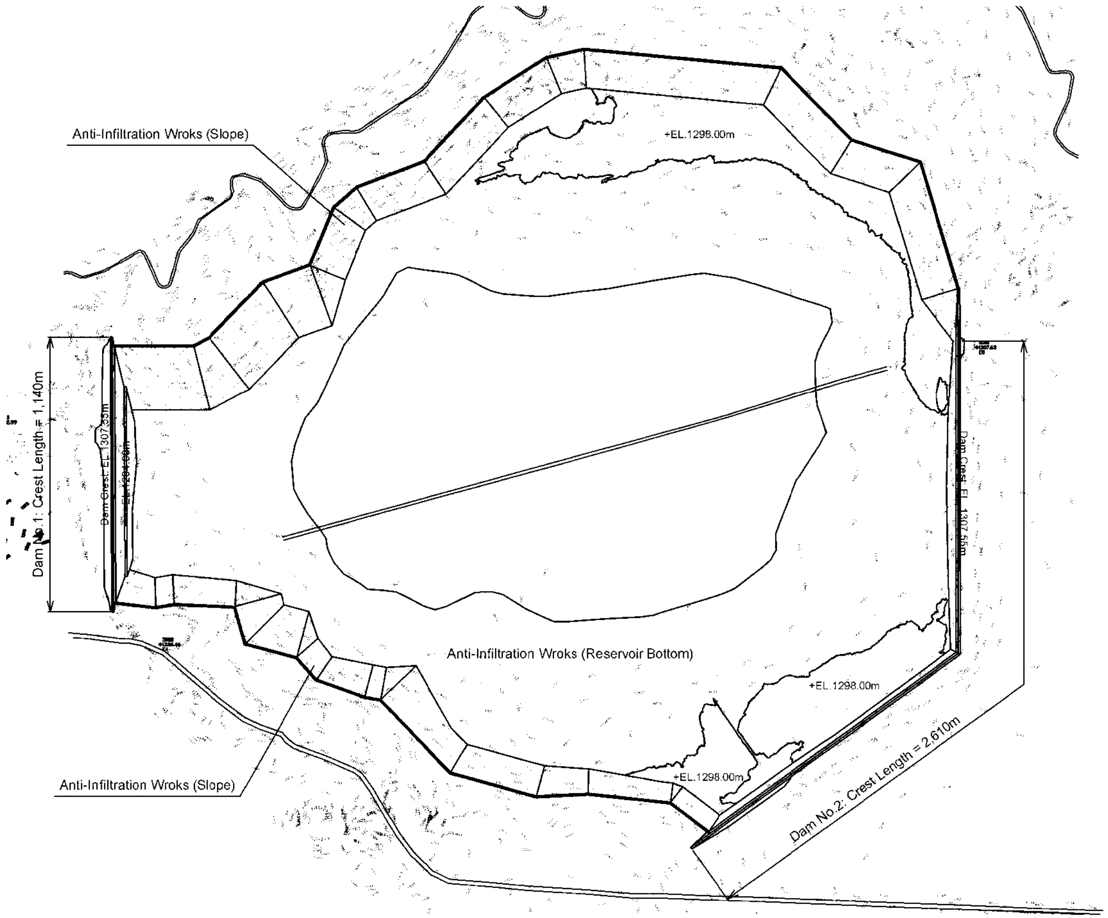
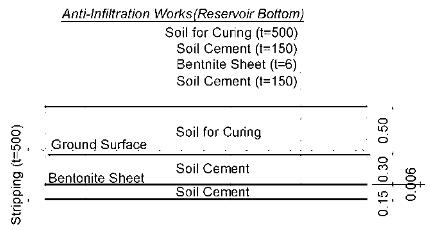
APPENDIX G

Reservoir Planning

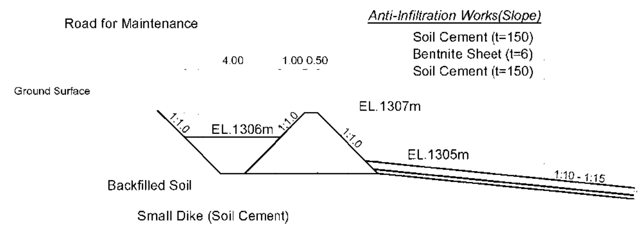
DWG No.	Title of Drawings
01	Dam, Plan View and Typical Cross Section of Anti-Infiltration Works
02	Dam, Typical Cross Section and Detail of Crest



Plan View of Dams
Scale 1 : 20,000

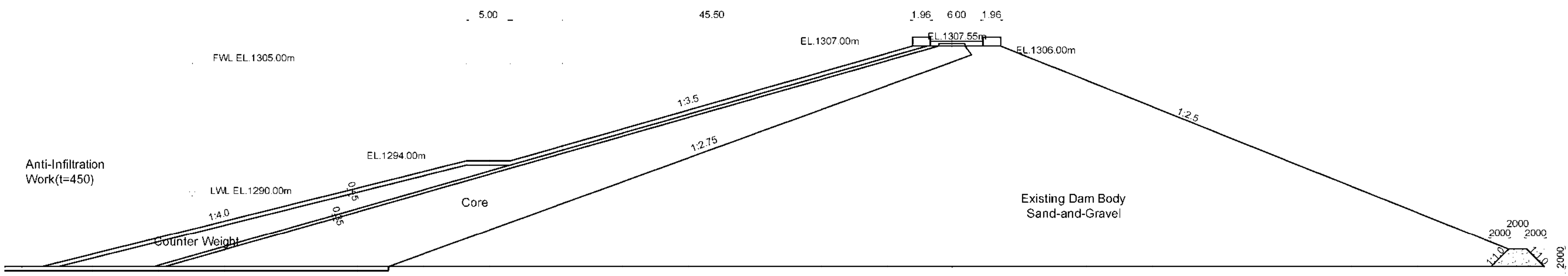


Scale 1 : 50
Typical Cross Section of Anti-Infiltration Works (Reservoir Bottom)

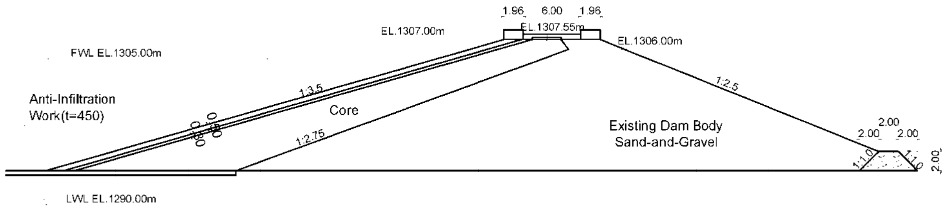


Typical Cross Section of Anti-Infiltration Works (Slope)
Scale 1 : 200

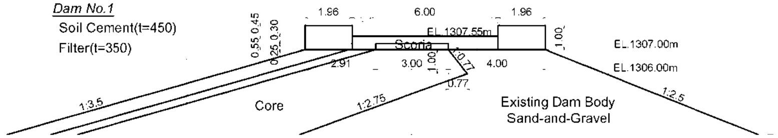
Project: Preparatory Survey for Yeghvard Irrigation System Improvement Project		Drawing No:	Drawn by: Sanyu Consultants Inc.
Drawing Title: Dam, Plan View and Typical Cross Section of Anti-Infiltration Works		Scale: Indicated	Checked by:
Revision	Initials	All dimension in: Meter	Approved by:



Typical Cross Section (Dam No.1)
Scale 1 : 500



Typical Cross Section (Dam No.2)
Scale 1 : 500



Detail of Dam Crest
Scale 1 : 200

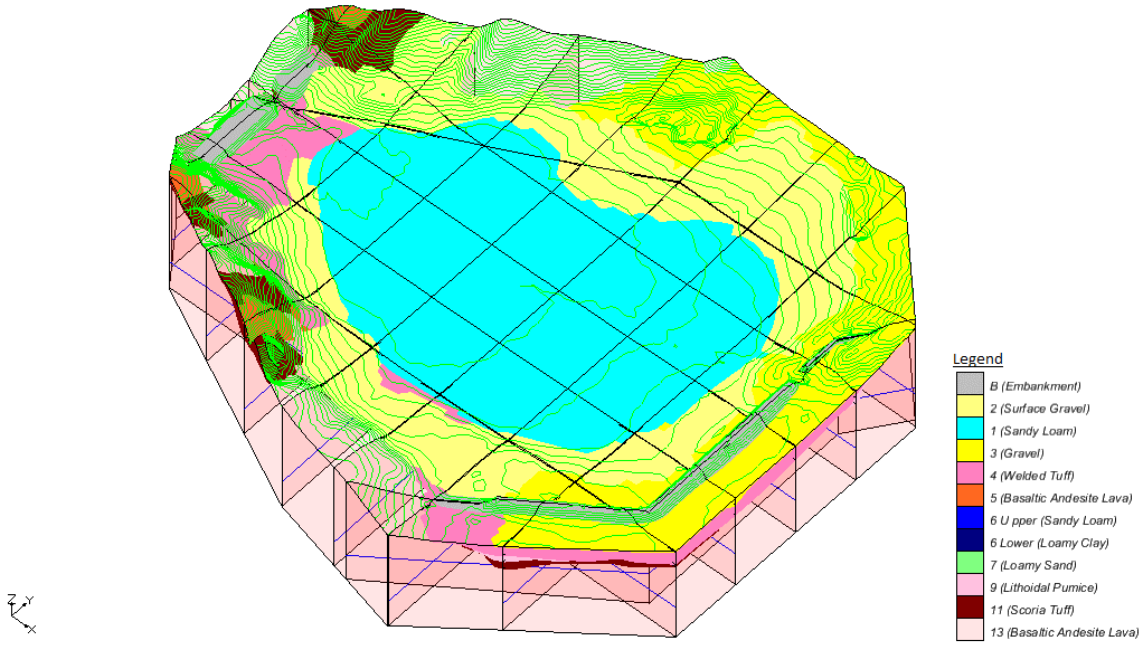
Project: Preparatory Survey for Yeghvard Irrigation System Improvement Project		Drawing No:	Drawn by: Sanyu Consultants Inc.
Drawing Title: Dam, Typical Cross Section and Detail of Crest		Scale: Indicated	Checked by:
Revision	Initials	All dimension in: Meter	Approved by:

APPENDIX H

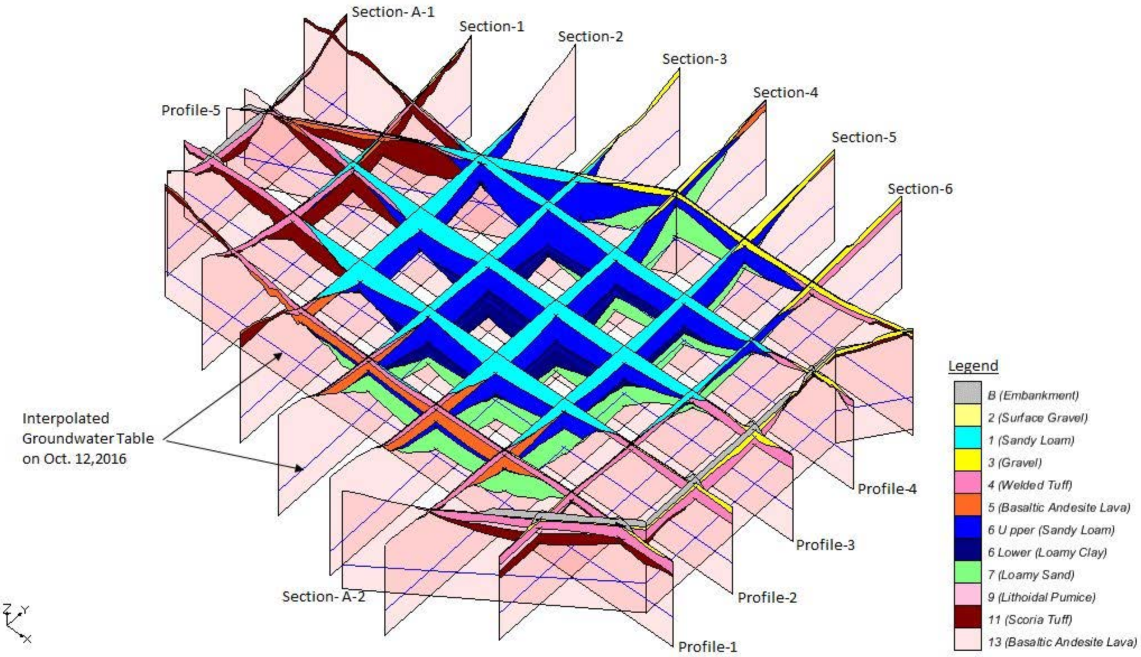
Estimation of Leakage Rate

Source: JICA Study Team if not specified

Appendix H-1: Panel Diagram of Geology in Yeghvard Reservoir Site



Surface Geology and Location of Section Lines

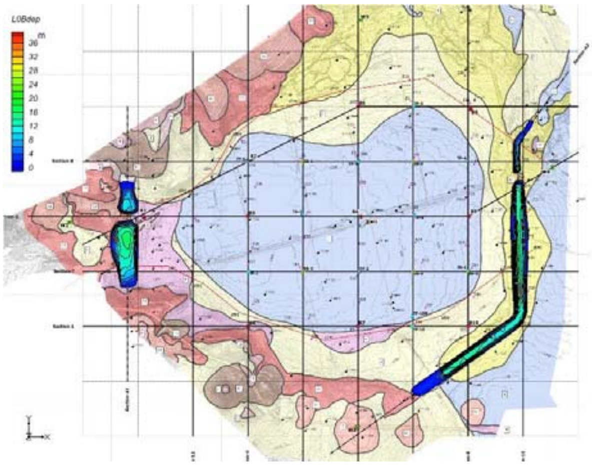


Panel Diagram of Geologic Layers

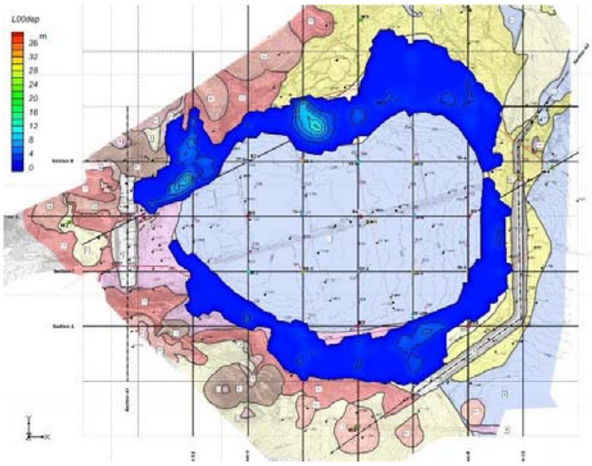
H:V=1:5

Note: The thin layers of the layer 1, layer 2 and Layer 12 distributing on the slope are included in the underling layer

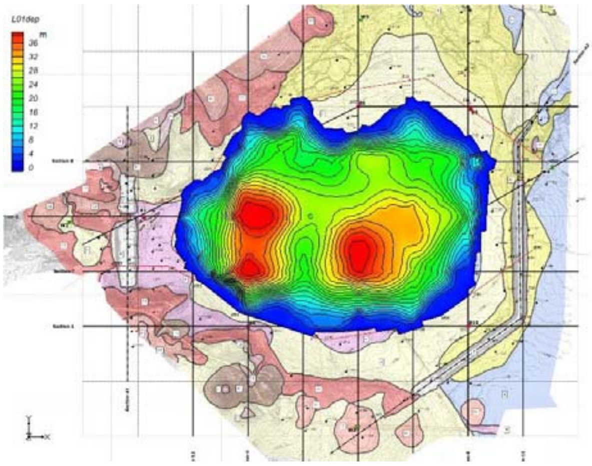
Appendix H-2: Distribution of Main Geologic Layers in Yeghvard Reservoir Site



