-
BS-1	Proposed Spillway site	492,486	9,133,951	143.500	30	14	4	2
BS-2		492,512	9,133,948	143,500	30	12	4	2
BS-3		492,530	9,133,942	143,500	30	12	5	1
BS-4		492,505	9,133,913	141.700	30	13	5	1
BS-5		492,503	9,133,977	143.200	30	10	4	2
Total					150	61	22	8
2006								
B-1	Proposed Spillway site	491,928.143	9,134,009.536	124.300	25	5		
B-2		492,017.635	9,134,001.529	129.000	25	10		
B-3		492,194.728	9,133,966.929	132.300	20	5		
B-4		492,367.073	9,133,988.380	139.800	20	9		
B-5	Proposed Closure Dike	492,386.610	9,133,667.087	130.100	20	2		
B-6		492,438.792	9,133,667.087	129.000	20	5		
B-7		429,256.929	9,133,388	129.200	20	2		
B-8	Proposed Overflow weir	429,529.120	9,133,596.320	134.400	15	4		
B-9		429,843.141	9,132,290.466	134.800	15	7		
B-10	Proposed Closure Dike	492,323.257	9,133,482.781	129.900	20	10		
B-11		492,344.988	9,133,533.435	130.563	20	14		
Total					220	73		

Source: JICA Study Team

4.2 Results of Geological Investigation

4.2.1 Wonogiri Reservoir

(1) Geology

Results of drilling works carried out in Reservoir Area are summarized in Table 1.4.3. Relationship between soil type and SPT N values is summarized in Table 1.4.4.

Table 4.2.1 Results of Drilling Works of Wonogiri Reservoir

Drilling No	Name of River	Length (m)	Geological condition (m)			
			Sediments after the dam was completed	Original river deposit, Terrace deposit	Base rock (rock type)	Remarks
BH-1	Solo	15	0.0-2.5		2.5-15.0 (tuffaceous sand)	2.5-4.0 Organic soil
BH-2	Solo	16	0.0-2.0	2.0-8.0	8.0-16.0 (tuffaceous sand)	2.0-5.0 Organic soil
BH-3	Temon	9	0.0-7.6	7.6－9.0		
BH-4	Solo	12	0.0-3.6	3.6-9.2	9.2-12.0 (tuff)	
BH-5	Tirutomoyo	12	0.0-1.5		1.5-12.0 (tuffaceous sand)	1.5-3.0 Organic soil
BH-6	Tirutomoyo	13	0.0-3.5		3.5-13.0 (tuff)	
BH-7	Solo	13	0.0-0.8	0.8-1.5	1.5-12.0 (tuff)	
BH-8	Solo	14	0.0-2.0		2.0-14.0 (lapilli tuff, tuffaceous sand)	
BH-9	Solo	13	0.0-1.7		1.7-13.0 (lapilli tuff)	
BH-10	Solo	23	0.0-3.2		3.2-23.0 (lapilli tuff)	
BH-11	Keduang	25	0.0-17.5	17.5-25.0		
BH-12	Keduang	17	0.0-8.0		8.0-17.0 (tuff breccia)	

Source: JICA Study Team

Table 4.2.2 Summary of Relationships between Geological Condition and SPT N Value

Geology	Soil type	N-value
Sediment deposited after the completion of the dam	silt and clay/sandy soil	0-1
Riverbed deposits (original)	sand and gravel	3-more than 5
Terrace deposits (original)	sand and gravel	more than 20-50
Residual soil (original surface)	brown clay	1-10
Weathered rock		10-more than 50

Source: JICA Study Team

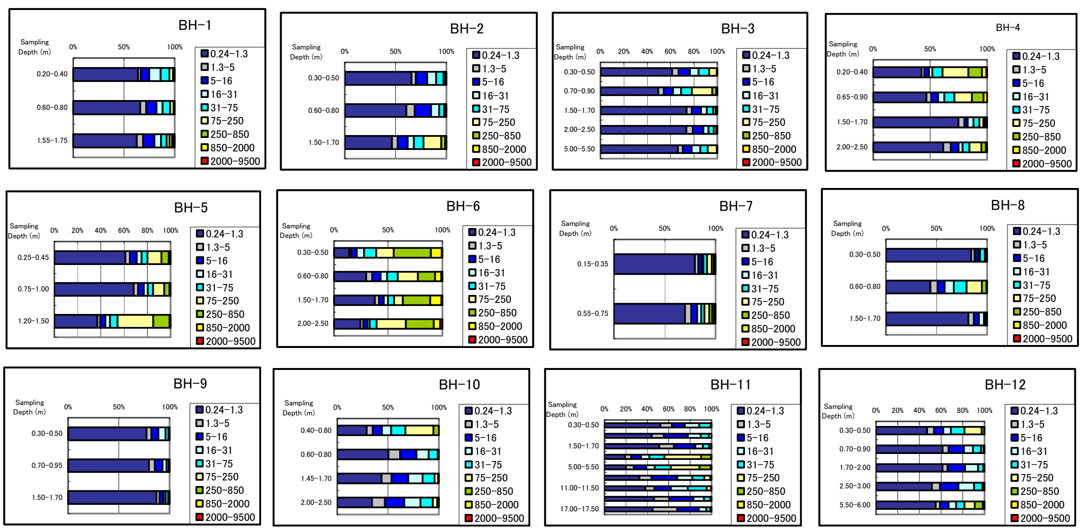
(2) Grain Size

Grain size distribution of each drilling hole is shown in Table 1.4.5 and Figure1.4.1.