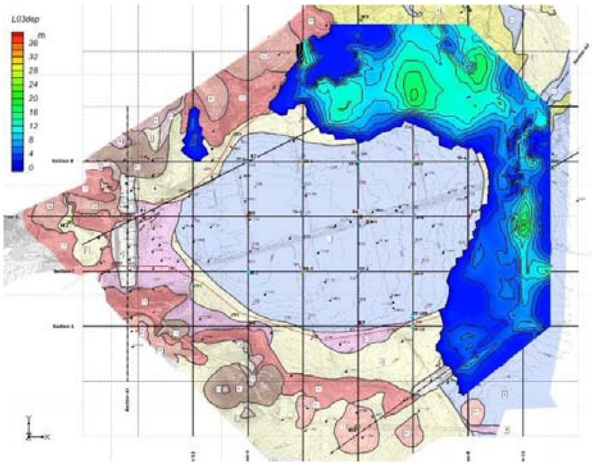
Embankment



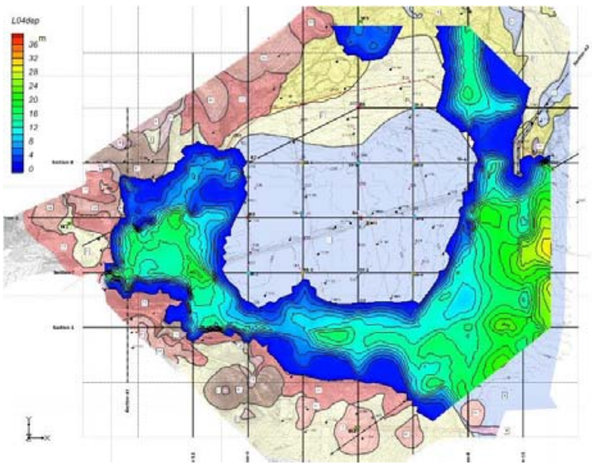
Layer 2



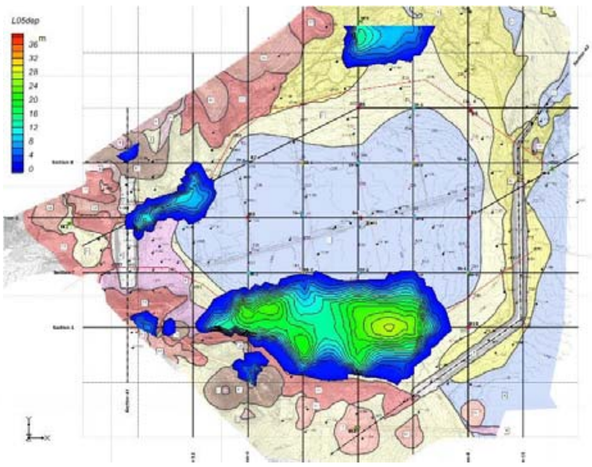
Layer 1



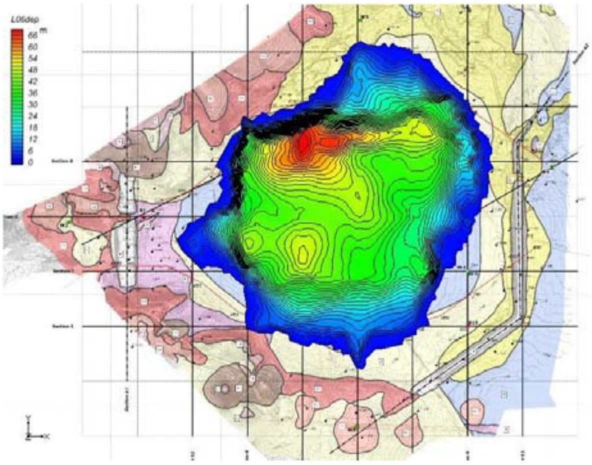
Layer 3



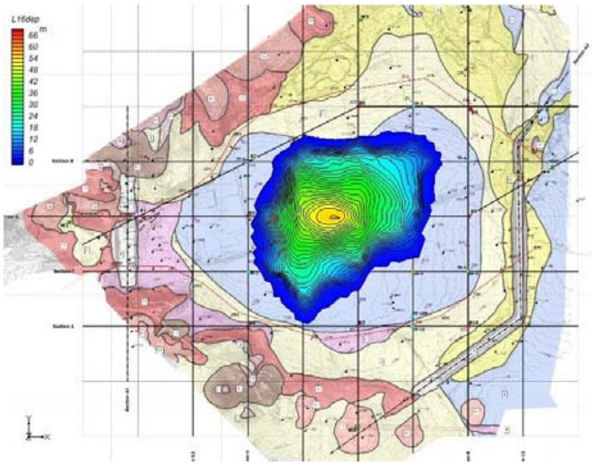
Layer 4



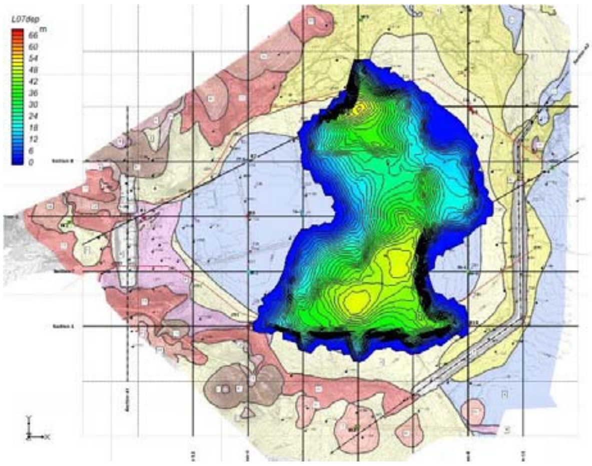
Layer 5



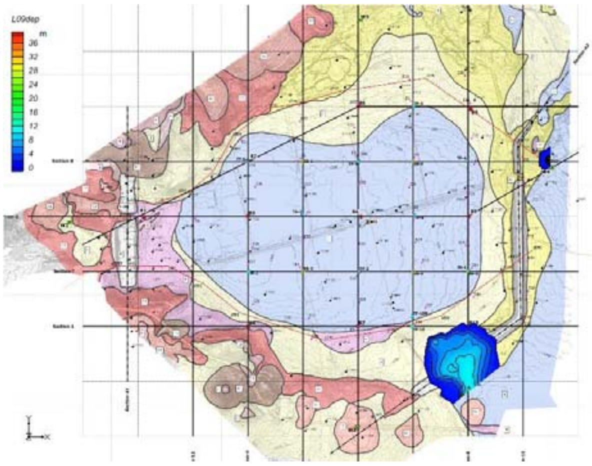
Layer 6 upper



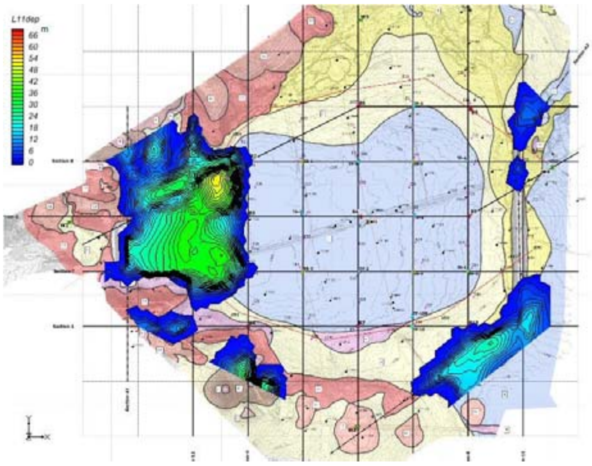
Layer 6 lower



Layer 7



Layer 9



Layer 11

Appendix H-3: Frequency Graph of Permeability Coefficient of Main Impervious Layers in Yeghvard Reservoir Site

1. Geologic Layer 1

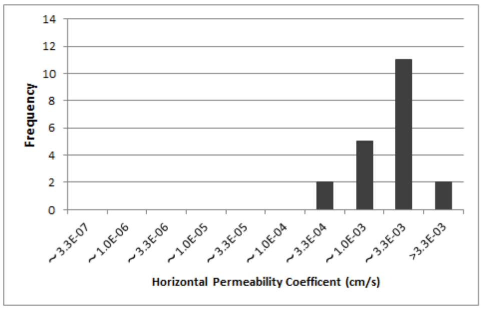
Test Pit

Present Investigation, 2015/16

Past Investigation, 1985

Horizontal Permeability

Present Investigation, 2015/16:

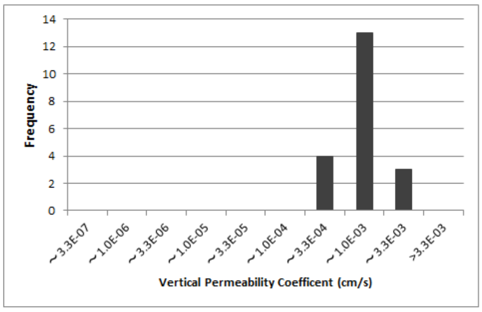


k_{GM}	1.00 m/day	**1.2E-03** cmc/s
$k_{AM,weighted}$	1.42 m/day	1.6E-03 cmc/s

Past Investigation, 1985: (No data)

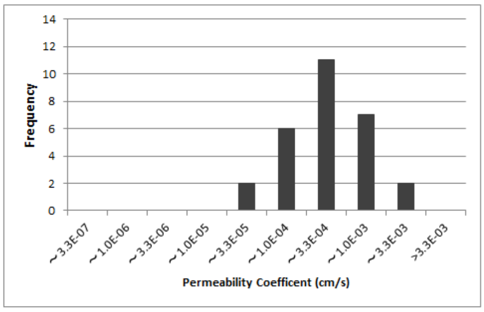
Vertical Permeability

Present Investigation, 2015/16:



$k\_GM_{weighted}$	0.37 m/day	**4.3E-04** cmc/s
$k\_AM_{weighted}$	0.44 m/day	5.1E-04 cmc/s

Past Investigation, 1985:



$k\_GM_{weighted}$	0.18 m/day	**2.1E-04** cmc/s
$k\_AM_{weighted}$	0.27 m/day	3.1E-04 cmc/s

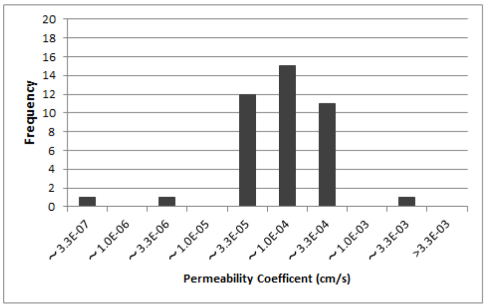
Borehole

Present Investigation, 2015/16

Past Investigation, 1985

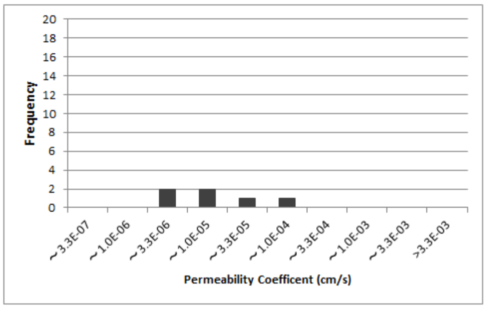
Horizontal Permeability

Present Investigation, 2015/16:



$k\_GM_{weighted}$	0.042 m/day	**4.9E-05** cmc/s
$k\_AM_{weighted}$	0.086 m/day	1.0E-04 cmc/s

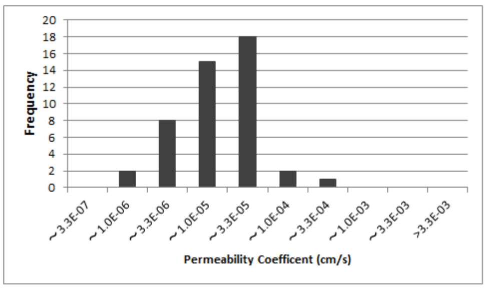
Past Investigation, 1985:



$k\_GM_{weighted}$	0.008 m/day	**9.7E-06** cmc/s
$k\_AM_{weighted}$	0.015 m/day	1.7E-05 cmc/s

Vertical Permeability

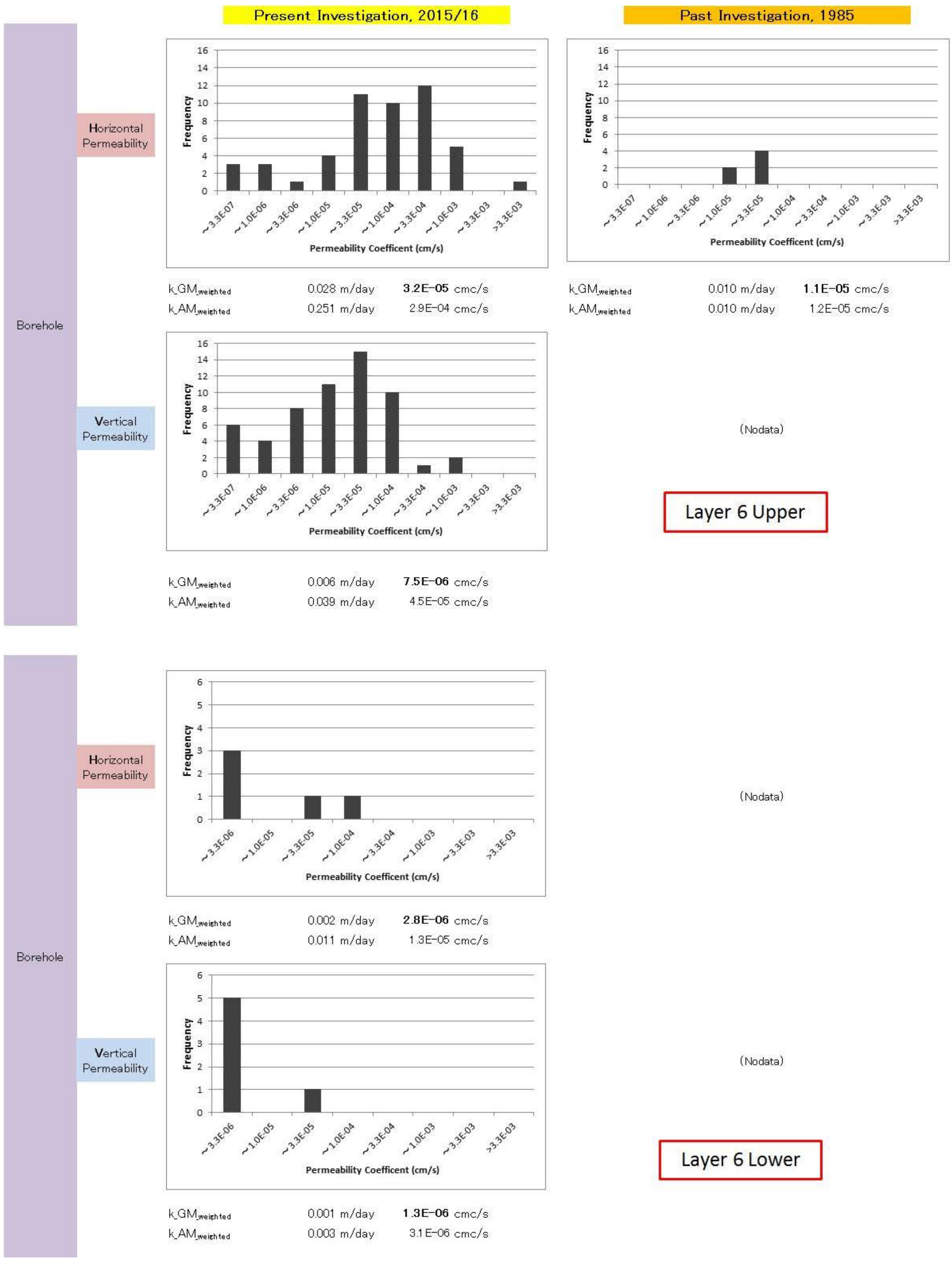
Present Investigation, 2015/16:



$k\_GM_{weighted}$	0.007 m/day	**8.3E-06** cmc/s
$k\_AM_{weighted}$	0.014 m/day	1.6E-05 cmc/s

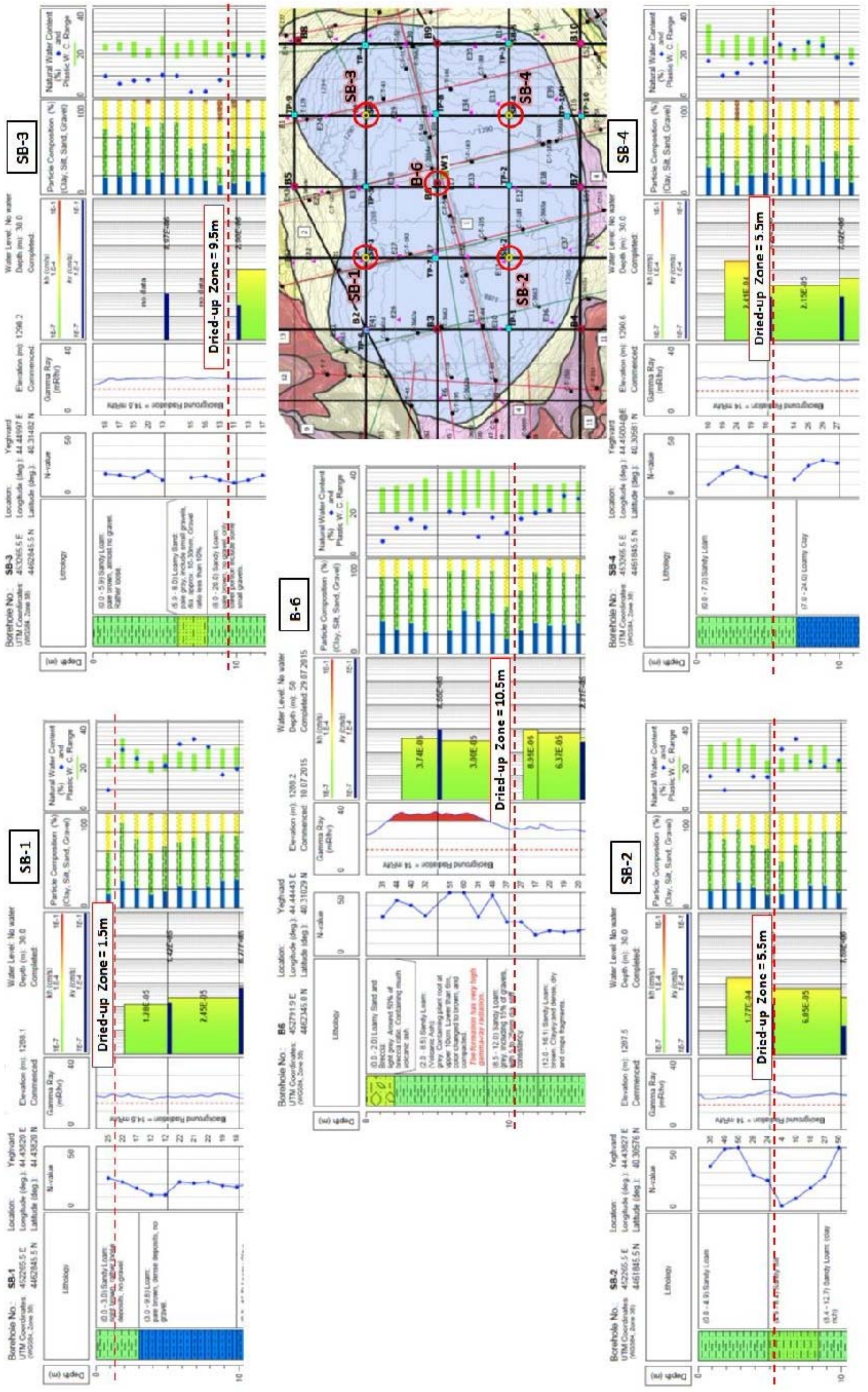
Past Investigation, 1985: (No data)