Table4.2.3 Grain Size Distribution of Sediments in Wonogiri Reservoir

Boring No.	Depth of Sediment	Sampling Depth	Grain size (μm)								
			Clay		Silt			Sand			Gravel
			0.24-1.3	1.3-5	5-16	16-31	31-75	75-250	250-850	850-2000	2000-9500
	(m)	(m)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
BH-1	2.5	0.20-0.40	64.0	2.5	8.5	11.0	8.8	3.8	1.0	0.5	0.0
		0.60-0.80	66.0	6.0	10.0	6.0	7.7	3.1	0.6	0.4	0.1
		1.55-1.75	62.5	6.5	11.0	6.5	5.6	2.8	2.8	1.4	0.9
BH-2	2	0.30-0.50	65.6	4.4	11.0	9.0	7.1	2.0	0.9	0.0	0.0
		0.60-0.80	60.7	8.3	16.0	8.0	4.7	1.2	1.0	0.0	0.0
		1.50-1.70	46.5	5.5	10.0	6.0	9.6	17.3	4.1	0.8	0.2
BH-3	7.6	0.30-0.50	61.5	5.5	9.5	7.5	9.1	6.3	0.4	0.2	0.0
		0.70-0.90	49.5	4.5	8.0	7.0	9.2	17.4	3.5	0.8	0.1
		1.50-1.70	73.7	4.3	8.0	5.0	5.7	2.1	0.4	0.8	0.1
		2.00-2.50	73.6	5.4	9.0	4.5	4.4	2.2	0.4	0.3	0.2
		5.00-5.50	66.4	4.1	7.5	7.5	6.4	7.8	0.3	0.1	0.0
BH-4	3.6	0.20-0.40	42.4	2.6	4.0	3.0	8.8	22.8	11.9	3.8	0.7
		0.65-0.90	46.8	4.2	6.0	5.5	8.8	15.3	10.3	3.0	0.0
		1.50-1.70	74.8	5.2	3.0	5.0	5.3	3.3	1.0	1.9	0.5
		2.00-2.50	61.5	6.5	7.0	3.5	6.0	10.6	3.9	0.9	0.2
BH-5	1.5	0.25-0.45	61.3	3.7	6.0	4.0	5.3	12.0	6.3	1.3	0.2
		0.75-1.00	68.2	3.8	5.0	3.5	4.5	9.6	4.4	0.6	0.3
		1.20-1.50	37.0	2.5	4.5	4.0	6.4	30.6	14.2	0.6	0.1
BH-6	3.5	0.30-0.50	14.2	1.8	5.0	7.0	11.1	16.1	34.3	9.8	0.7
		0.60-0.80	29.7	5.8	7.5	6.0	9.8	18.7	15.8	5.7	1.0
		1.50-1.70	37.6	3.9	4.5	4.0	5.5	8.1	25.1	10.5	0.8
		2.00-2.50	24.5	2.5	4.0	2.0	6.3	27.0	25.7	6.0	2.0
BH-7	0.8	0.15-0.35	79.8	3.2	3.5	1.5	3.8	4.4	2.1	1.4	0.3
		0.55-0.75	70.0	6.0	6.0	4.0	3.2	4.7	3.0	1.8	1.3
BH-8	2	0.30-0.50	84.2	3.3	3.5	2.0	4.8	1.6	0.5	0.2	0.0
		0.60-0.80	43.9	7.1	7.0	9.0	12.7	15.1	4.7	0.4	0.1
		1.50-1.70	81.4	5.6	5.0	5.0	1.2	1.2	0.5	0.2	0.0
BH-9	1.7	0.30-0.50	77.2	4.8	7.0	7.0	3.0	0.6	0.3	0.1	0.0
		0.70-0.95	79.6	5.9	7.5	4.0	2.1	0.4	0.3	0.1	0.0
		1.50-1.70	86.9	3.1	4.0	2.0	2.7	0.9	0.3	0.1	0.0
BH-10	3.2	0.40-0.60	28.9	6.1	9.0	9.0	14.2	27.7	5.1	0.0	0.0
		0.60-0.80	50.4	11.6	16.0	12.0	9.0	0.8	0.2	0.0	0.0
		1.45-1.70	43.7	9.8	16.5	14.0	11.9	3.5	0.5	0.0	0.0
		2.00-2.50	34.1	12.9	19.0	16.0	12.2	4.3	1.5	0.0	0.0
BH-11	17.5	0.30-0.50	52.3	10.7	12.0	13.5	10.8	0.5	0.1	0.1	0.0
		0.60-0.80	44.1	11.4	22.5	12.0	7.5	2.5	0.0	0.0	0.0
		1.50-1.70	51.1	13.9	20.0	7.0	5.8	2.0	0.2	0.0	0.0
		2.00-2.50	19.2	5.8	9.0	8.0	14.0	34.3	9.3	0.4	0.0
		5.00-5.50	20.0	7.5	11.5	8.0	14.9	27.0	10.6	0.5	0.0
		8.00-8.50	32.5	11.5	24.0	14.0	11.1	5.6	1.2	0.0	0.0
		11.00-11.50	38.2	8.4	15.5	16.0	17.6	4.0	0.3	0.2	0.0
		14.00-14.50	46.3	14.2	22.5	10.0	5.7	0.8	0.4	0.0	0.0
		17.00-17.50	44.9	23.1	20.0	7.0	3.9	0.7	0.2	0.2	0.0
BH-12	8	0.30-0.50	47.1	6.4	8.5	7.0	12.7	15.7	2.4	0.2	0.0
		0.70-0.90	61.4	5.6	14.0	8.5	7.3	2.4	0.6	0.2	0.0
		1.70-2.00	61.4	4.6	16.0	12.0	4.9	0.7	0.3	0.2	0.0
		2.50-3.00	51.5	7.5	17.0	14.5	7.7	1.2	0.4	0.2	0.0
		5.50-6.00	54.9	4.1	8.0	7.0	7.6	9.5	7.2	1.7	0.0

Source: JICA Study Team



Source: JICA Study Team

Figure 4.2.1 Grain Size Distribution

The character of sediment material component of main tributaries in Wonogiri Multipurpose dam catchment area was described as below.

- Sediment materials in the reservoir derived from the Keduang River are composed mainly of silt and clay, and drastically changes in grain size from riverbed materials. According to site survey, sand and gravels upstream of the reservoir are very dense (SPT N value: more than 50) and stable. Therefore most sediment in the reservoir of the Keduang River is inferred to have been transported as suspended load (See Figure 4.2.2 and Figure 4.2.6).
- Sediment of the reservoir from the Alang River, Solo River, Temon River and Tirutomoyo River gradually become finer downstream ward and form sandy to clayey foreset bed in the vicinity of the upstream end of the reservoir. Transportation analysis of the sediment from these rivers needs to consider tractional load in addition to suspended load (See Figure 4.2.3 to Figure4.2.6).
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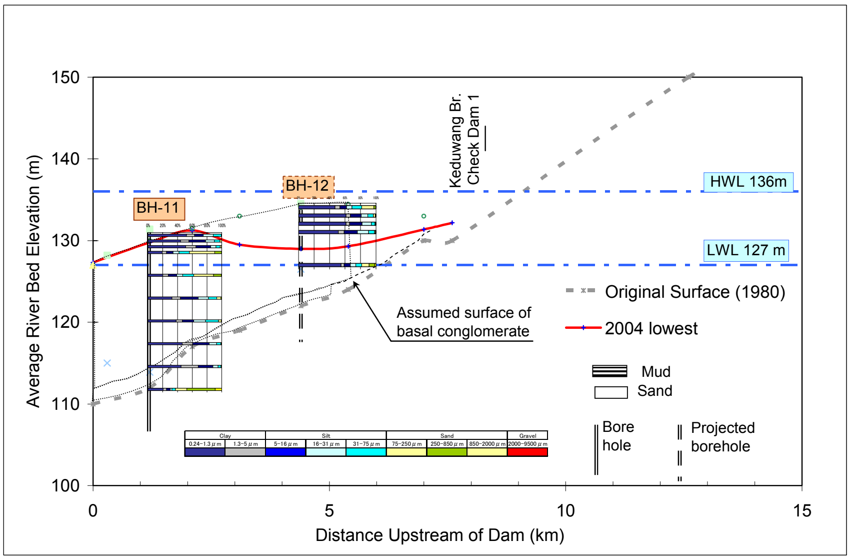
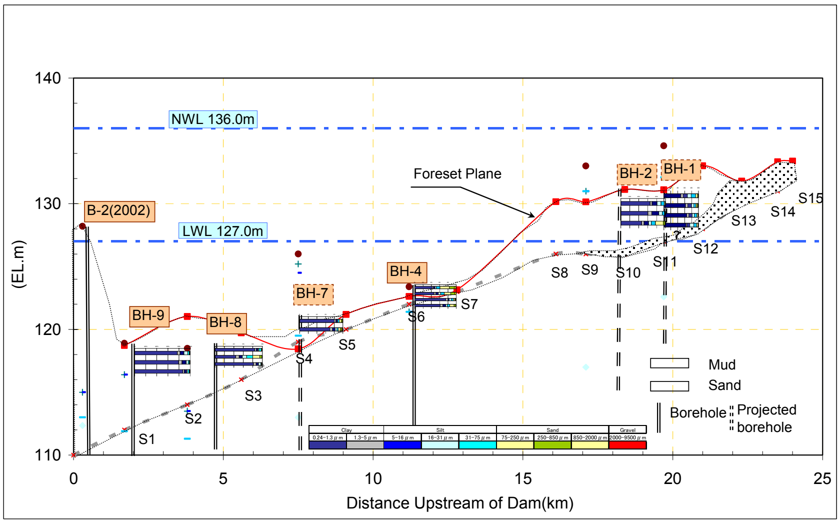


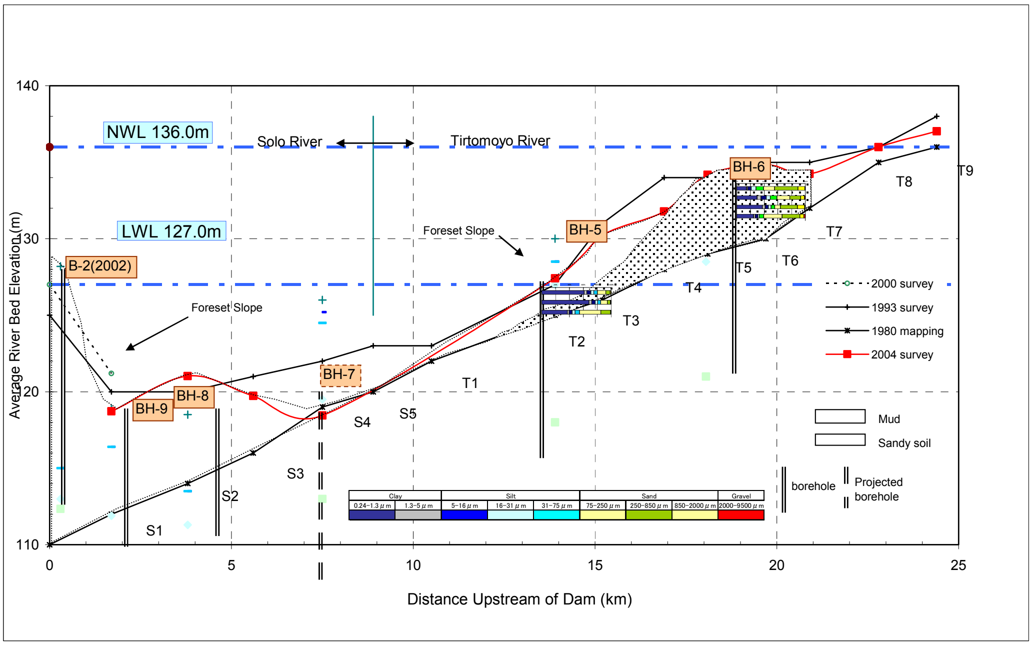
Source: JICA Study Team

Figure 4.2.2 Geological Section of Keduang River



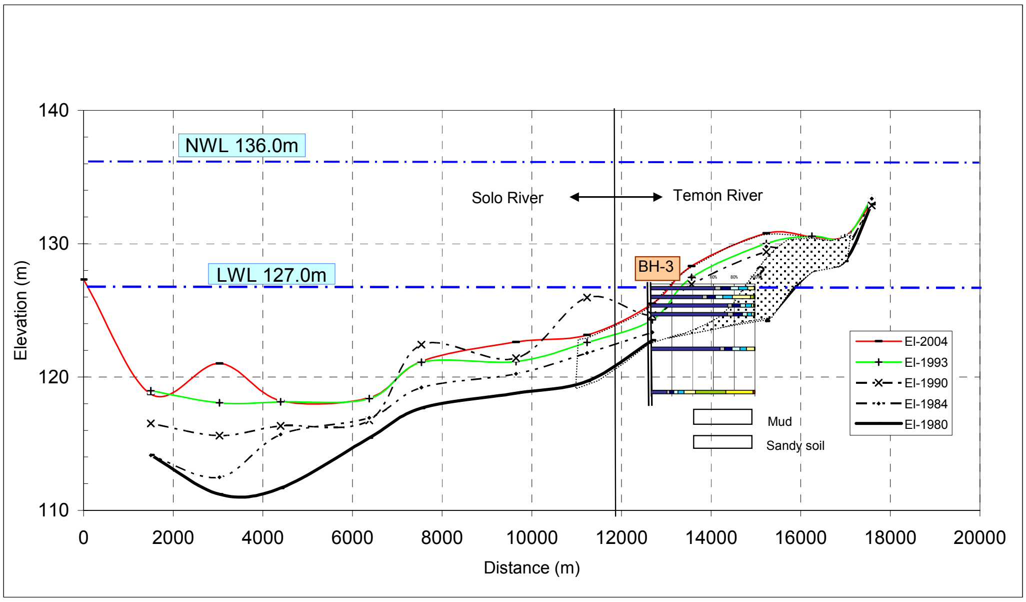
Source: JICA Study Team

Figure 4.2.3 Geological Section of Bengawan Solo River



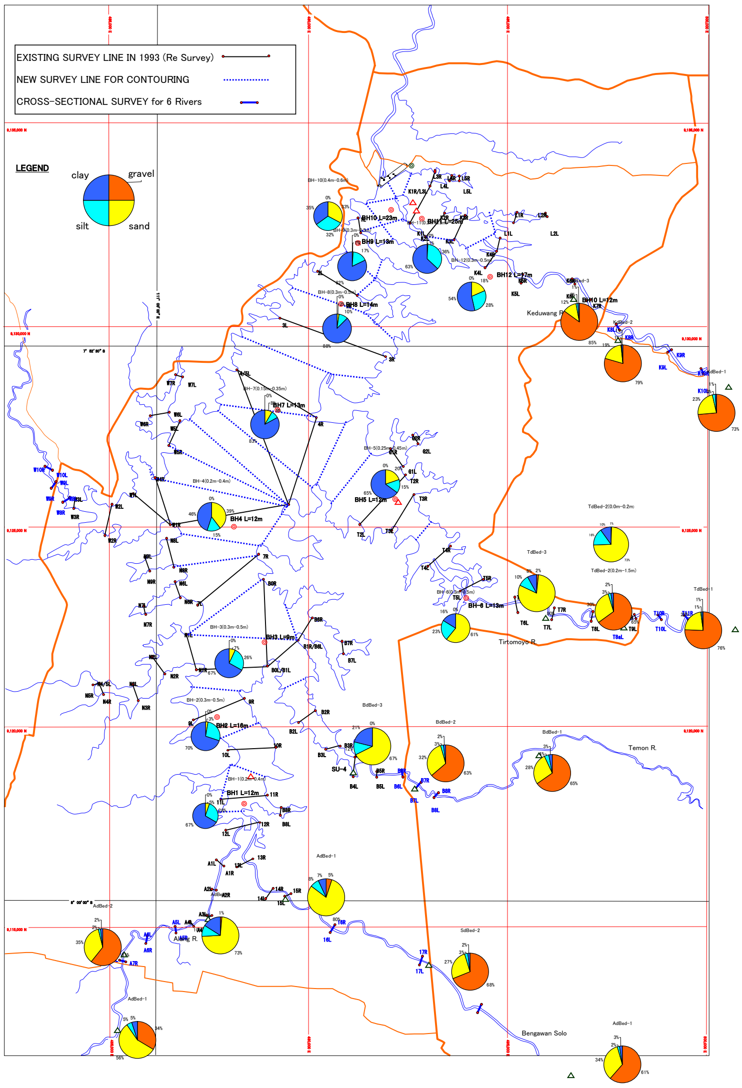
Source: JICA Study Team

Figure 4.2.4 Geological Section of Tirtomoyo River



Source: JICA Study Team

Figure 4.2.5 Geological Section of Temon River



Note: The Sediment Materials were Sampled in the Section of the Boring Core Between 0.2 m-0.6 m in Depth and Test Pitting Samples of 0.5 m in Depth.

Source: JICA Study Team

Figure 4.2.6 Component of Surface Sediment Materials in Wonogiri Multipurpose Dam Reservoir and 5 Main Distributaries

(3) Specific Gravity of Soil

No significant differences of the specific gravity were detected among the samples in the Wonogiri reservoir

Maximum: 2.728, minimum: 2.538, Average: 2.670

(4) Bulk Density

Bulk density tests were executed by using undisturbed samples selected in three sections of 0.2-0.4 m, 0.6-0.8 m and 1.5-1.7 m in depth for each boring core.

Half of boring core samples was almost constant in depth. No correlation between bulk density and sampling depth was detected.

Items	Max (g/cm^3)	Min (g/cm^3)	Ave (g/cm^3)	Standard Distribution
Wet density	1.889	1.485	1.639	0.09
Dry density	1.438	0.792	1.063	0.15
Saturated	1.910	1.488	1.664	0.10

(5) Consistency

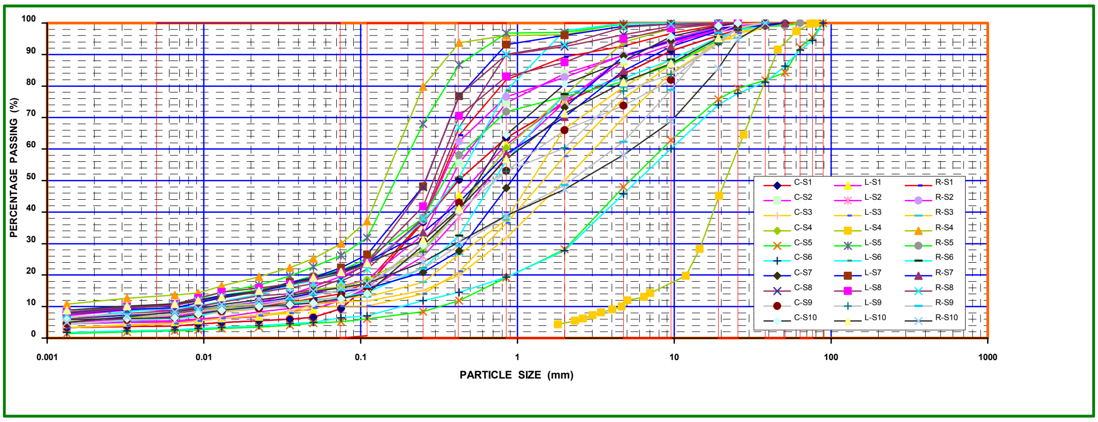
Almost of the samples were classified into CH.