2. Geologic Layer 6



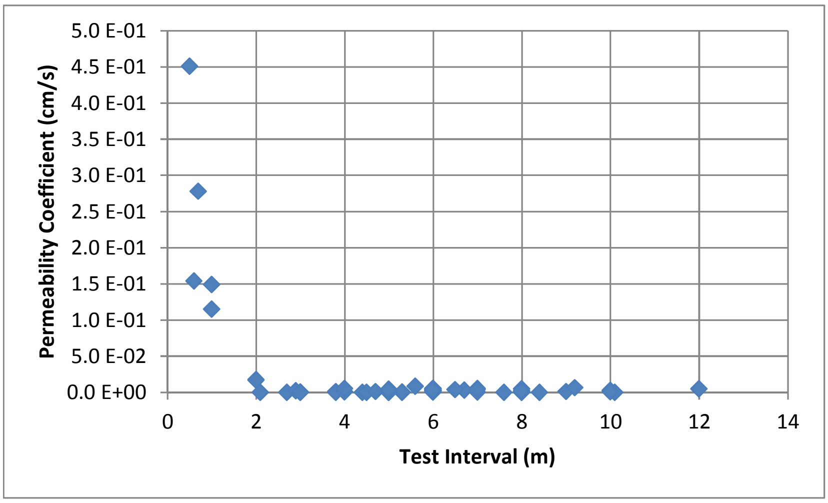
Source: JICA Study Tean(2015/16) and ArmGiproVodxoz(1985)

Appendix H-4: Surface Dried-up Zone of Geologic Layer 1

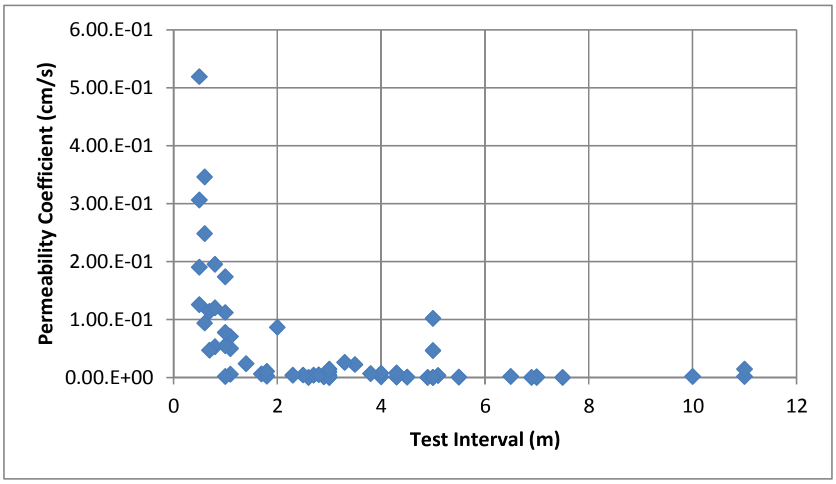


Note: The coefficient of permeability obtained by test pit is larger than that by borehole. The test pit value is used for the upper 10m of the layer 1 in leakage calculation assuming that it represents the surface dried up portion where a large suction pressure may exert in infiltration.

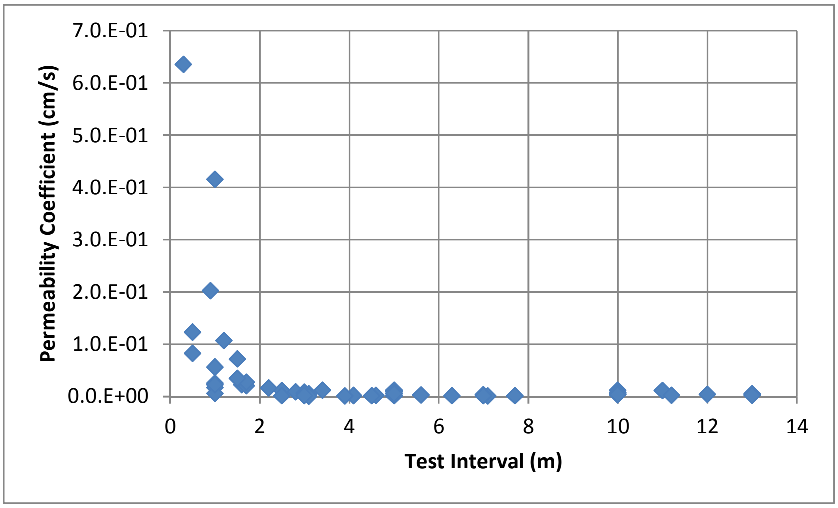
Appendix H-5: Relationship between Test Interval and Permeability Coefficient of Main Volcanic Effusive Layers



Layer 4 (Welded Tuff)



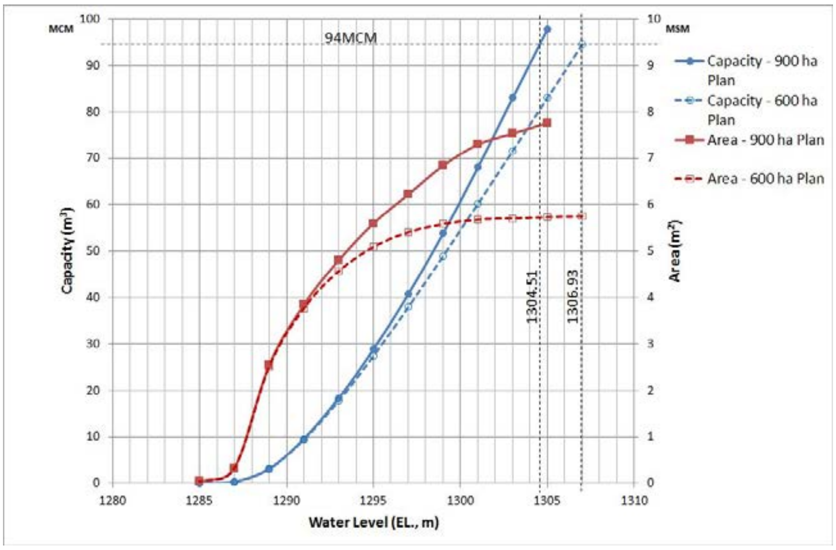
Layer 11 (Scoria Tuff/Volcanic Breccia)



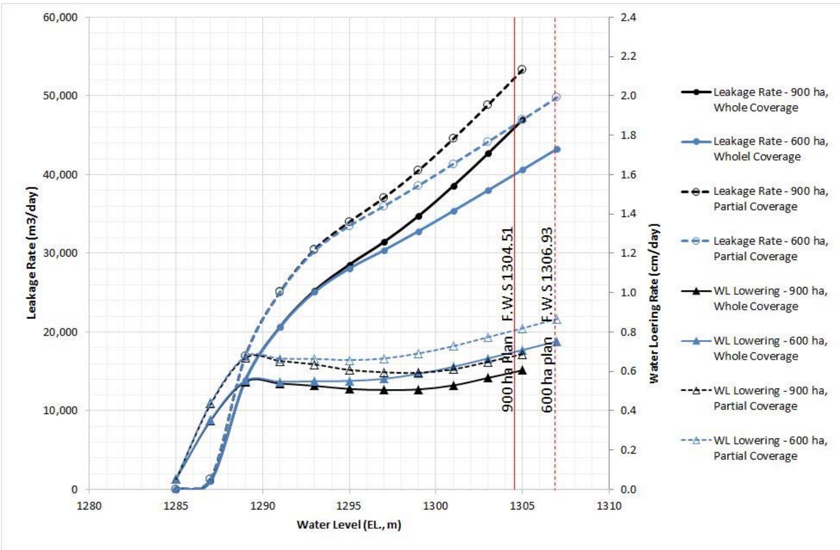
Layer 13&15 (Basalt Lava)

Source: ArmGiproVodxoz(1985)

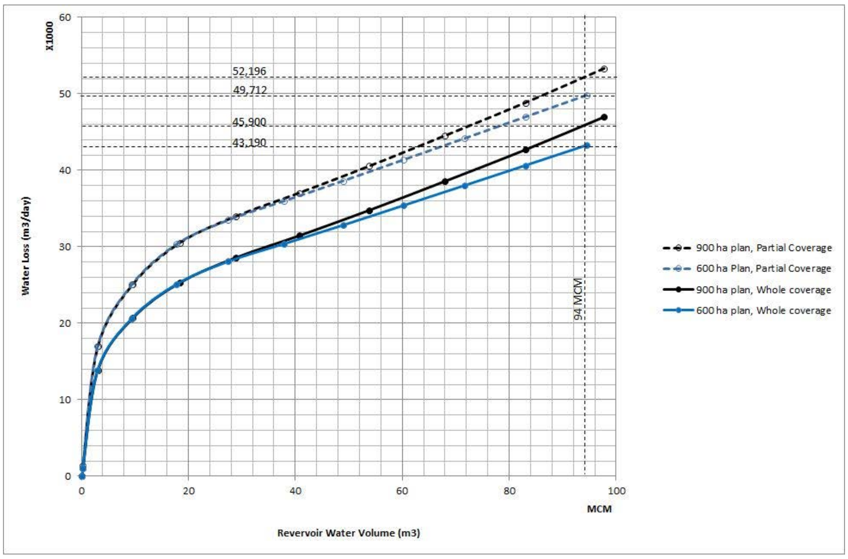
Appendix H-6: H-V and H-A Curves Calculated by TIN



Appendix H-7: Reservoir Water Level – Leakage Rate Curve



Appendix H-8: Reservoir Water Volume – Leakage Rate Curve



Appendix H-9: Leakage Rate Summary Calculated by 2-D Simple Method

1. Leakage Rate at 94 MCM

Anti-Infiltration Layer Coverage	FWS	Area	Capacity	Ave. Depth	Max. Depth	Leakage Rate (m3/day)				Leakage Rate/94 MCM	Water Level Lowering Rate	Area (1,000 m2)			
	(m)	(1,000 m2)	(1,000 m3)	(m)	(m)	Zone 1	Zone 2	Zone 3	Total	(%/day)	(m/day)	Zone 1	Zone 2	Zone 3	Total
No Coverage	1304.5	7,737	94,031	12.15	22.45	7,662,083 *91.2%*	708,701 *8.4%*	26,368 *0.3%*	8,397,152 *100.0%*	8.930%	1.085	3,482 *45.0%*	1,629 *21.1%*	2,626 *33.9%*	7,737 *100.0%*
Partial Coverage						12,992 *0.2%*	12,836 *0.2%*	26,368 *0.3%*	52,196 *0.6%*	0.056%	0.007				
Whole Coverage						12,992 *0.2%*	12,836 *0.2%*	20,072 *0.2%*	45,900 *0.5%*	0.049%	0.006				

Case 2 - 600 ha Plan

Anti-Infiltration Layer Coverage	FWS	Area	Capacity	Ave. Depth	Max. Depth	Leakage Rate (m3/day)				Leakage Rate/Capa-city	Water Level Lowering Rate	Area (1,000 m2)			
	(m)	(1,000 m2)	(1,000 m3)	(m)	(m)	Zone 1	Zone 2	Zone 3	Total	(%/day)	(m/day)	Zone 1	Zone 2	Zone 3	Total
No Coverage	1306.9	5,745	94,043	16.37	24.87	2,813,005 *33.5%*	746,422 *8.9%*	27,208 *0.3%*	3,586,635 *42.7%*	3.814%	0.464	1,490 *25.9%*	1,629 *28.3%*	2,626 *45.7%*	5,745 *100.0%*
Partial Coverage						8,507 *0.1%*	13,997 *0.2%*	27,208 *0.3%*	49,712 *0.6%*	0.053%	0.006				
Whole Coverage						8,507 *0.1%*	13,997 *0.2%*	20,686 *0.2%*	43,190 *0.5%*	0.046%	0.006				

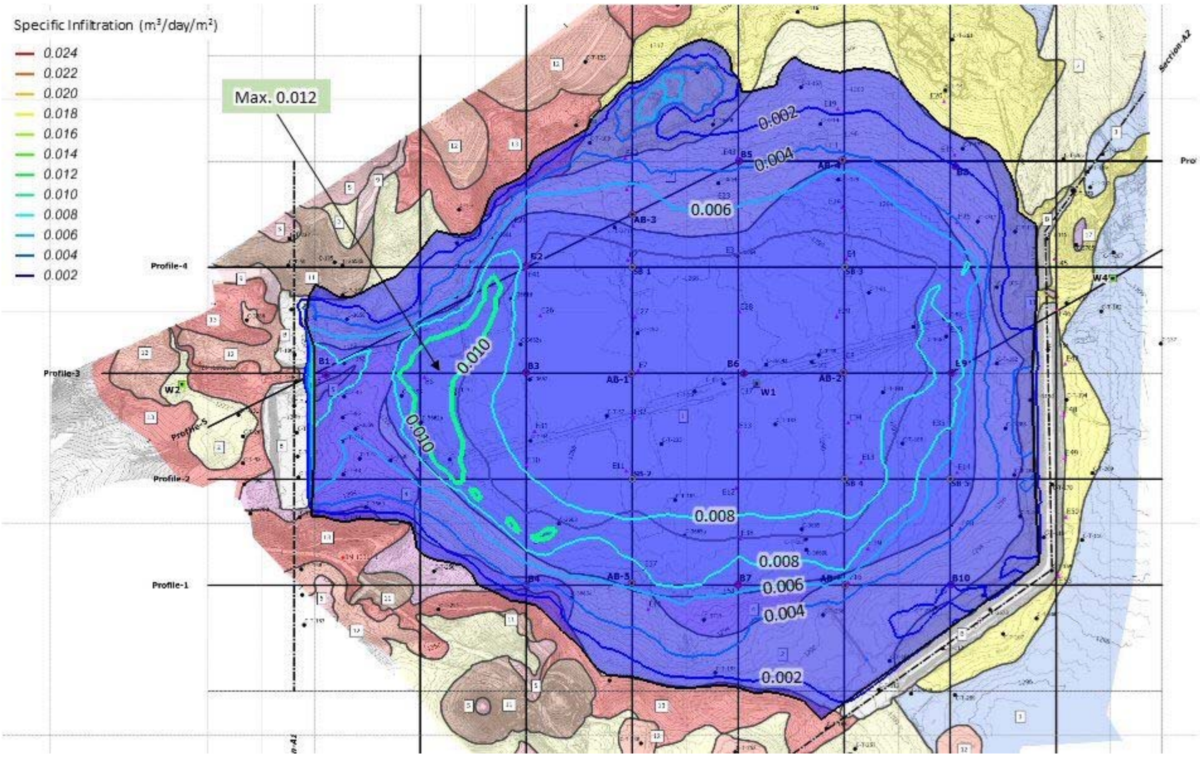
(shaded cell) Anti-infiltration covering assumed