4.2.2 Downstream of the Wonogiri Dam

River deposits were sampled at the center and the both banks of the river at 10 locations along the Solo River downstream of the Wonogiri Dam up to the confluence of the Solo River and the Madune River.

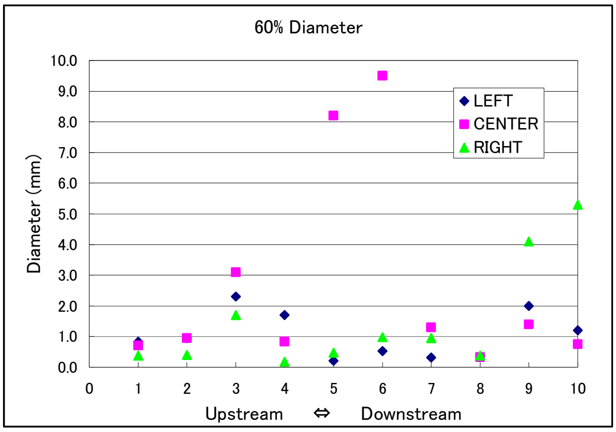
(1) Grain Size

Maximum grain size ranges from 88.90 mm to 4.75 mm, and 60% diameter of grain size ranges from 9.50 mm to 0.18 mm (average 1.73 mm). No correlation between grain size of the samples and distance from the dam site was detected.



Source: JICA Study Team

Figure 4.2.7 Particle Size Distribution of the River Sediment Materials at 10 Points Along the Solo River Downstream of the Wonogiri Multipurpose Dam



Source: JICA Study Team

Figure 4.2.8 60% Diameter of the River Sediment Materials at 10 Points Along the Solo River downstream of the Wonogiri Multipurpose Dam

(2) Specific Gravity of Soil

No significant differences of the specific gravity were detected among the samples along the Solo River downstream of the dam.

Maximum: 2.731, minimum: 2.671, Average: 2.700

CHAPTER 5 SITE CONDITION OF THE WONOGIRI WATERSHED

5.1 Keduang River

5.1.1 Upstream Area (Right Bank, About EL. 600 m ~)

Slope gradient: More than 20 degrees in general, more than 30 degrees in valley

Geology: Grey, brownish grey, purple, volcanic breccia. Bedrocks of Keduang R. are sometimes exposed in some portions.

Soil Condition: Litosol, or Mediteran. Less than 3 m in thickness in general.

Riverbed deposits: Sand and gravels including boulders of more than one meter in diameter. Debris flow deposits were observed.

Condition:

<u>EL. 900 m ~</u>

Most mountainous lands are covered by natural forests. There are few gulley erosion sites. Soil degradation is not serious.

<u>About EL.600 m - EL.900 m</u>

Most hilly areas are covered by Kubun or Tegule. Paddy fields are distributed along the tributaries of the Keduang River.

Source of Sediment Discharge:

Sheet erosion and rill erosion in cassava fields etc. are supposed. There are no large active landslides, although some suspicious landcreep slopes are observed. Recently small irrigation canals are constructed by local people and water infiltration from canals or paddy fields might cause landslide.

5.1.2 Middle Area (Right Bank, EL.600 m - Mainstream of Keduang River)

Slope gradient: Less than 10 degrees in general, about 20-30 degrees along small stream ridges

Geology: Lahar deposit (soft) and volcanic breccia (relatively soft) are exposed along the river

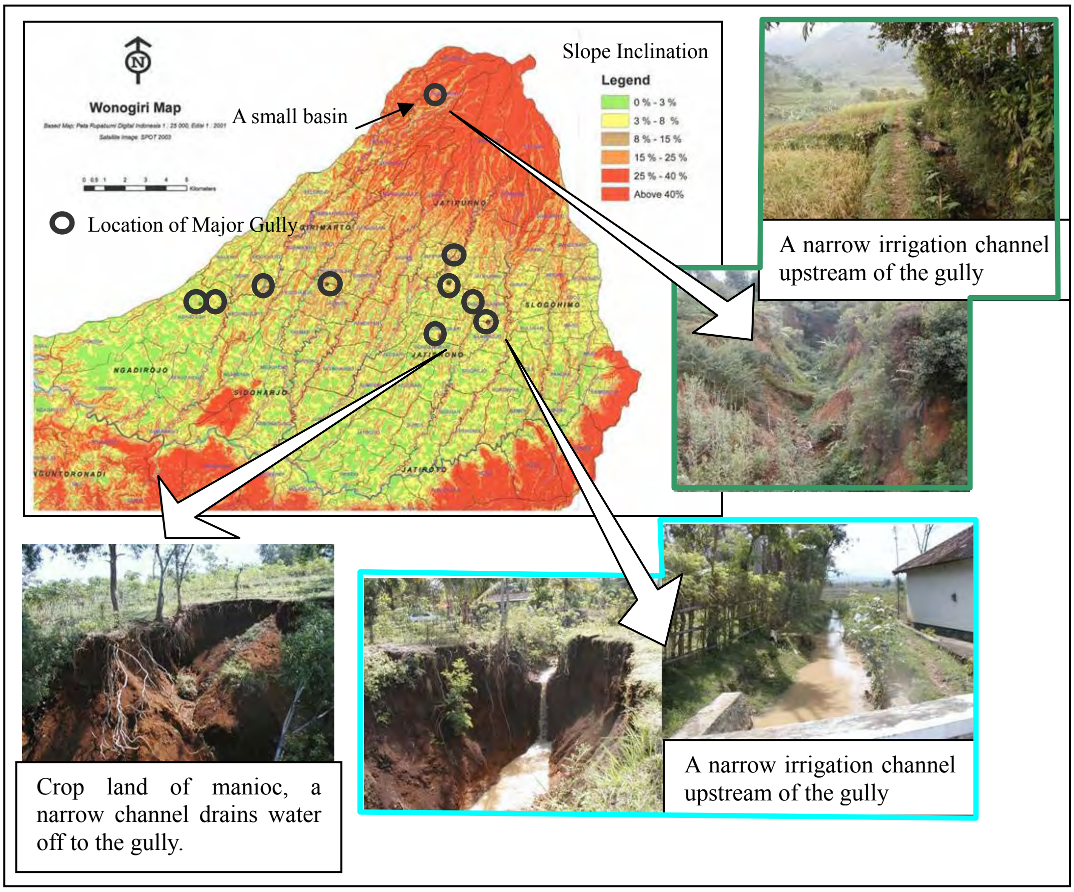
Soil type: Latosol and mediteran of 5-8 m in thickness

Condition: Spring points are distributed about EL. 600 m and EL.150 m beside the crossing road on the flank of Mt. Lawu. Gentle hills and wide valleys covered with paddy fields.

Source of Sediment Discharge:

Sheet erosion of thick latosol covering gentle hills

Gully erosions at spring points. Additionally discharged water from narrow channels or drains causes gully erosions as shown in the following figure in many cases.



Source: JICA Study Team

Figure 5.1.1 Major Gully of Keduang River Basin

5.1.3 Downstream Area

Slope gradient: Less than 10 degrees

Geology: White to grey, tuffaceous sand, tuffaceous silt, thin bedded, intercalated thin silty conglomerate layers.

Small terraces are distributed along the Keduang River. Terrace deposits are very dense.

Soil Type: Mediteran

Condition: Paddy fields are expanded.

Source of Sediment Discharge:

Low potential of sheet erosion and gully erosion due to low gradient

Erosion by wave is detected at some potions.

5.1.4 Mountainous Area (Left Bank)

Slope gradient: 5-more than 20 degrees, about 50-60 degrees at the escarpment

Geology: Volcanic breccia, relatively hard.

Soil type: Mediteran and litosol

Condition:

Paddy fields are expanded at the plain (slope gradient of less than about 5 degrees)

Cassava fields and forests (Kubun) are distributed hilly area

Bedrocks are exposed near the mountain ridge

Source of Sediment Discharge:

Sheet erosion of the fields is the major source.