2. Average Leakage Rate in Irrigation Period of Standard Year

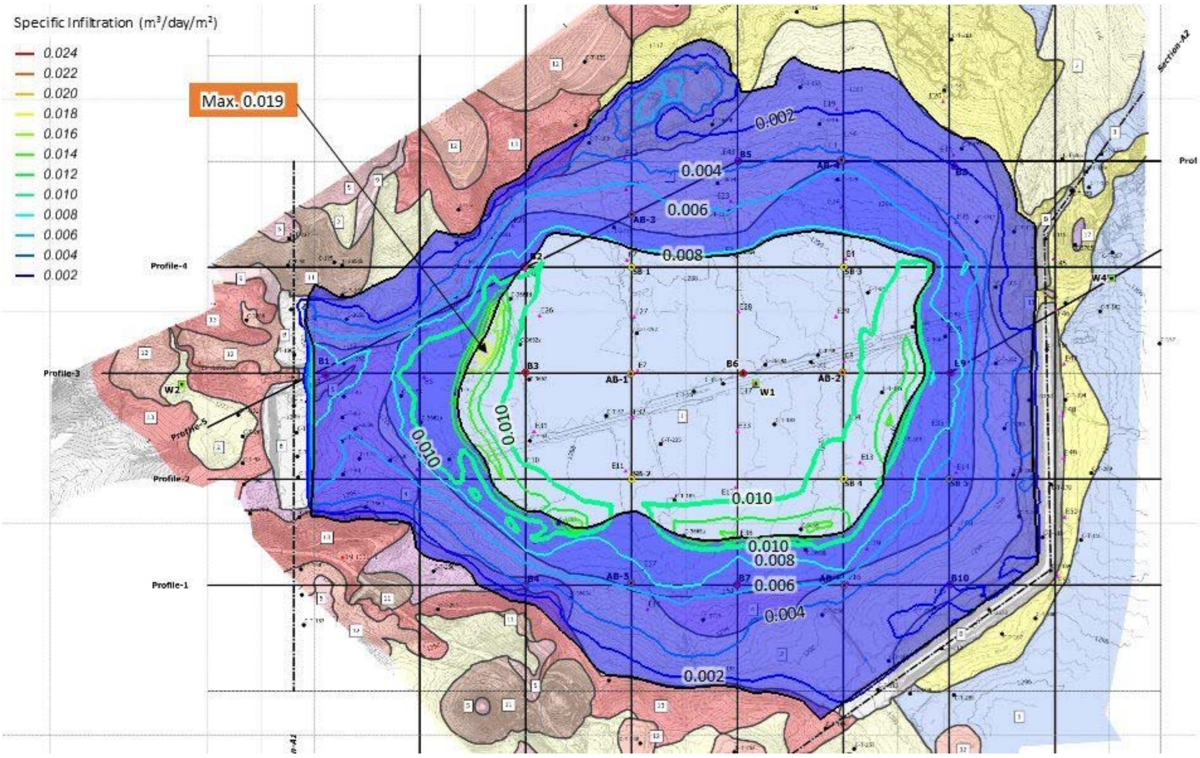
Reservoir Volume Change in Standard Year					900 ha Plan						600ha Plan			
Preiod			Days	Reservoir Volume	Whole		Partial				Whole		Partial	
				(MCM)	Imperviousness: Standard		Imperviousness: Standard		Imperviousness: Zone 2 - 2/3		Imperviousness: Standard		Imperviousness: Standard	
					m^3/d	m^3/period	m^3/d	m^3/period	m^3/d	m^3/period	m^3/d	m^3/period	m^3/d	m^3/period
Jan	01-10	1	10	0.00	0		0		0		0		0	
	11-20	2	10	0.00	0		0		0		0		0	
	21-31	3	11	0.00	0		0		0		0		0	
Feb	01-10	1	10	0.00	0		0		0		0		0	
	11-20	2	10	0.00	0		0		0		0		0	
	21-28	3	28	0.00	0		0		0		0		0	
Mar	01-10	1	10	6.00	16931.2	84656	20602.3	103012	21520.8	107604	17025.5	85128	20721.4	103607
	11-20	2	10	19.04	25500.5	212159	30737.7	256700	32502.3	270116	25499.8	212627	30749.6	257355
	21-31	3	11	32.35	29419.5	302060	34885.7	360929	37295.7	383889	29162	300640	34660.8	359757
Apr	01-10	1	10	50.99	34056.5	317380	39800.4	373431	42755.4	400256	33301.7	312319	39119.8	368903
	11-20	2	10	66.83	38259.3	361579	44214	420072	47576.7	451661	36918.2	351100	42997.2	410585
	21-30	3	10	74.37	40318.4	392889	46367.6	452908	49913.1	487449	38648.5	377834	44850.6	439239
May	01-10	1	10	84.81	43211.4	417649	49390.9	478793	53188.5	515508	41055.6	398521	47427.8	461392
	11-20	2	10	93.55	45759.3	444854	52049.9	507204	56062.8	546257	43075.9	420658	49590.1	485090
	21-31	3	11	93.86	45849.6	503849	52144.3	573068	56164.7	617251	43147.6	474229	49666.8	545913
Jun	01-10	1	10	87.40	43966.4	449080	50178.9	511616	54040.3	551025	41654.3	424010	48068.6	488677
	11-20	2	10	78.14	41351.6	426590	47447.6	488133	51083.8	525621	39517.3	405858	45780.8	469247
	21-30	3	10	67.78	38513.8	399327	44480.9	459643	47867.7	494758	37135.6	383265	43230.2	445055
Jul	01-10	1	10	59.22	36220.8	373673	42075.8	432784	45245.6	465567	35177.2	361564	41131.6	421809
	11-20	2	10	50.46	33922.2	350715	39658.5	408672	42598.9	439223	33180.9	341791	38990.3	400610
	21-31	3	11	41.07	31542.5	360056	37145	422419	39826.3	453339	31092.5	353504	36743.4	416535
Aug	01-10	1	10	33.21	29628.5	305855	35108.2	361266	37545.1	386857	29352.4	302225	34866.5	358050
	11-20	2	10	25.65	27568.4	285985	32922.9	340156	35048.8	362970	27527.9	284402	32905.1	338858
	21-31	3	11	18.26	25236.9	290429	30453.4	348570	32174.6	369729	25260.5	290336	30495.2	348702
Sep	01-10	1	10	13.10	22515.6	238763	27255.7	288546	28649.5	304121	22603.6	239321	27378.2	289367
	11-20	2	10	10.34	21060	217878	25545.3	264005	26764	277068	21118.6	218611	25625.6	265019
	21-30	3	10	6.88	17845.2	194526	21698.7	236220	22679.1	247216	17952.6	195356	21834.5	237301
Oct	01-10	1	10	3.62	14459.2	161522	17637.1	196679	18388.1	205336	14518.1	162354	17710.9	197727
	11-20	2	10	1.66	7375.9	109176	9012.8	133250	9476.9	139325	7539.2	110287	9213.3	134621
	21-31	3	11	0.47	1904.5	51042	2342.5	62454	2598	66412	1978.8	52349	2433.5	64057
Nov	01-10	1	10	0.47	1904.5		2342.5		2598		1978.8		2433.5	
	11-20	2	10	0.47	1904.5		2342.5		2598		1978.8		2433.5	
	21-30	3	10	0.47	1904.5		2342.5		2598		1978.8		2433.5	
Dec	01-10	1	10	0.47	1904.5		2342.5		2598		1978.8		2433.5	
	11-20	2	10	0.47	1904.5		2342.5		2598		1978.8		2433.5	
	21-31	3	11	0.47	1904.5		2342.5		2598		1978.8		2433.5	
Total			245			7,251,689		8,480,525		9,068,552		7,058,282		8,307,475
Average (m^3/day)					29598.7		34614.4		37014.5		28809.3		33908.1	
Proprtion to 94 MCM					0.031%		0.037%		0.039%		0.031%		0.036%	

Appendix H-10: Specific Leakage Rate Distribution at Full Water Level by 2-D Simple Method – 900 ha Plan

Unit: $m^3/day/m^2$



Whole Coverage of Anti-infiltration Layer

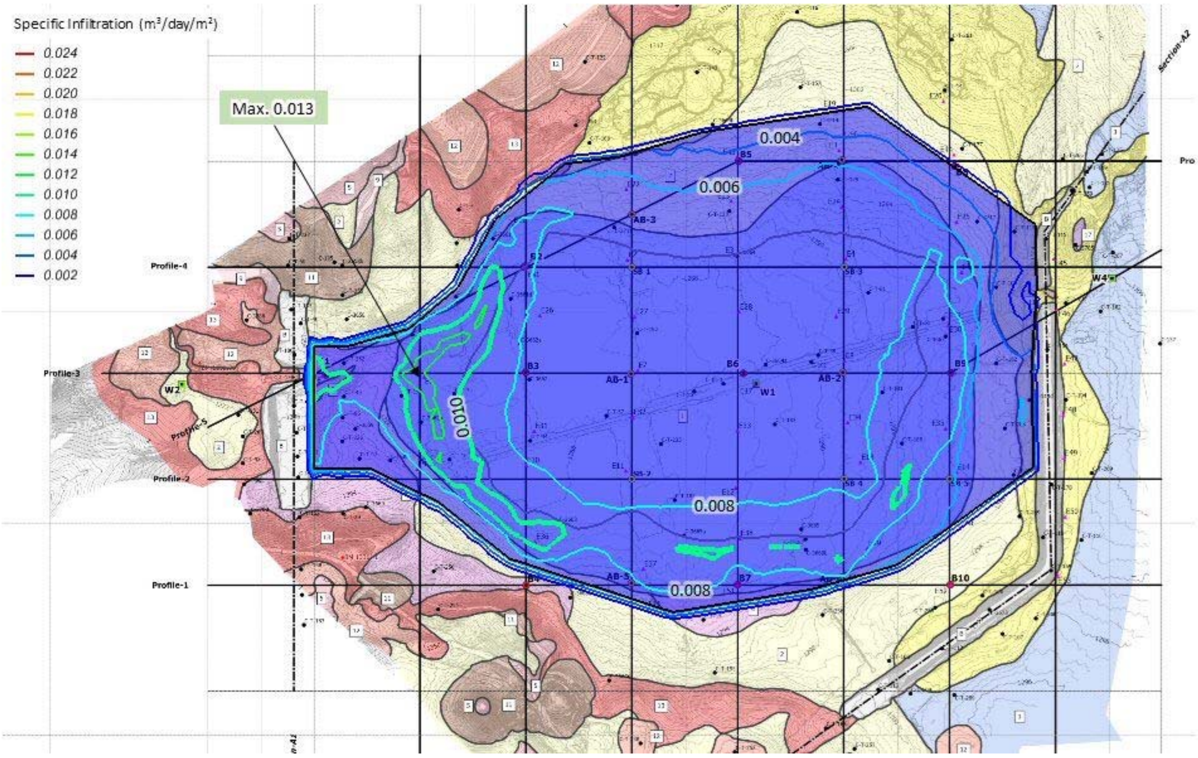


Partial Coverage of Anti-infiltration Layer

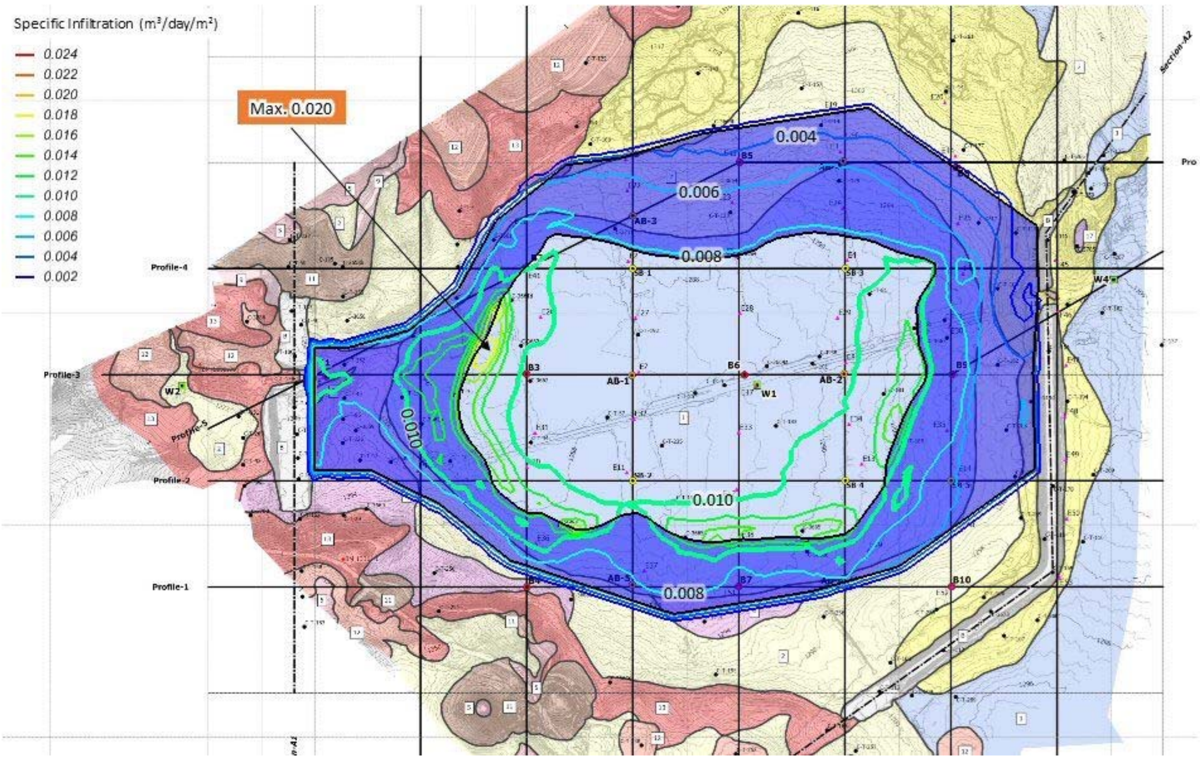
Note: The area painted blue shows an extent covered with the anti-infiltration layer.

Appendix H-11: Specific Leakage Rate Distribution at Full Water Level by 2-D Simple Method – 600 ha Plan