5.2 Tirtomoyo River

5.2.1 Mountain Area

Slope gradient: Mainly more than 15 degrees

Geology: Volcanic breccia (relatively hard)

Soil type: Litosol and mediteran

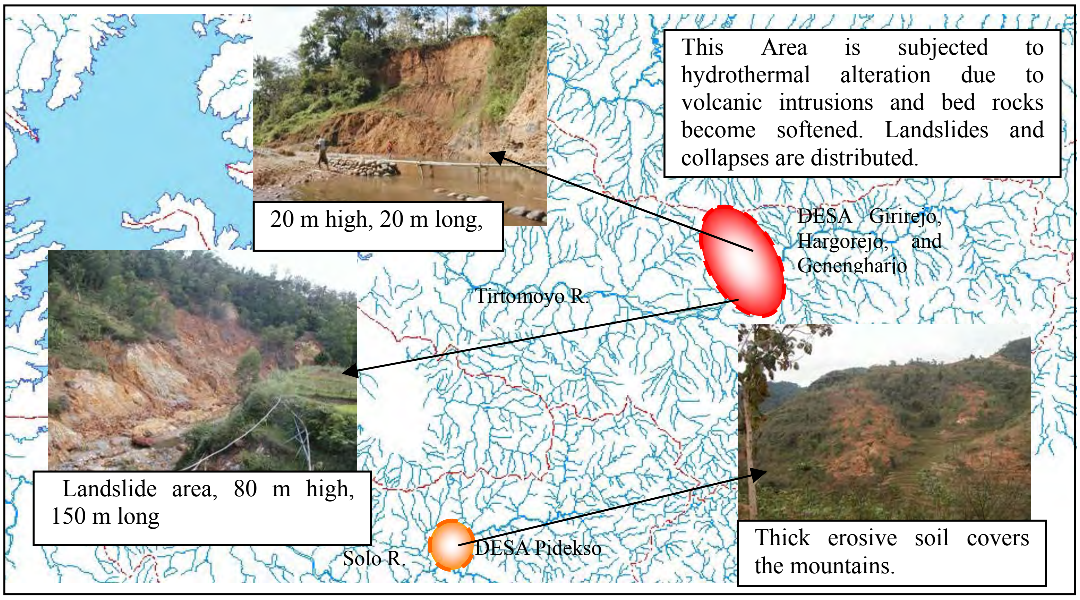
Condition: Residual soil is 1-2 m in thickness in general. Bedrocks are exposed at some mountain ridges. Most upstream area is a peneplain covered by forests.

Relative thick residual soil covers the hilly area of Desa Girirejo, Desa Hargorejo, and Desa Genengharjo at the midstream of Tirtomoyo River (See Figure 5.2.1).

Source of Sediment Discharge:

Sheet erosion is main source, although the most upstream area covered by forests has low potential of erosion.

Relatively large landslides were detected in Desa Girirejo, Desa Hargorejo, and Desa Genengharjo. Landslide high potential zone is probably restricted in the area subjected to hydrothermal alteration due to volcanic intrusions.



Source: JICA Study Team

Figure 5.2.1 Erosive Soil Distribution Area of Tirtomoyo River and Solo River Basin

5.2.2 Plain Area

Slope gradient: Mainly less than 3 degrees

Geology: Lacustrine deposits and terrace deposits on the both bank of the river.

Soil type: Grumosol

Condition: Terrace deposits of 2-3 m in thickness are loose and erosive.

Source of sediment discharge: Bank erosion is the major source.

5.3 Temon River

5.3.1 Upstream Area

Slope gradient: Mainly more than 8 degrees

Geology: Volcanic breccia

Soil type: Mediteran

Condition:

Cassava fields and forests (Kubun) are distributed hilly area

Bedrocks are exposed near the mountain ridge

Source of Sediment Discharge:

Sheet erosion of the fields is the major source.

5.3.2 Downstream Area

Slope gradient: Mainly less than 8 degrees

Geology: Marly limestone

Soil type: Grumosol

Condition:

Hard bedrocks are exposed along the river. Residual soil is less than one meter in general.

Source of Sediment Discharge:

Low potential

5.4 Bengawang Solo River

5.4.1 Mountain Area

Slope gradient: Mainly more than 15 degrees

Geology: Volcanic breccia (relatively hard), tuff breccia

Soil type: Mediteran and litosol

Condition: Residual soil is 1-2 m in thickness in general. Bedrocks are exposed at some mountain ridges. Most upstream area is a peneplain covered by forests.

Relative thick residual soil covers the hilly area of Desa Pidekso at the midstream of Bengawang Solo River (See Figure 5.2.1). The solo river basin is mainly underlain by volcanic breccia or tuff breccia, which includes many quartz particles. Residual soil of this area is sort of coarse compared with another river basin.

Source of Sediment Discharge:

Sheet erosion is main source, although the most upstream area covered by forests has low potential of erosion.

Large size gullies were detected in Desa Pidekso.

5.4.2 Plain Area

Slope gradient: Mainly less than 3 degrees

Geology: Lacustrine deposits and terrace deposits on the both bank of the river.

Soil type: Grumosol

Condition: Terrace deposits of 2-3 m in thickness are relatively loose to relatively stiff.

Source of sediment discharge: Bank erosion is the major source, although the potential would not high.

5.5 Alang River

5.5.1 Karst Tableland

Slope gradient: 3-15 degrees

Geology: Limestone.

Soil type: Mediteran and litosol

Condition: Residual soil of 1-2 m in thickness in general is very loose and erosive. However most rainwater seeps into the ground or is caught in small ponds on the tableland.

Source of sediment discharge: Low potential, because the Alang River rises from some springs in limestone area to the south of Wonogiri Reservoir, and flowing water is clean in general.

5.5.2 Plain Area

Slope gradient: Mainly less than 3 degrees

Geology: Lacustrine deposits and terrace deposits

Soil type: Grumosol

Condition: Loose and erosive lacustrine deposits and terrace deposits are distributed on the plain below EL. 200 m surrounding the Wonogiri Reservoir.

Source of sediment discharge: Bank erosion is the major source. Cultivation sometimes causes sediment discharge of this area.

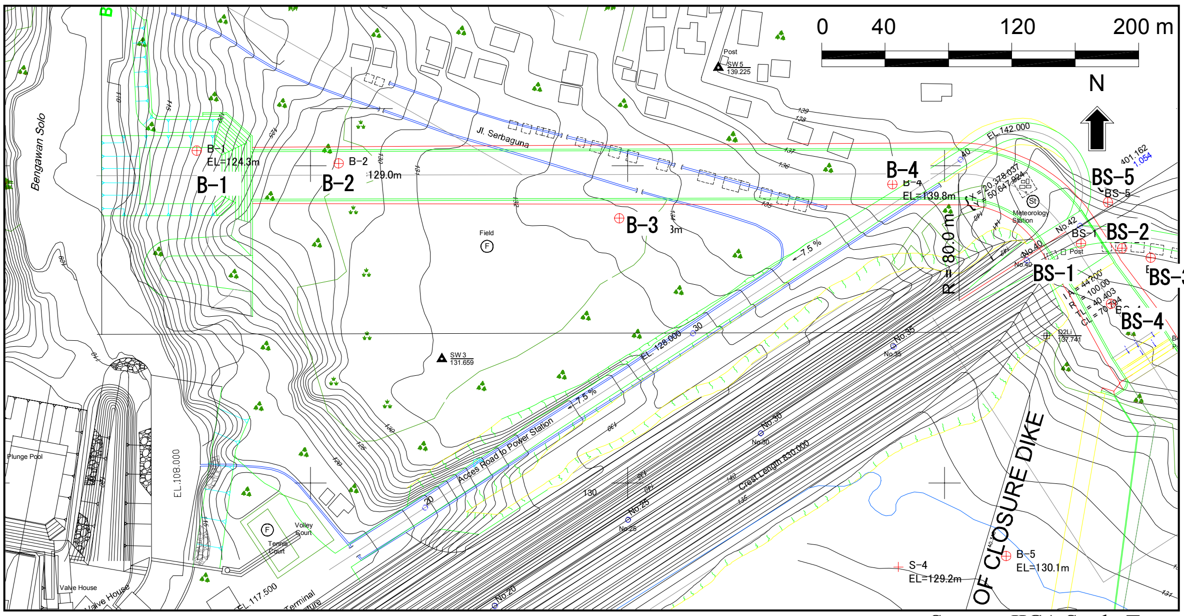
Erosive soil of Alang River Basin

CHAPTER 6 COUNTERMEASURE STRUCTURES

6.1 Proposed Spillway

6.1.1 Geological Investigations for Weir Site

A new spillway to discharge sediment in the Wonogiri dam reservoir is planned on the gentle hill of the right abutment of the Wonogiri Multipurpose Dam. Location Map of the drill holes is shown in Figure 6.1.1.