Unit: $m^3/day/m^2$

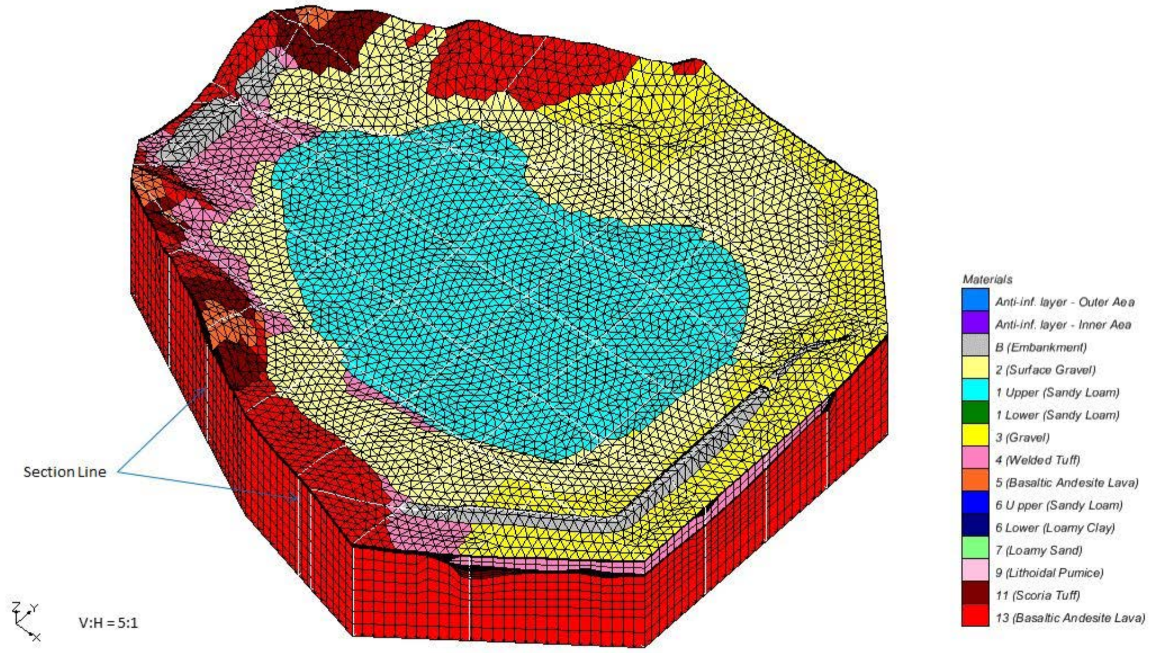


Whole Coverage of Anti-infiltration Layer

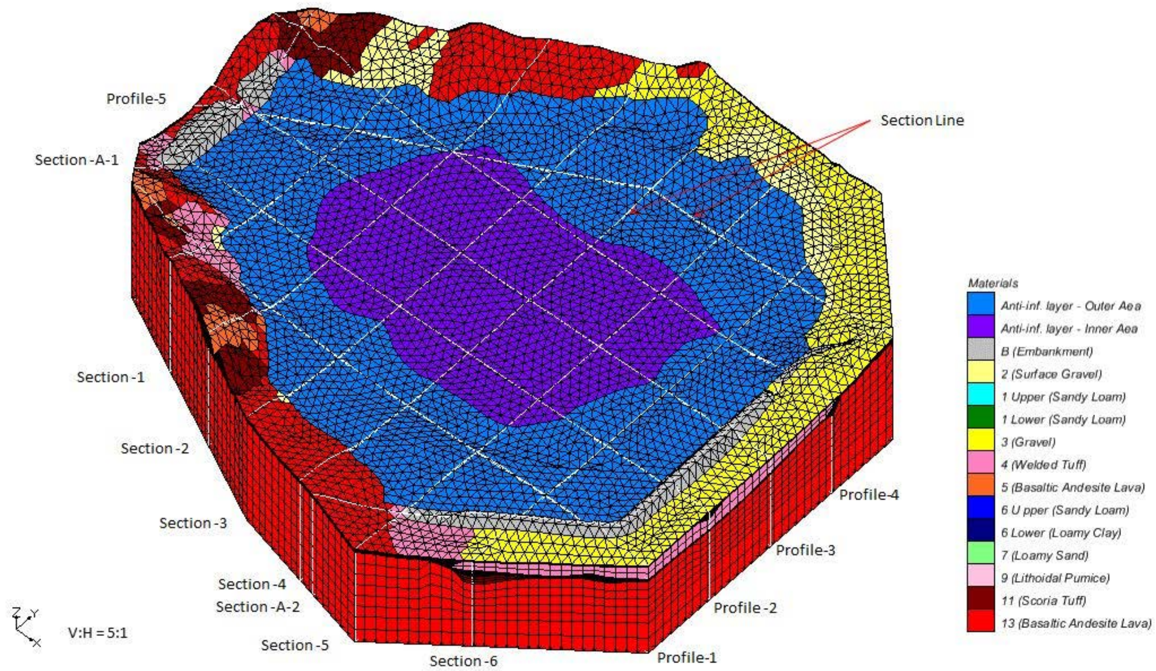


Partial Coverage of Anti-infiltration Layer

Appendix H-12: Model Mesh of 3-D FEM Method – Whole

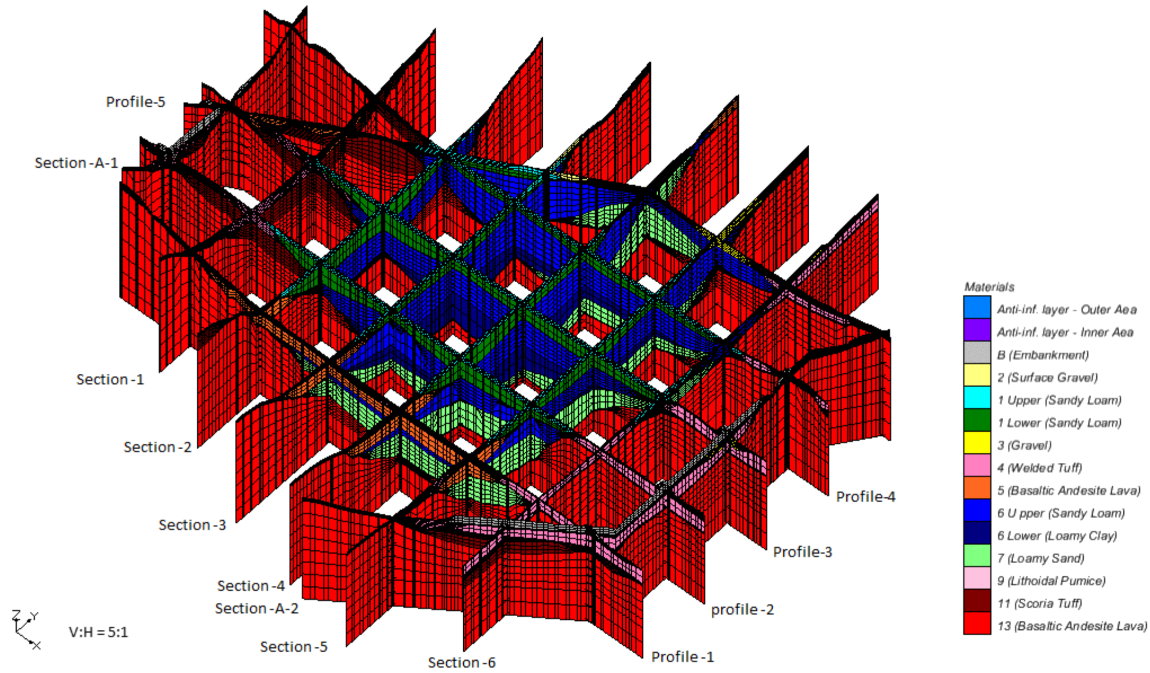


No Anti-infiltration Layer Covered

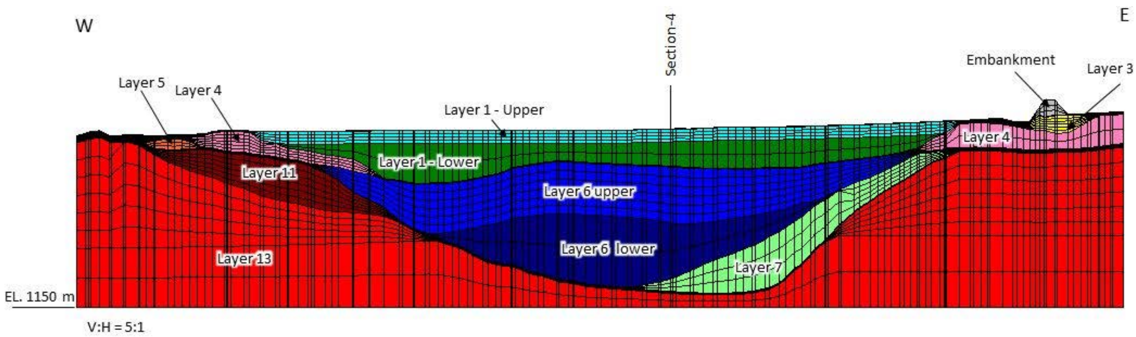


Anti-infiltration Layer Covered (600 ha Plan)

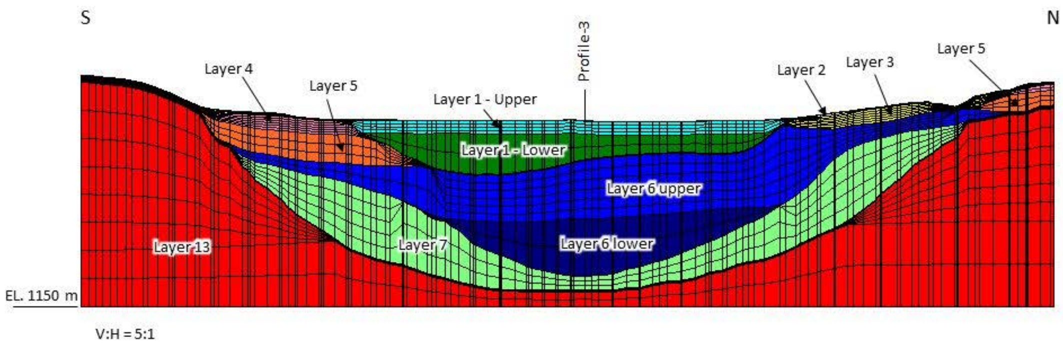
Appendix H-13: Model Mesh of 3-D FEM Method – Main Sections



Panel Diagram

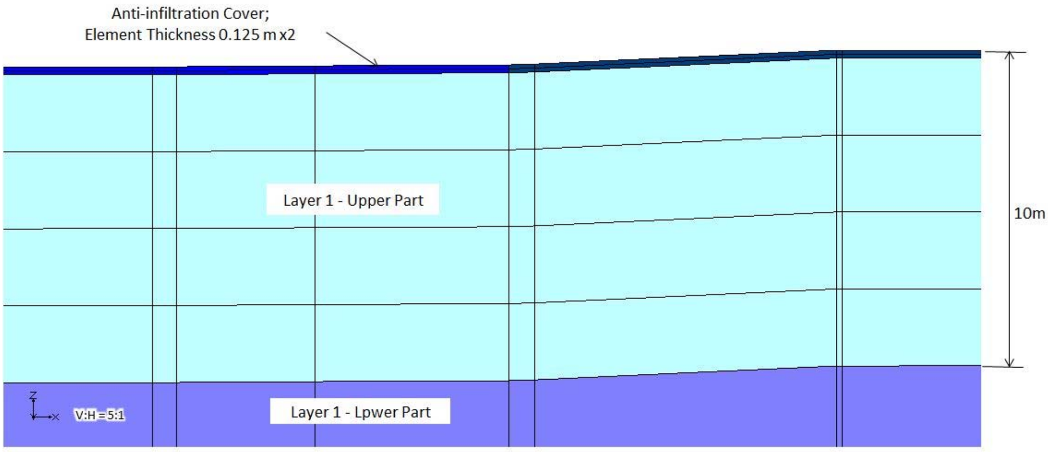


Profile-3

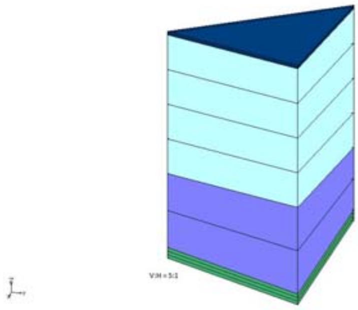


Section-4

Appendix H-14: Model Mesh of 3-D FEM Method – Surface Part

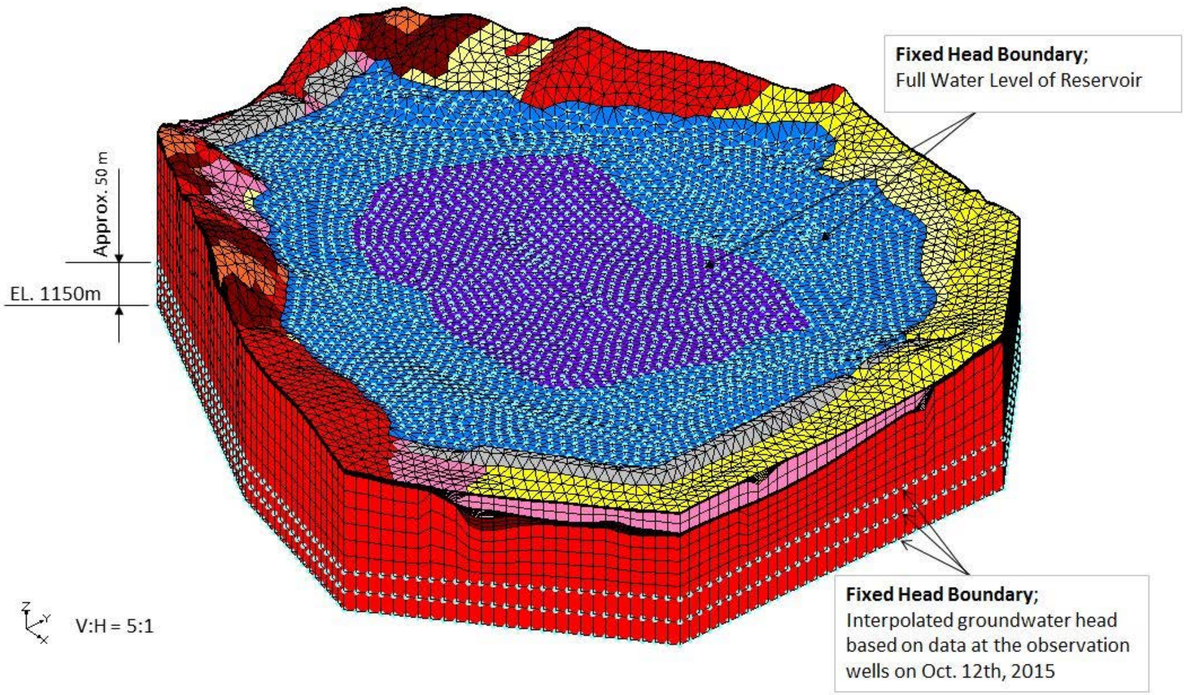


Mesh Condition of Surface Part including Anti-Infiltration Layer



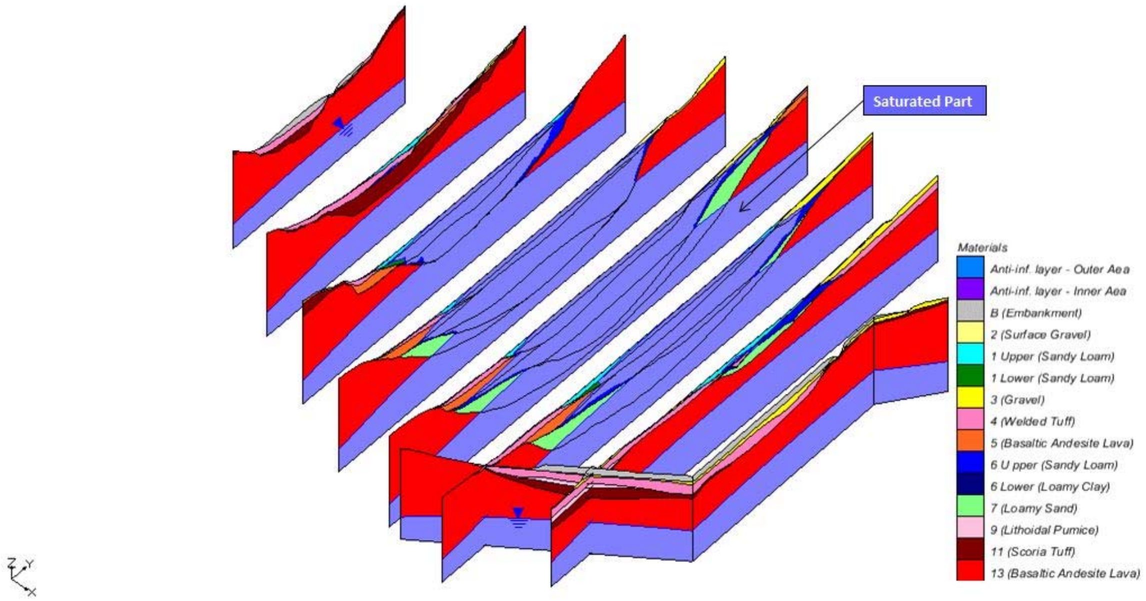
Prism Elements

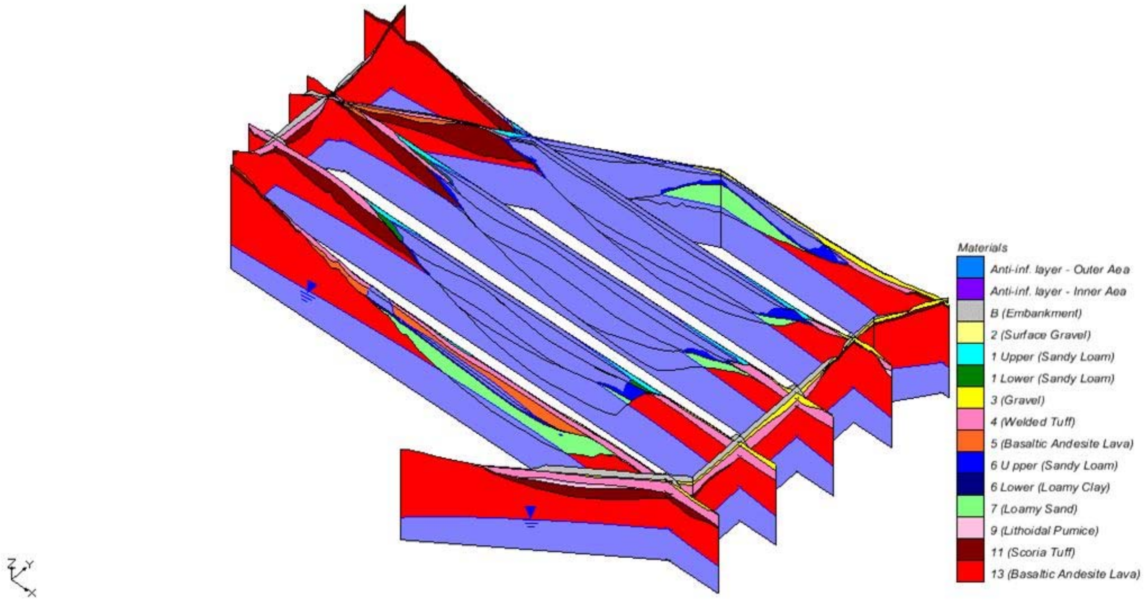
Appendix H-15: Boundary Condition of 3-D FEM Method



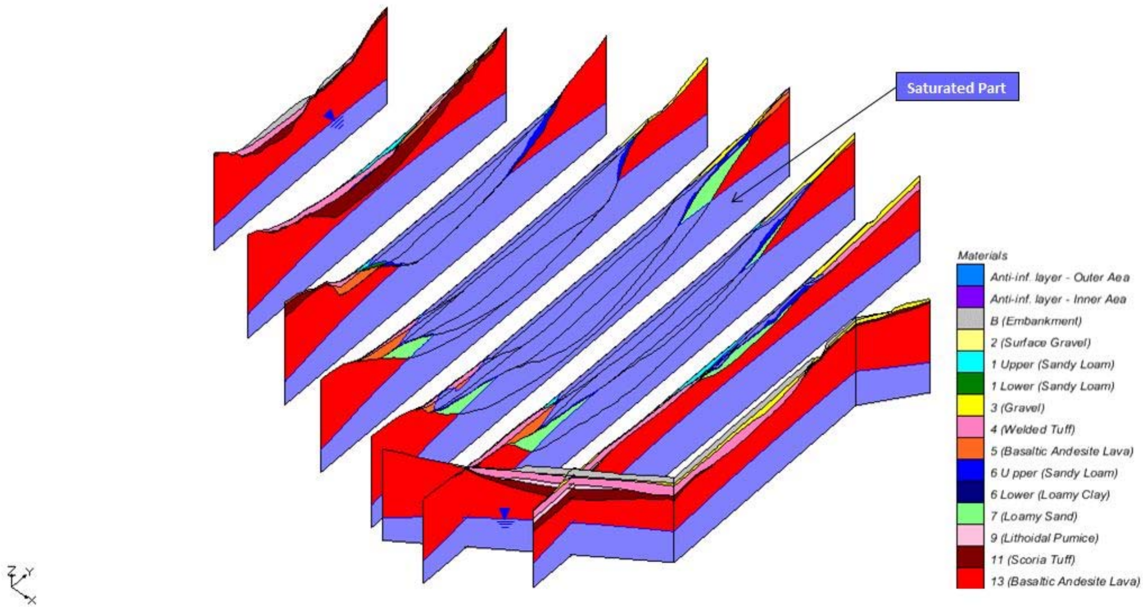
Appendix H-16: Panel Diagram Showing Saturated and Unsaturated Zones Calculated by 3-D FEM Method