Source: JICA Study Team

Figure 6.1.1 Location Map of Drilling Point for Proposed Spillway

Results of drilling works carried out at proposed spillway and the laboratory tests using drilling core samples are summarized in Table 6.1.1 and Table 6.1.2 respectively.

Table 6.1.1 Results of Drilling Survey in Proposed Spillway

Drilling No	Length (m)	Ground water Level (m)	Geological condition (m)				
			Organic soil	Lapilli tuff	Sandy tuff	Tuff Breccia	
				D class (CL class)	D class	D class	CL class
BS-1	30	11.5	0.0-0.7	0.7-9.8 (6.0-9.8)	9.8-15.2	15.2-19.0	19.0-
BS-2	30	12.1	0.0-0.2	0.2-9.5	9.5-15.0	15.0-19.0	19.0-
BS-3	30	11.3	0.0-0.8	0.8-10.0	10.0-14.8	14.8-18.0	18.0-
BS-4	30	11.2	0.0-0.2	0.2-11.0	11.0-14.5	14.5-19.0	19.0-
BS-5	30	11.2	0.0-0.8	0.8-10.8 (6.6-10.8)	10.8-14.5	14.5-17.0	17.0-

Source: JICA Study Team

Table 6.1.2 Summary of Laboratory Test for Rock Core Sample (CL class)

Hole No.	Depth (m)	Density (g/cm^3)	Unconfined Compressive Strength (kgf/cm^2)	Axial strain (%)	Specific gravity			Absorption (%)
					Dry	Saturated Surface-Dry	Apparent	
BS-1	7.20 - 7.50	1.587	31.92	2.51	1.838	2.117	2.548	15.14
BS-1	28.70 - 29.00	2.008	31.19	4.07	1.847	2.123	2.552	14.95
BS-2	18.20 - 18.50	1.973	171.13	1.19	2.018	2.244	2.605	11.16
BS-4	27.60 - 27.80	1.666	18.93	2.74	1.717	2.010	2.430	17.10
BS-4	28.15 - 28.35	1.975	68.21	2.30	1.891	2.138	2.511	13.07
BS-5	10.50 - 10.70	1.694	38.67	2.20	1.810	2.085	2.498	15.23
Average		1.817	60.008	2.50	1.854	2.120	2.524	14.44
Max		2.008	171.130	4.07	2.018	2.244	2.605	17.10
Min		1.587	18.930	1.19	1.717	2.010	2.430	11.16

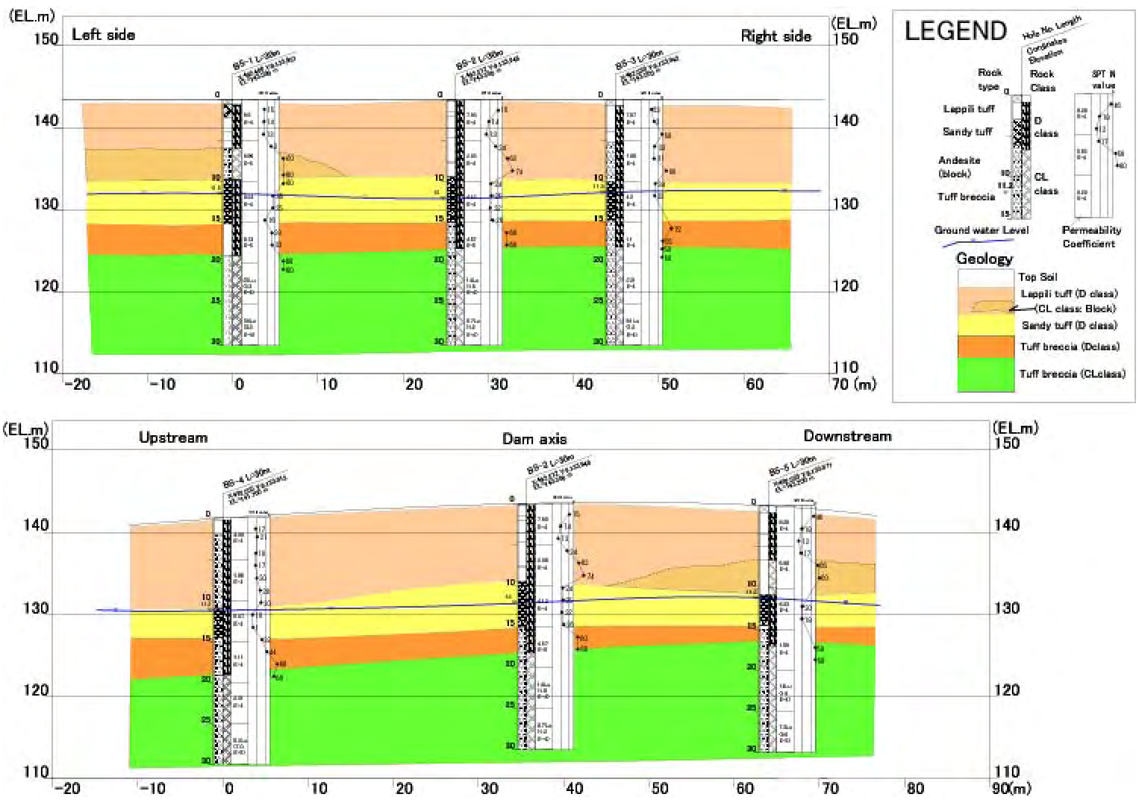
Source: JICA Study Team

6.1.2 Engineering Geology

(1) Geology

This area consists of lapilli tuff, sandy tuff and tuff breccia in descendant order and completely weathered from the surface to 17 - 19 m deep (D class), except for a moderately hard lapilli tuff block (CL class) at the depth of 6-10 m of the leftward and downstream side of the proposed site.

The base rock of the proposed spill way is moderately hard tuff breccia (CL class) (See Figure 6.1.2).



Source: JICA Study Team

Figure 6.1.2 Geological Profile of Proposed Spillway

(2) Geotechnical Assessment

The physical and mechanical properties of the bedrock are estimated as shown in Table 6.1.3 based on field tests and laboratory tests.

Moderately hard tuff breccia (CL class) has bearing capacity adequate for the foundation of the proposed spillway.

Table 6.1.3 Basic Properties of Bedrock

Facies	Depth (m)	SPT N Value	Unconfined Compressive Strength (kgf/cm2)	Bulk density (g/cm3)	Estimated Strength C= Φ=	Estimated Permeability Coefficient (cm/s)
Lappili tuff	0-6	12-50 (23)				5 E-4
	6-10	31-74 (40)				5 E-4
Sandy tuff	10-15	11-35 (24)				5 E-4
Tuff Breccia (D class)	15-19	32-72 (51)				1E-4
Tuff breccia (CL class)	19-		19-171 (60)	1.6-2.0 (1.8)	3 kg/cm2 35 degrees	1E-4

Note: Parenthetic numbers show average of the test results.
Source: JICA Study Team

6.2 Spillway

6.2.1 Geological Investigations for Proposed Spillway Alignment

Results of drilling works carried out at proposed spillway alignment are summarized in Table 6.2.1.

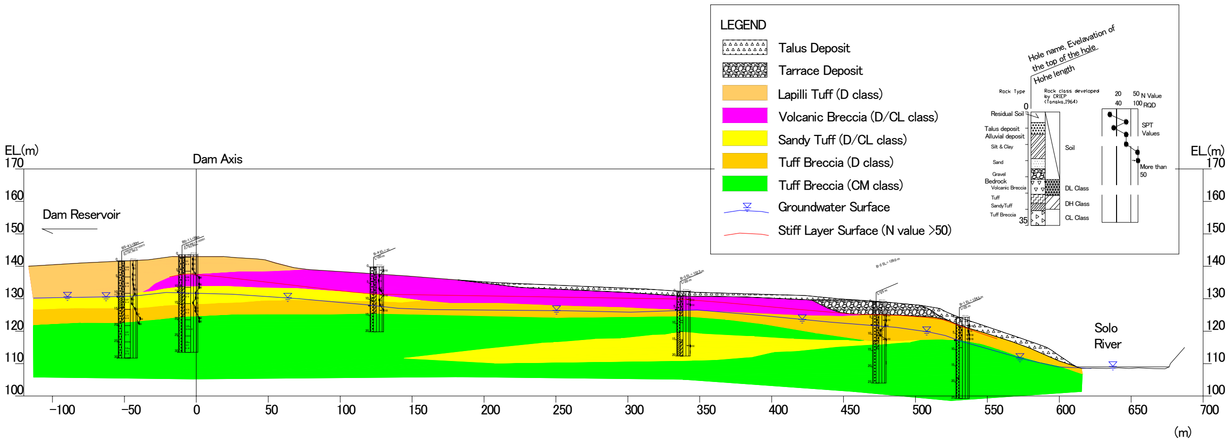
Table 6.2.1 Results of Drilling Survey Along the Proposed Spillway Alignment

Drilling No	Length (m)	Ground water Level (m)	Depth (m) / Geology	Depth (m) / Rock condition
B-1	25	7.2	0.0-2.5 Talus deposits/Embankment 2.5-25.0 Tuff breccia (18.6-19.0 Sandy tuff)	0.0-2.5 Soil 2.5-7.0 D class 7.0-25.0 CL class
B-2	25	5.3	0.0-3.8 Terrace deposit/Embankment 3.8-12.0 Tuff breccia 12.0-13.0 Tuff 13.0-25.0 Tuff breccia	0.0-3.8 Soil 3.8-14.5 D class (3.8-12.0 DL class, 12-14.5 DH class) 14.5-25.0 CL class
B-3	20	6.0	0.0-1.5 Talus deposit/Embankment 1.5-12.7 Volcanic breccia 12.7-20.0 Tuff breccia	0.0-1.5 Soil 1.5-7.6 D class (1.5-6.0 DL class, 6.0-7.6 DH class) 7.6-15.0 CL class 15.0-20.0 D class (DH)
B-4	20	12.0	0.0-0.2 Residual Soil 0.2-8.35 Volcanic Breccia 8.35-9.5 Tuff breccia 9.5-10.5 Tuff 10.5-20.0 Tuff breccia	0.0-0.2 Soil 0.2-14.3 D class (DL class 0.2-8.35, 8.35-14.3 DH class) 14.3-20.0 CL class
Total	90			

Source: JICA Study Team

6.2.2 Engineering Geology

This area is underlain by lapilli tuff, volcanic breccia, sandy tuff and tuff breccia in descendant order and a relative soft sandy tuff layer is intercalated by tuff breccia as shown in Figure 6.2.1. The depth of ground water surface is 6 m-12 m. Very stiff layers (SPT N Value>50), which is suitable for the foundation of spillway channel, will be encountered at the depth of 2.5 m-8 m.



Source: JICA Study Team

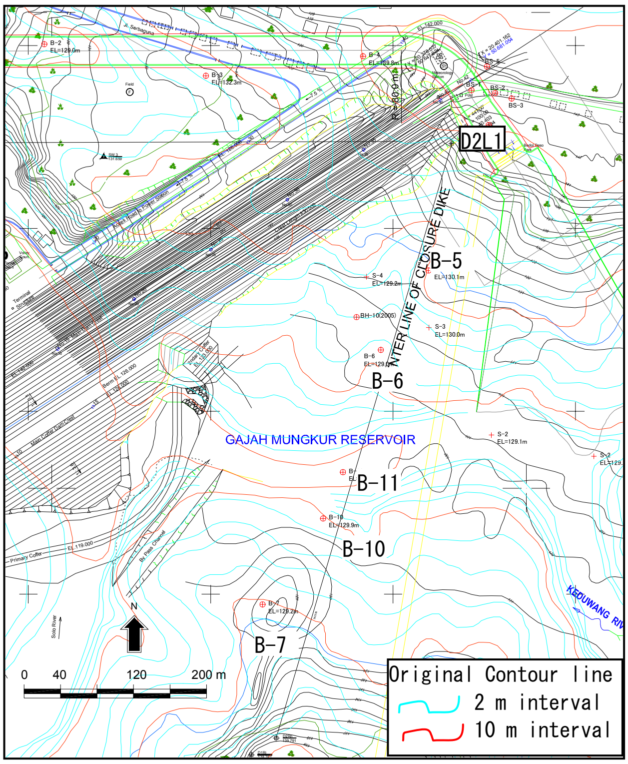
Figure 6.2.1 Geological Profile of Proposed Spillway Alignment

6.3 Closure Dike

6.3.1 Geological Investigations for Closure Dike

Location Map of drilling points is shown in Figure 1.6.4. The original Keduang River is supposed to have flowed westward around the drilling point B-11(about 370 m S17W from bench mark D2L1).

Results of drilling works are summarized in Table 1.6.5.



Note: Original Topographic Feature is Based on 10,000 Scale Map by PBS (1982), Source: JICA Study Team

Figure 6.3.1 Location Map of Closure Dike

Table 6.3.1 Results of Drilling Survey for Closure Dike

Drilling No	Length (m)	Ground water Level (m)	Depth (m) / Geology	Depth(m) / Soil or Rock Condition (SPT N value)
B-5	20	1.5	0.0-1.55 clay 1.55-1.60 sandy clay 1.60-15.0 tuff breccia 15.0-17.0 sandy tuff 17.0-20.0 tuff breccia	0.0-1.60 very soft (N <1) 1.6- 4.50 very stiff 4.5-6.0 hard (N>50) 6.0-20.0 rock
B-6	20	0.0	0.0-0.5 clay 0.5-1.0 sand 1.0-1.6 clay 1.6-3.2 sandy clay 3.2-7.0 clay 7.0-20.0 tuff breccia (10.7-10.9 tuff)	0.0-7.0 very soft (N <1) 7.0-8.5 very stiff (N=36) 8.5-9.5 hard (N>50) 9.5-20.0 rock
B-7	20	0.0	0.0-2.6 clay 2.6-5.0 tuff breccia 5.0-12.2 tuff 12.2-20.0 tuff breccia	0.0-2.6 very soft (N <1) 2.6-5.0 stiff (N =13) 5.0-11.2 hard (N>50) 11.2-20.0 rock
B-10	20	0.0	0.0-1.85 clay 1.85-2.0 sand 2.0-4.2 clay 4.2-5.0 clayey sand 5.0-7.0 clay 7.0-7.4 clayey sand 7.4-9.9 clay 9.9-20.0 tuff breccia	0.0-9.9 very soft (N<1) 9.9-10.0 soft 10.0-13.0 very stiff (N=24-50) 13.0-20.0 hard (N>50)
B-11	23	0.0	0.0-10.0 clayey sand (0.3-0.5, 0.8-1.8, 2.0-2.3, 2.32-2.45, 2.46-3.2, 4.0-4.5, 4.7-5.0, 5.5-6.8 and 9.5-9.7 clay layer) 10.0-21.0 clay 21.0-23.0 volcanic conglomerate	0-21 very soft (N<1) 21-23 hard (N>50)
Total	103			

Note: Groundwater data were obtained immediately after drilling work.
Source: JICA Study Team

6.3.2 Engineering Geology

(1) Geology

At the closure dike site, very soft dam reservoir sediments (SPT N value <1) cover near-horizontal strata of tuff breccia and volcanic breccia, which formed meandering and narrow valleys of Keduang River before Wonogiri Multipurpose Dam construction (See Figure 6.3.1).