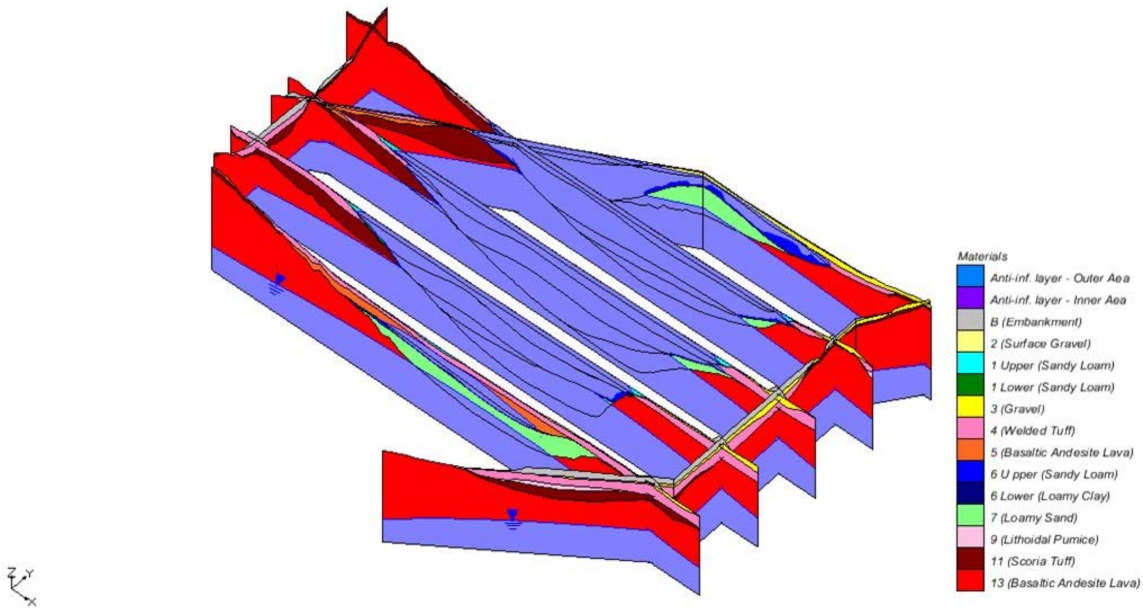
(1) Whole Coverage of Anti-infiltration Layer – 900 ha Plan





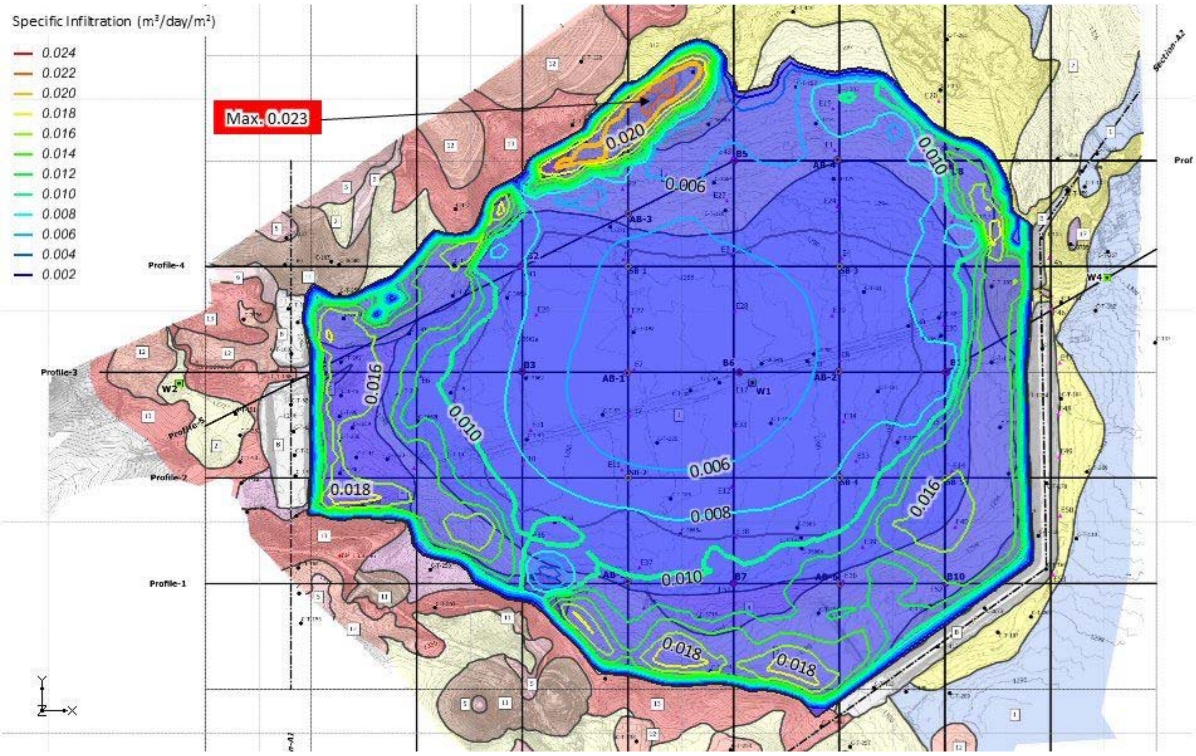
(2) Partial Coverage of Anti-infiltration Layer – 900 ha Plan



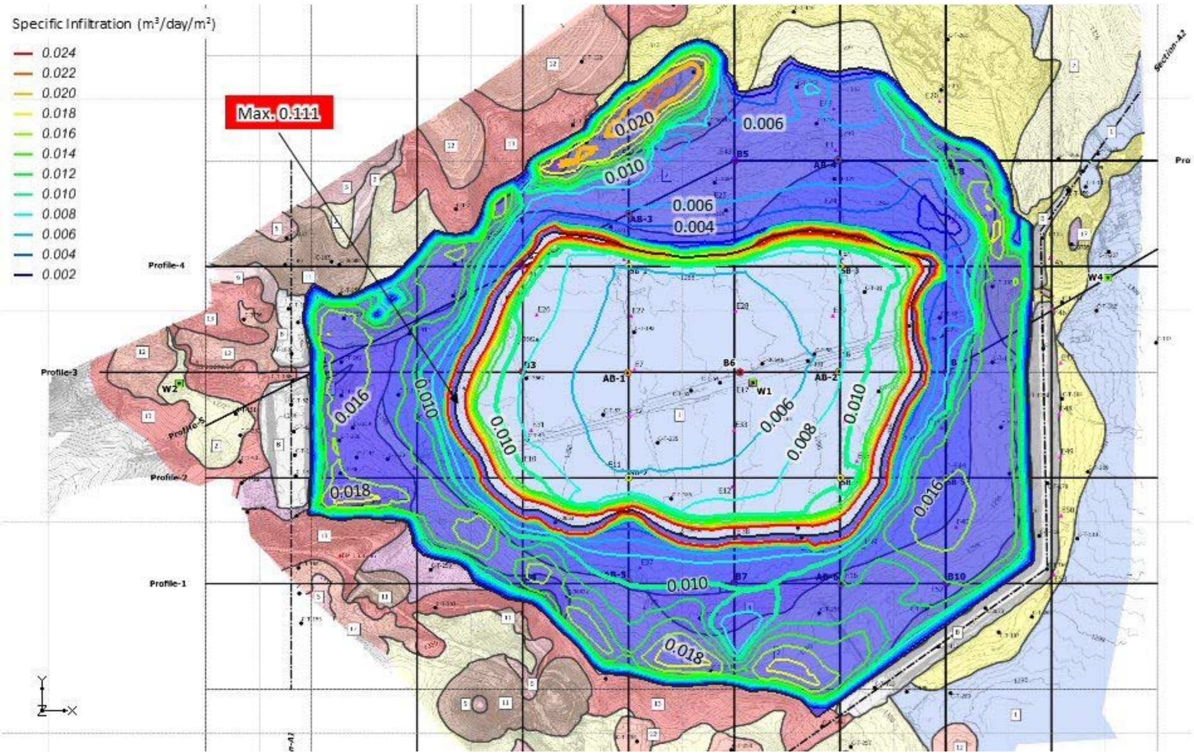


Appendix H-17: Specific Leakage Rate Distribution at Full Water Level by 3-DFEM Method – 900 ha Plan

Unit: m^3/day/m^2



Whole Coverage of Anti-infiltration Layer



Partial Coverage of Anti-infiltration Layer

APPENDIX I

Laboratory Test

Appendix I-1: Summarization and Analysis of the Test Results

1-1. Soil investigation and laboratory test in Yehgvard reservoir area

Laboratory soil test was conducted using disturbed soil samples collected from test-pits in which sandy loam and sand and gravel distribute in designated area. The main purpose of the test was to obtain a property of soil on site and to select the optimum material for the anti-filtration method. As the anti-filtration method, bentonite-soil mixture and soil-cement were examined. Test items and its applied standard were shown in table 1-1-1. Location of collected soil sample and its coordinates were shown in table 1-2 and figure 1-1-1.

Table 1-1-1 Test items and applied standard

Test Items		Local soil		Anti-filtration		Standard
		Sandy Loam	Sand and gravel	Bentonite	Cement	
Moisture content		✔	✔	✔	✔	ASTM D2216
Specific Gravity		✔	✔	✔	✔	ASTM D854
Grain size distribution		✔	✔	✔	✔	ASTM D422
Atterberg limit		✔	✔	✔	✔	ASTM D4318
Standard compaction		✔	✔	✔	✔	ASTM D698
Direct shear		✔	✔	✔	✔	ASTM D3080
Unconfined compression		✔	✔	✔	✔	ASTM D2166
Triaxial UU		✔				ASTM D2850
Triaxial CU bar		✔				ASTM D4767
Consolidation		✔				ASTM D2435
Falling head permeability		✔	✔	✔	✔	ASTM D5084
Freezing / thawing	Unconfined completion	✔		✔	✔	ASTM D2166
	Falling head permeability	✔		✔	✔	ASTM D5084
Observation in water				✔		-
Slaking					✔	ASTM D4644
Soundness of aggregate			✔		✔	JIS A 1122
Hexavalent chromium dissolution					✔	JIS K 0102

Table 1-1-2 Coordinates of test-pit

Number of Test Pit	Coordinates	
15TP-1	40°18’20.72”N	44°25’56.82”E
15TP-2	40°18’20.79”N	44°26’39.33”E
15TP-3	40°18’21.19”N	44°27’21.44”E
15TP-4	40°18’53.63”N	44°27’20.59”E
15TP-5	40°18’53.23”N	44°26’38.85”E
15TP-6	40°18’52.88”N	44°25’55.92”E
15TP-7	40°18’37.44”N	44°26’17.49”E
15TP-8	40°18’37.49”N	44°27’0.39”E
15TP-9	40°19’9.61”N	44°26’59.86”E
15TP-10	40°18’4.52”N	44°27’0.02”E
Sand and Gravel (15TP-17)	40°19’39”N	44°26’59”E
Sandy Loam	40°18’37”N	44°26’21”E

Figure 1-1-1 Location of soil samples taken from

(1) Property of local soil

Laboratory soil test consists of ‘‘Physical Soil Test’’ and ‘‘Mechanical Soil Test’’. Physical soil tests were conducted to obtain a value of basic properties of soil. Nineteen (19) disturbed soil samples were collected from top and bottom of each ten (10) test-pits. Mechanical soil tests were conducted to determine strength and deformation properties of soil in order to predict the behavior during engineering activities, such as foundation, excavation, cutting and embankment. Five (5) samples were prepared through grouping nineteen (19) samples for physical soil tests into five (5). The summary of the soil tests was shown in Table 1-1-3.

Table 1-1-3 Summary of Laboratory Test for local soil

	Specific Gravity ρs (g/cm3)	Moisture Content Wn (%)	Atterberg Limit			Grain Size Distribution				Standard Compaction	
			Liquid Limit WL (%)	Plastic Limit Wp (%)	Plastic Index Ip	Gravel 2~75 mm (%)	Sand 0.075~ 2mm (%)	Silt 0.005~ 0.075 mm (%)	Clay <0.005 mm (%)	Maximum Dry Density	Optimum Moisture Content
15TP-1u	2.64	13.11	22.5	17.1	5.4	0.9	34.9	31.2	33.0	1.6	21.2
15TP-1d	2.59	19.50	28.5	24.5	4.0	0.0	17.4	40.5	42.1	1.53	26.0
15TP-2u	2.58	16.48	33.9	23.9	10.0	0.2	7.7	32.8	59.3	1.56	23.0
15TP-2d	2.55	17.83	28.6	25.3	3.3	0.1	34.0	46.1	19.8	1.45	26.3
15TP-3u	2.57	15.15	30.0	20.2	9.8	0.6	44.3	19.5	35.6	1.60	22.2
15TP-3d	2.66	8.97	-	-	-	1.0	47.8	38.8	12.4	1.70	16.5
15TP-4u	2.57	22.56	-	-	-	6.2	29.8	39.0	25.0	1.60	20.8
15TP-4d	2.55	28.73	-	-	-	0.6	30.2	45.6	23.6	1.41	24.8
15TP-5u	2.63	12.30	21.9	17.5	4.4	4.5	31.5	41.9	22.1	1.71	17.6
15TP-5d	2.67	8.01	-	-	-	6.6	44.9	35.8	12.7	1.66	19.2
15TP-6u	2.64	8.51	20.1	16.8	3.3	2.2	28.4	47.7	21.8	1.73	16.4
15TP-6d	2.60	14.63	-	-	-	7.0	43.9	31.5	17.5	1.81	13.0
15TP-7u	2.58	25.20	30.2	27.6	2.6	0.3	21.9	45.1	32.7	1.42	22.7
15TP-7d	2.49	25.56	34.1	29.5	4.6	1.3	9.5	45.3	43.9	1.45	25.5
15TP-8u	2.59	19.12	38.5	22.2	16.3	0.0	3.4	39.2	57.4	1.49	24.0
15TP-8d	2.64	13.38	24.5	20.5	4.0	0.5	13.1	44.6	41.8	1.65	18.7
15TP-9u	2.6	10.28	25.0	20.0	5.0	0.5	13.6	53.5	32.4	1.64	20.5
15TP-10u	2.53	8.08	23.8	20.0	3.8	17.4	36.1	21.9	24.5	1.66	18.2
15TP-10d	2.52	12.37	-	-	-	1.6	39.8	42.7	15.9	1.44	23.6

Sample number [u] indicates the sample taken from upper side of test-pits.
Sample number [d] indicates the sample taken from downward, lower depth of test-pits.

	Direct Shear				Triaxial UU		Triaxial CU-bar		Permeability		
	Point-A		Point-B		Point-B		Point-B		Point-A	Point-B	Point-C
	C (kN/m2)	φ (°)	C (kN/m2)	φ (°)	C (kN/m2)	φ (°)	C (kN/m2)	φ (°)	Coefficient of Permeability (cm/sec)		
G-1 15TP-10u	23.9	25.5	15.6	23.9	8.0	25.2	28.0	30.1	$5.2x10^{-7}$	$1.9x10^{-6}$	$2.9x10^{-5}$
G-2 15TP-1d	12.7	23.3	11.4	24.3	12.0	10.2	26.0	24.7	$4.3 x10^{-7}$	$3.5 x10^{-7}$	$1.3 x10^{-5}$
G-3 15TP-2u	7.5	22.3	6.5	21.0	13.0	16.7	34.0	23.7	$3.2 x10^{-7}$	$4.7 x10^{-7}$	$2.8 x10^{-6}$
G-4 15TP-5d	7.9	24.8	7.7	24.8	3.0	17.2	10.0	33.8	$2.3 x10^{-6}$	$1.7 x10^{-6}$	$1.1 x10^{-5}$
G-5 15TP-4d	11.9	23.4	8.6	22.4	13.0	24.7	35.0	27.9	$2.9 x10^{-6}$	$2.0 x10^{-6}$	$1.1 x10^{-5}$

(a) Physical Soil Test

- Moisture content

  The moisture contents were between 8.01 and 28.73%. Samples taken from upper side of test-pit [u] indicated comparatively lower moisture content than samples taken from bottom [d].

- Specific gravity

  The specific gravities were between 2.49 and 2.67 g/cm^3. Generally, value of inorganic soil refers to between 2.60 and 2.75 g/cm^3. Some samples indicated lower value than inorganic soil. Therefore, these samples mainly consist of inorganic soil but it is considered that they might contain some organic material.

- Grain size distribution test

  The results of the grain size distribution are plotted in below. Most of the sample included fine fraction more than 50%, but some samples, i.e. T5-d, T6-d and T10-u, were composed of slightly higher content of sand.

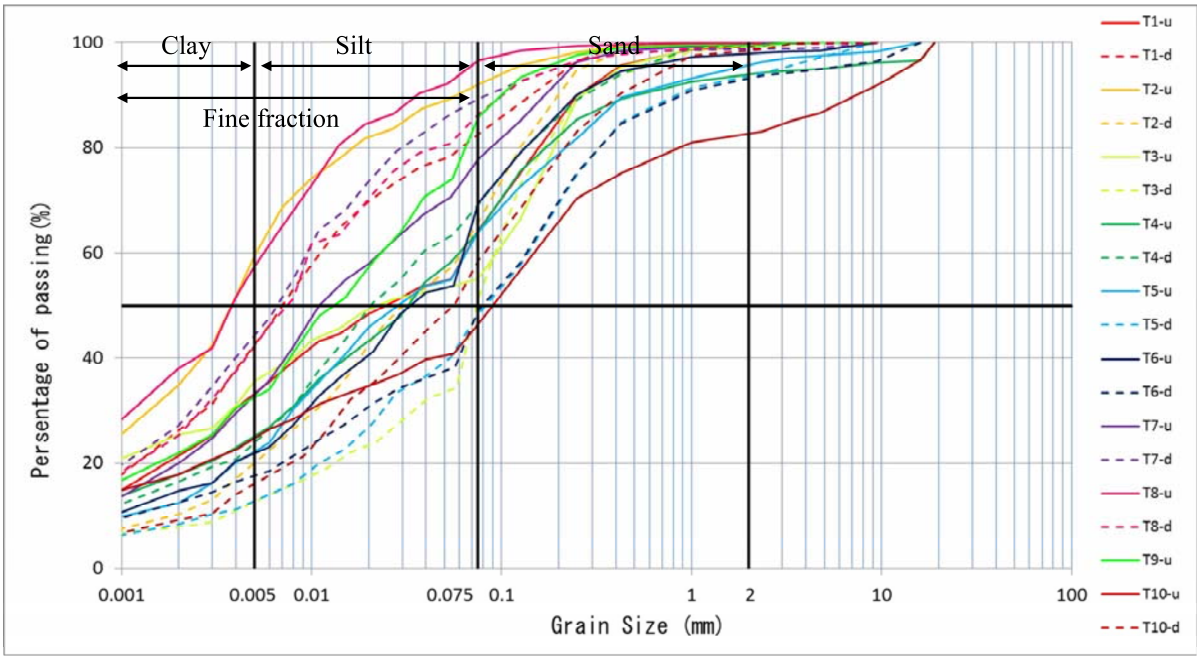


Figure 1-1-2 Grain Size Distribution

- Atterberg limit test

Liquid limit was between 20.1 and 38.5%. Plastic limit was between 16.8 and 25.3%. Moisture content indicates lower value than plastic limit, so the state of these soils is in "Semi solid" at natural condition. However, as PI is small, i.e. from 3.3 to 16.3, the soil is easy to be a liquid phase with additional small amount of water. The relationship between atterberg test and moisture content is shown in Figure 1-1-3, and typical values of liquid limit and plastic limit in Japan are shown in Table 1-1-4 for reference.

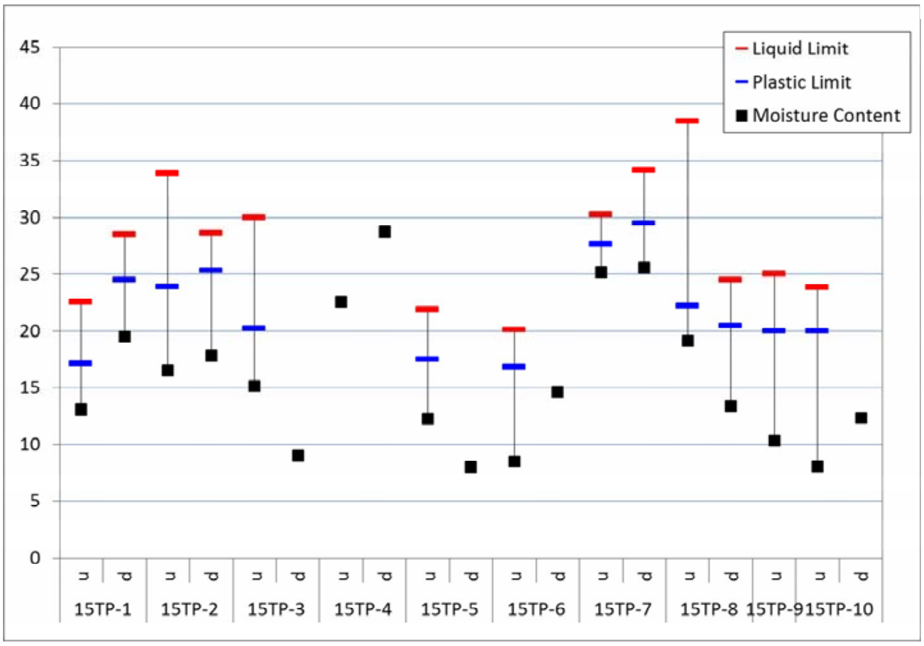


Figure 1-1-3 Relationship between Atterberg limit and Moisture content

Table 1-1-4 Typical value of liquid limit and plastic limit in Japan

(Japanese Geotechnical Society)

Soil	Liquid Limit w_L(%)	Plastic Limit w_p(%)
Clay (alluvium)	50～130	30～60
Sylt (alluvium)	30～80	20～50
Clay (diluvium)	35～90	20～50
Kanto Loam	80～150	40～80

(b) Mechanical soil tests

✓ Grouping of the samples and selection of the representative sample

Samples for Mechanical soil tests, except for Standard compaction test, were selected based on the result of Grain size distribution test and Atterberg limit test. First, samples were divided into (3) three groups (High, Medium and Low percentage of fine fraction content) from the result of grain size distribution test. Next, it was divided into total of five (5) groups from the relationship with the fine fraction content and plastic index. The grouping of the sample and its representative sample for Mechanical soil tests were shown in below.

Table 1-1-5 Grouping of the samples and selection of the representative sample

Group	Characteristics	Samples belonging to	Representative sample
G-1	Low P.I. Medium - Low percentage of 0.005mm content	1u, 2d, 5u, 6u, 10u	15TP -10u
G-2	Low P.I. High percentage of 0.005mm content	1d, 7u, 7d, 8d, 9u	15TP -1d
G-3	Medium P.I High-Medium percentage of 0.005mm content	2u, 3u, 8u	15TP -2u
G-4	Non Plastic Low percentage of 0.005mm content	3d, 5d, 6d	15TP -5d
G-5	Non Plastic Medium percentage of 0.005mm content	4u, 4d, 10d	15TP-4d

Table 1-1-6 Matrix for Grouping by Grain size distribution and atterberg test

		Plastic Index		
		Non	Low	Medium
fine fraction content	High	-	1d, 7u, 7d, 8d, 9u	2u, 8u
	Medium	4u, 4d, 10d	1u, 2d, 5u, 6u	3u
	Low	3d, 5d, 6d	10u	-

Figure 1-1-4 Location of soil samples taken from

➢ Standard compaction test

Maximum density at optimum moisture content was measured under 3 layers ~ 25 blows condition. The result was shown in below. Coarser soil with wide range of particle size generally form sharp curve and tend to be high maximum dry density and low optimum moisture content, which is the value of moisture content at maximum dry density. On the other hand, finer soils with narrow range of particle size form flat curve and tend to be low maximum dry density and high optimum moisture content.

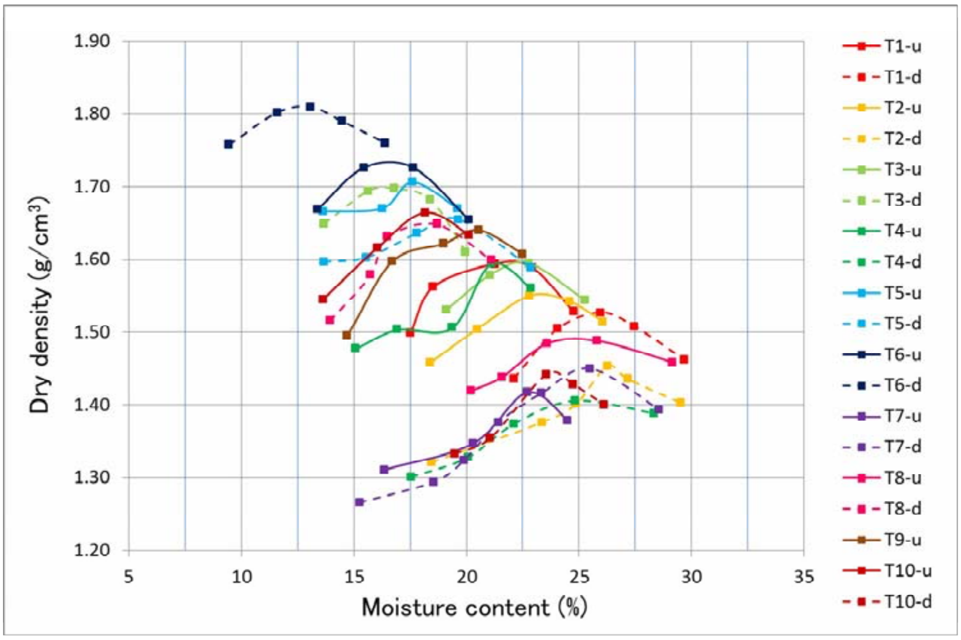


Figure 1-1-5 Result of standard compaction test

✓ Conditions of specimen to conduct the tests

Three (3) conditions of soil specimen were set for the following tests. Soil specimens were remolded to meet the following conditions in terms of "Dry Density" & "Moisture content" obtained by standard compaction test.

Point-A: Dry density condition = Maximum dry density
Moisture content condition = Optimum moisture content

Point-B: Dry density condition = Maximum dry density × 0.97 (= relative density: D-97%)
Moisture content condition = Moisture content corresponding to D-97% on the compaction curve in wet side

Point-C: Dry density condition = Maximum dry density × 0.97 (= relative density:D-97%)
Moisture content condition = Moisture content corresponding to the intersection point between the D-97% line and the saturation rate curve of 85%

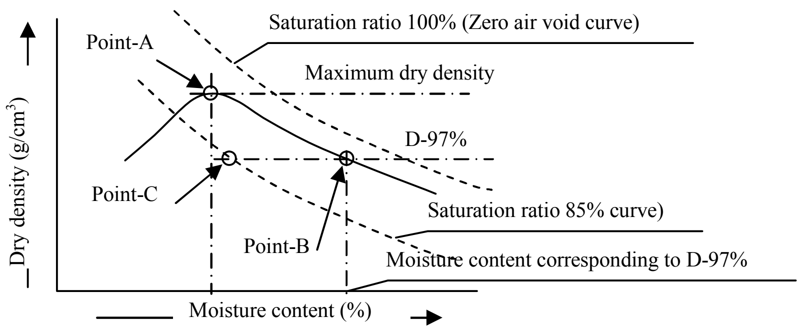


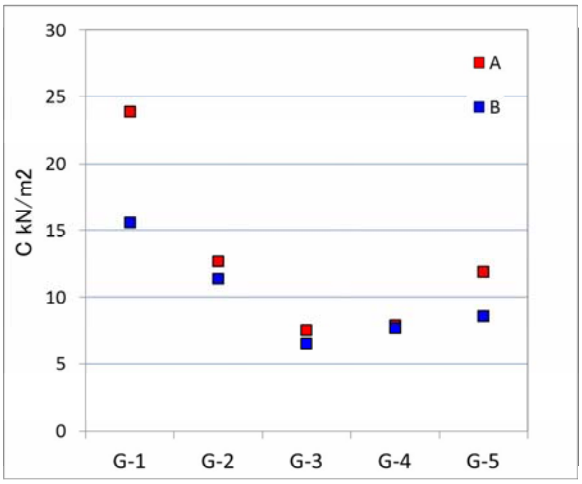
Figure 1-1-6 Set of the soil specimen condition by standard compaction test

Table 1-1-6 Testing point of each test

Test Item	Point A	Point B	Point C
Direct Share Test	✔	✔	
Triaxial UU Test		✔	
Triaxial CU-bar Test		✔	
Consolidation Test		✔	
Permeability Test	✔	✔	✔

- Direct shear test

  Direct shear test was conducted at two (2) testing points (Point-A and B indicated Figure 1-1-6) per one sample. On the result of direct of shear test, the shear resistance angle (ϕ) converged between 21.0 and 25.5. On the other hand, cohesion (C) was spread over without any clear relationship between particle size and PI. In all of the samples, cohesion (C) at Point A tends to be higher value than the one at Point B.



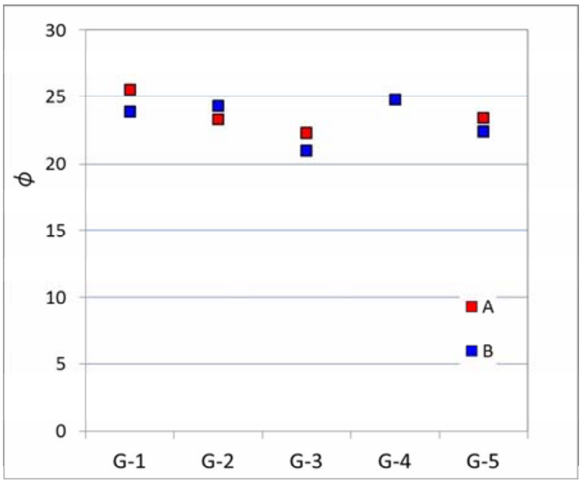


Figure 1-1-7 Result of direct shear test

➢ Triaxial UU and CU-bar test

Triaxial test was conducted at one (1) testing points (Point-B indicated Figure 1-1-6) per one sample. Generally, triaxial test is divided into four (4) tests, which are UU (Unconsolidated Undrained), CU and CU-bar (Consolidated Undrained) and CD (Consolidated Drained) by consolidation and drainage condition. In this study, UU (Unconsolidated Undrained) test and CU-bar (Consolidated Undrained) test were conducted in order to determine soil parameters needed to design.

Figure 1-1-8 shows the result of Triaxle UU test and CU-bar test. By consolidation, it was confirmed that cohesion (C) and shear resistance angle (φ) of CU-bar test increased. Besides, on both tests, cohesion (C) of G-4 group (low percentage of 0.005mm particle) is relatively lower value than that of other samples.

Figure 1-1-9 shows a comparison of the results of triaxial CU-bar test and direct shear test. Generally both of shear resistance angle (φ) were equal. On this result, it indicated similar tendency.

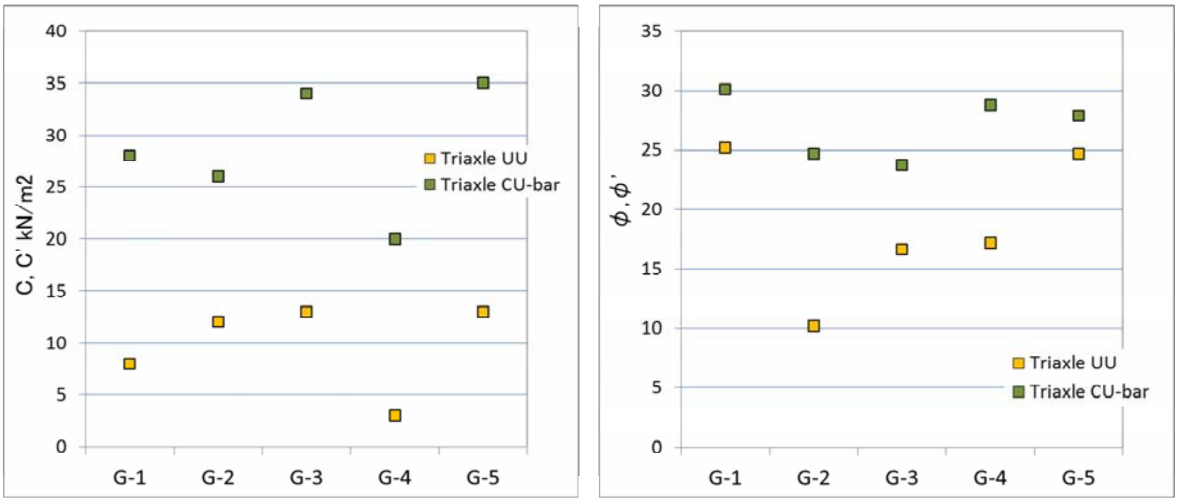


Figure 1-1-8 Result of triaxial test

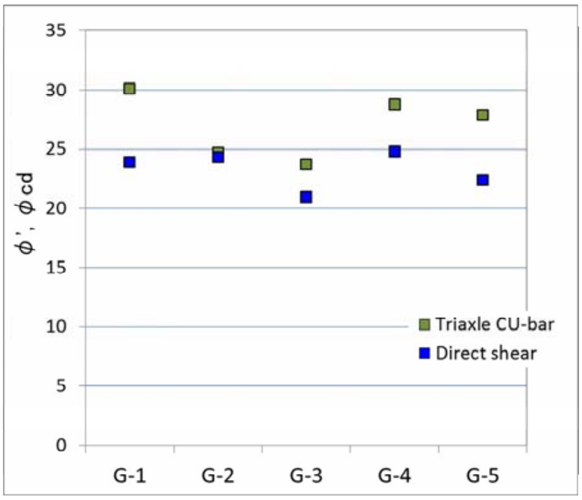


Figure 1-1-9 Comparison between Triaxial (CU-bar) and direct shear test

- Consolidation test

  Consolidation test was conducted at one (1) testing points (Point B indicated Figure 1-1-6) per one sample. In the case of compacting with same energy, all specimens reached yielding at approximately 100kPa of consolidation pressure although there were differences on void-ratio (e).