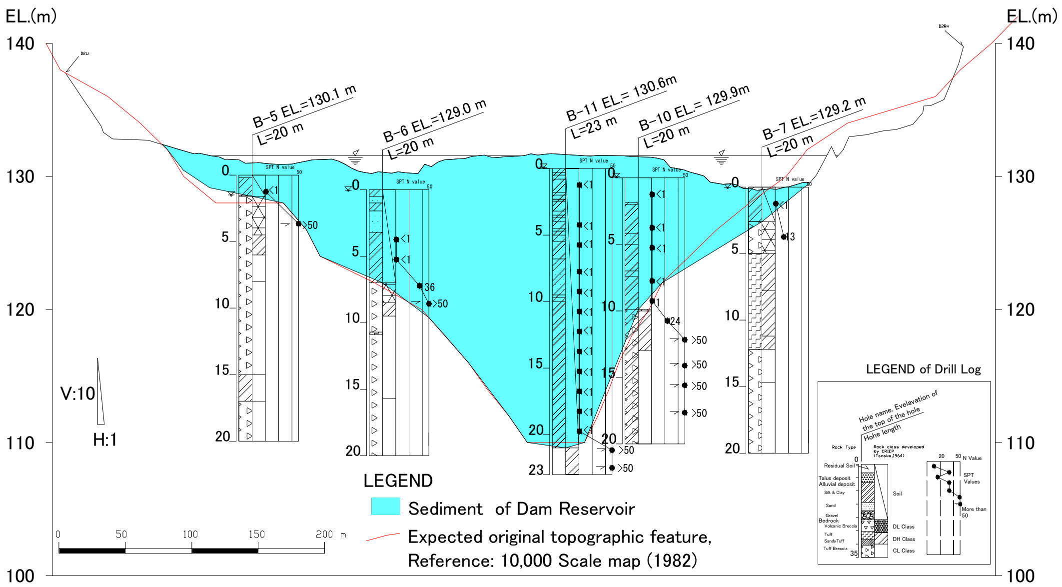
Dam reservoir sediments reaching 21 m in thickness at the middle of the river, are consists mainly of clay. Relatively thin sand strata are sometimes intercalated in some portions of the sediment, which are expected to have been river traces.

(2) Geotechnical Assessment

Tuff breccia underlying soft reservoir sediments is suitable for the foundation of closure dike except for surface weak zone.

Dam reservoir sediments are consists mainly of very soft clay (classified into MH by the Unified Soil Classification System of ASTM D-2487), and often includes detritus of crops, bamboo and plastic sheet especially in surface zone or along the recent course of Keduang River according to drilling core and test pit observation. Therefore, reservoir sediments are not suitable for embankment sources.

Excavation of completely weathered tuff breccia on the reservoir shore instead of dam reservoir sediments would contribute both to embank material acquisition and to the reservoir rehabilitation.



Source: JICA Study Team

Figure 6.3.2 Geological Profile of Closure Dike

6.4 Overflow Weir

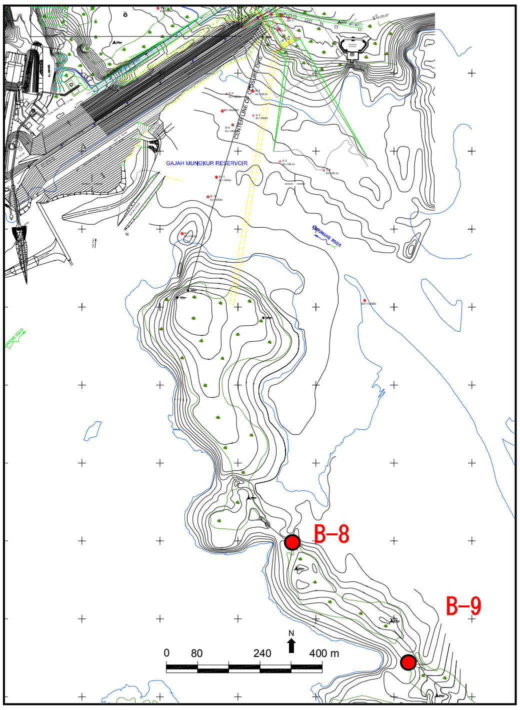
6.4.1 Geological Investigations for Overflow Weir

Location Map of drilling points is shown in Figure 6.4.1. Results of drilling works are summarized in Table 6.4.1.

6.4.2 Engineering Geology

This area is underlain by near-horizontal strata of volcanic breccia, tuff breccia, tuff, and sandy tuff in descendant order.

After removal of surface residual soil including plant detritus etc, embankment dike and small structures of 2-3 m in height can be founded on the base rock (See Figure 6.4.2 and Figure 6.4.3)



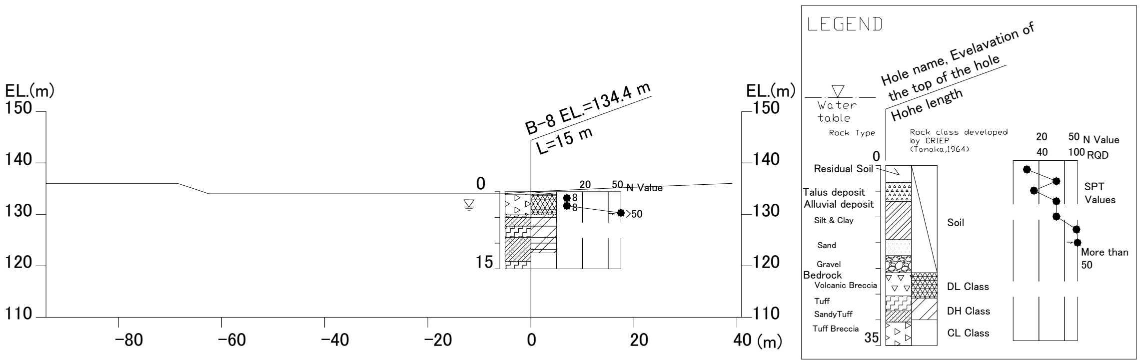
Source: JICA Study Team

Figure 6.4.1 Location Map of Drilling Points for Overflow Weir

Table 6.4.1 Results of Drilling Survey for Closure Dike

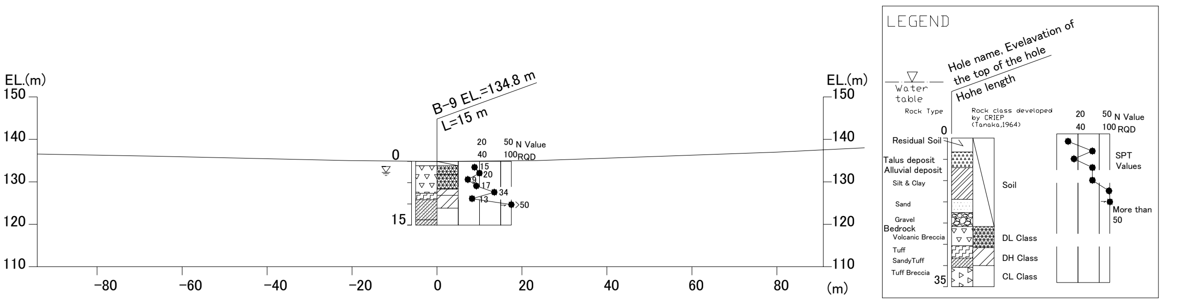
Drilling No	Length (m)	Ground water Level (m)	Depth (m) / Geology	Depth(m) / Soil or Rock Condition (SPT N value)
B-8	15	3.0	0.0-0.5 residual soil 0.5-4.5 tuff breccia 4.5-5.0 tuff 6.5-6.7 sandy tuff 6.7-8.9 tuff 8.9-13.55 sandy tuff 13.55-15.0 tuff breccia	0.0-0.5 very soft-soft 0.5- 4.5 firm (N=8) 4.5-11.0 hard (N>50) 11.0-20.0 rock
B-9	15	2.6	0.0-1.0 residual soil 1.0-7.5 volcanic breccia 7.5-9.0 tuff 9.0-15.0 sandy clay	0.0-1.0 very soft-soft 1.0-6.5 firm-stiff (N=9~20) 6.5-11.0 stiff-very stiff (N=13~50) 11.0-15.0 rock
Total	30			

Source: JICA Study Team



Source: JICA Study Team

Figure 6.4.2 Geological Profile of Overflow Weir (Drill hole B-8)



Source: JICA Study Team

Figure 6.4.3 Geological Profile of Overflow Weir (Drill hole B-9)

6.5 Construction Material for Concrete Aggregates

The quarry site exploited for the construction of the Wonogiri Mulutipurpose dam is located behind Wonogiri town approximately 2 km to the west from the dam site. The site, underlain by andesite and well-cemented volcanic breccia, is suitable for concrete source in both quantitative and qualitative aspects.

Quarry Site of the Wonogiri Dam