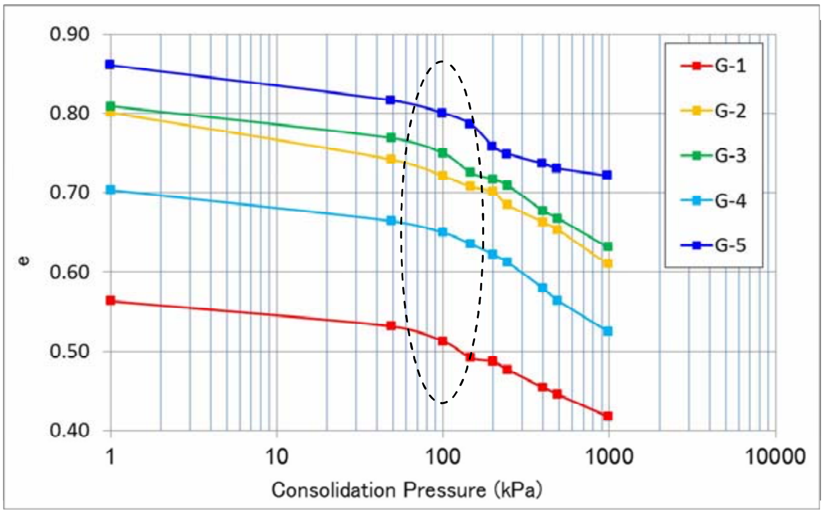


Figure 1-1-10 Result of consolidation test

- Permeability test

  Permeability test was conducted at three (3) testing points (indicated Figure 1-1-6) per one sample. The result was shown in below. Four (4) categories, "Very Low ", "Low", "Medium" and "High", are used to identify their permeability based on coefficient of permeability. At point A and B, permeability of all samples are categorized as "Very Low", while permeability of most samples are categorized as "Low" at point C (=85% Saturation).

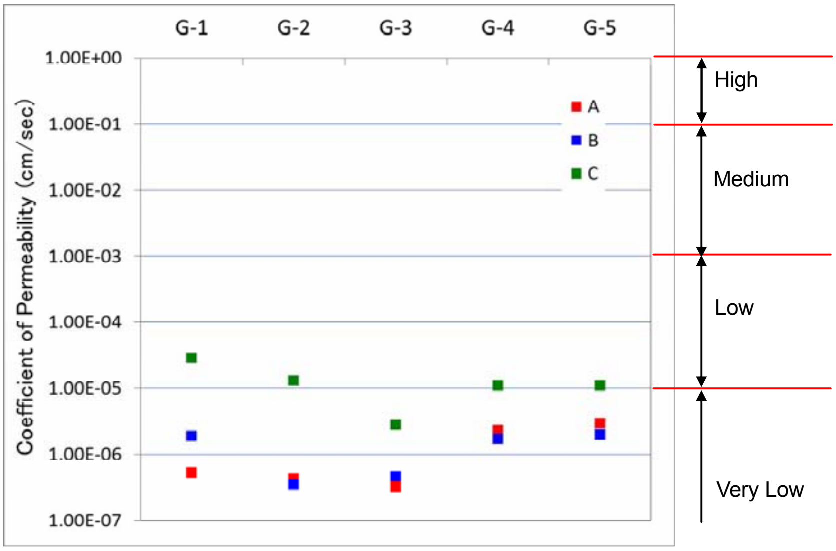


Figure 1-1-11 Result of permeability test

1-2. Bentonite-soil mixture & soil-cement laboratory test for Yehgvard reservoir

Bentonite-soil mixture and soil-cement were considered as anti-filtration material against leakage of the reservoir. The local soil was mixed with bentonite and cement at various ratios. Then, soil tests in laboratory were conducted to confirm (a) property changes of local soil by adding bentonite and cement, then to determine (b) the optimum material and its mixing ratio.

(1) Influences of adding bentonite and cement to local soil

- Atterberg limit test

Plastic Index of all specimens was increased by adding bentonite, and specimens with higher content of bentonite indicated higher PI. Addition of bentonite seems to increase moisture retention to local soil by water absorption property of bentonite.

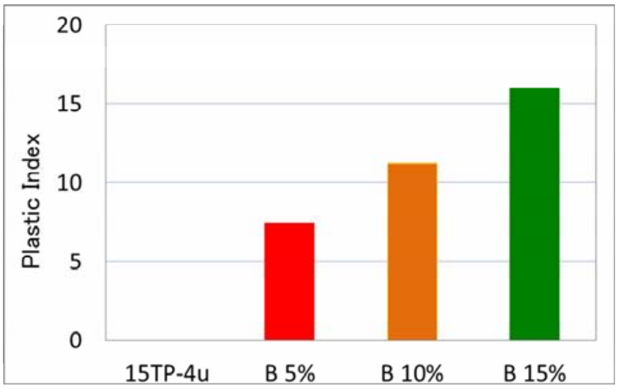


Figure 1-2-1 Effect of adding bentonite on Atterberg test

- Standard compaction test

Optimum moisture content of all specimens was increased by mixing bentonite. Generally, the soil containing larger amount of fine particle fraction has flat and smooth curve, and possesses lower maximum density and higher optimum moisture content. Bentonite consists of fine particle fraction, so depending on the mixing amount, maximum dry density decreased and optimum moisture content increased

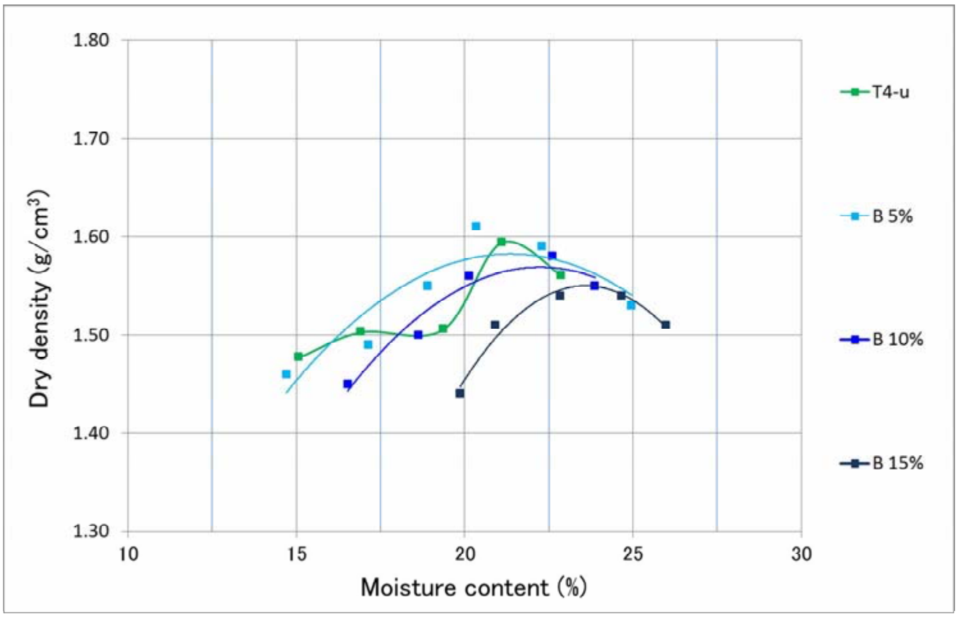


Figure 1-2-2 Effect of adding bentonite on standard compaction test.

➢ Permeability test

Permeability test was conducted to four (4) condition of specimen. Each condition was mixing ratio 5% and 15% with compacted 97% of maximum dry density, mixing ratio 15% with compacted 98% of maximum dry density and mixing cement ratio 3.4% with compacted 97% of maximum dry density. Permeability of all specimens was slightly decreased by mixing bentonite and cement. However, these values with bentonite were roughly equal each other in spite of change of adding quantity of bentonite. Sample with cement indicated the lowest permeability.

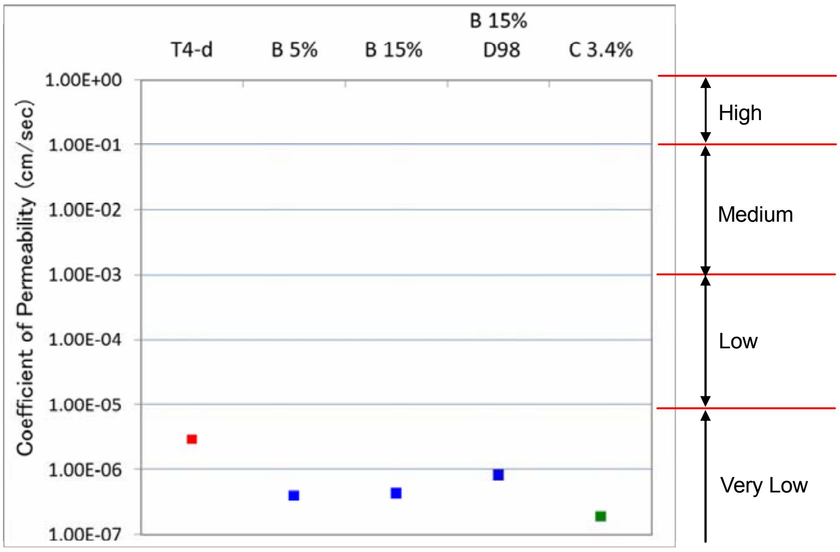


Figure 1-2-3 Effect of adding bentonite and cement on permeability test.

(2) Extra test

Extra soil tests were conducted to obtain more detail data for design and selecting proper material and its optimum mixing ratio. As the soil target mixed with bentonite and cement, two (2) type of soil, which are "sandy loam" and "sand and gravel", were collected from the site indicated in Figure 4-2-10. Sandy loam was served for the test with natural condition while sand and gravel are divided into "sand and gravel fine" and "sand and gravel coarse" by adjusting gravel content ratio. "Sand and gravel fine" was made by removing more than 20mm of particle (gravel content at this point was 25~30%), and "sand and gravel coarse" was adjusted gravel ratio to 50~60% by adding 4.75~20mm particle to "sand and gravel fine". Bentonite and Cement were added to these three (3) samples. Mixing ratio of bentonite was set at 7.5, 10.0 and 12.5%, and cement was set at 6.0, 8.0 and 10.0%. The tests were conducted in consideration of the environmental factors that there are possibility to occur in the field. The result of test was shown in Table 1-2-1 and Table 1-2-2.

Table 1-2-1 Summary of Laboratory Test for anti-filtration materials (1)

			Specific Gravity ρs (g/cm3)	Moistur Content Wn (%)	Atterberg Limit			Grain Size Distribution				Standard Compaction	
					Liquid Limit WL (%)	Plastic Limit Wp (%)	Plastic Index Ip	Gravel 2~75 mm (%)	Sand 0.075~ 2mm (%)	Silt 0.005~ 0.075 mm (%)	Clay <0.005 mm (%)	Maximum Dry Density (g/cm3)	Optimum Moisture Content (%)
Sandy Loam			2.66	9.88	21	17.4	3.6	6.7	52.7	40.6		1.71	16.8
Sand and gravel			2.59	9.31	-	-	-	77.0	20.1	2.9		1.64	14.4
Bentonite-soil Mixture	Sandy Loam	7.5	-	-	34.5	17.0	17.5					1.63	20.0
		10	-	-	38.2	17.4	20.8	6.7	52.7	40.6		1.65	18.9
		12.5	-	-	43.5	18.4	25.1					1.52	21.5
	Sand and gravel fine	7.5	-	-	39.5	39.2	0.3					1.61	21.00
		10	-	-	43.5	42.2	1.3	41.9	50.7	7.3		1.62	21.00
		12.5	-	-	46.5	45.0	1.5					1.56	24.00
	Sand and gravel coarse	7.5	-	-	41.0	39.0	2.0					1.65	19.20
		10	-	-	46.0	39.3	6.7	61.3	33.8	4.9		1.63	20.30
		12.5	-	-	49.0	40.6	8.4					1.57	23.00
Soil-cement	Sandy Loam	6	-	-	-	-	-					1.67	19.00
		8	-	-	-	-	-	6.7	52.7	40.6		1.70	18.00
		10	-	-	-	-	-					1.71	17.61
	Sand and gravel fine	6	-	-	-	-	-					1.72	18.92
		8	-	-	-	-	-	41.9	50.7	7.3		1.72	17.58
		10	-	-	-	-	-					1.70	18.95
	Sand and gravel coarse	6	-	-	-	-	-					1.77	17.42
		8	-	-	-	-	-	61.3	33.8	4.9		1.72	16.50
		10	-	-	-	-	-					1.74	16.00

Table 1-2-2 Summary of Laboratory Test for anti-filtration materials (2)

			Unconfined completion (kPa)		Falling head permeability(cm/sec)		Observation in water	Slaking (%)	Soundness of aggregate (%)	Hexavalent chromium dissolution (ml/L)
			Normal	Freezing / thawing	Normal	Freezing / thawing				
Sandy Loam			374	947	3.3E-05	5.1E-04	-	-	-	-
Sand and gravel			-	-	F:5.3E-04 C:3.4E-05	-	-	-	-	-
Bentonite-soil Mixture	Sandy Loam	7.5	-	-	1.8E-06※1 (2.2E-06)	-	decomposed	-	-	-
		10	277※1 (88)	531※1 (488)	1.7E-06※1 (2.6E-06)	4.4E-06※1 (2.3E-06)	decomposed	-	-	-
		12.5	-	-	2.9E-06※1 (2.0E-06)	-	decomposed	-	-	-
	Sand and gravel fine	7.5	-	-	2.2E-05※1 (1.1E-06)	-	decomposed	-	-	-
		10	239※1 (66)	208※1 (192)	7.0E-06※1 (4.7E-07)	1.7E-05※1 (3.0E-05)	decomposed	-	-	-
		12.5	-	-	2.5E-06※1 (4.6E-07)	-	decomposed	-	-	-
	Sand and gravel coarse	7.5	-	-	3.1E-06※1 (1.8E-06)	-	decomposed	-	-	-
		10	129※1 (76)	120※1 (179)	1.4E-06※1 (1.4E-06)	4.4E-06※1 (2.9E-06)	decomposed	-	-	-
		12.5	-	-	1.9E-06※1 (1.4E-06)	-	decomposed	-	-	-
Soil-cement	Sandy Loam	6	2653※2 (2678)	2258	3.4E-07	2.8E-07	-	4.13	11.27	0.11
		8	3061※2 (3406)	3542	8.0E-08※2 (2.2E-06)	4.7E-07	-	3.49	6.43	-
		10	4122※2 (5245)	4554	7.0E-08※2 (7.2E-06)	3.0E-07	-	2.73	4.06	0.12
	Sand and gravel fine	6	4208	3641	7.2E-07	1.0E-06	-	3.29	4.27	0.17
		8	4319※2 (4258)	4517	7.6E-08※2 (3.0E-06)	5.7E-07	-	2.61	2.80	-
		10	5479※2 (5985)	6072	7.7E-07※2 (2.4E-06)	2.6E-07	-	1.39	1.82	0.15
	Sand and gravel coarse	6	3998	3986	5.9E-08	2.6E-07	-	3.60	4.10	0.12
		8	4936※2 (5257)	5800	3.9E-08※2 (2.8E-06)	1.7E-07	-	2.18	2.80	-
		10	5788※2 (6269)	6911	4.1E-08※2 (2.4E-06)	6.1E-08	-	1.89	2.05	0.13

※1 Above is Value of "Point-A" and Below in parenthesis is "Point-B"

※2 Above is Value of "Cured" and Below in parenthesis is "Not Cured"

✓ Soil test for soil mixed with bentonite and cement

Mechanical Soil test was conducted to soil mixed with bentonite and cement in order to confirm the initial properties.

- Moisture content

  The moisture contents of "sandy loam" and "Sand and Gravel" were 9.88 and 9.31%, respectively.

- Specific gravity

  The specific gravities of "sandy loam" and "Sand and Gravel" were 2.66 and 2.59 g/cm3, respectively. They were similar to the soil of another test-pit.

- Grain size distribution test

  The results of the grain size distribution are plotted in below. As described, Sand and Gravel fine was made by removing particle more than 20mm from the original. Sand and Gravel coarse was made by adjusting that gravel ratio is between 50~60%.

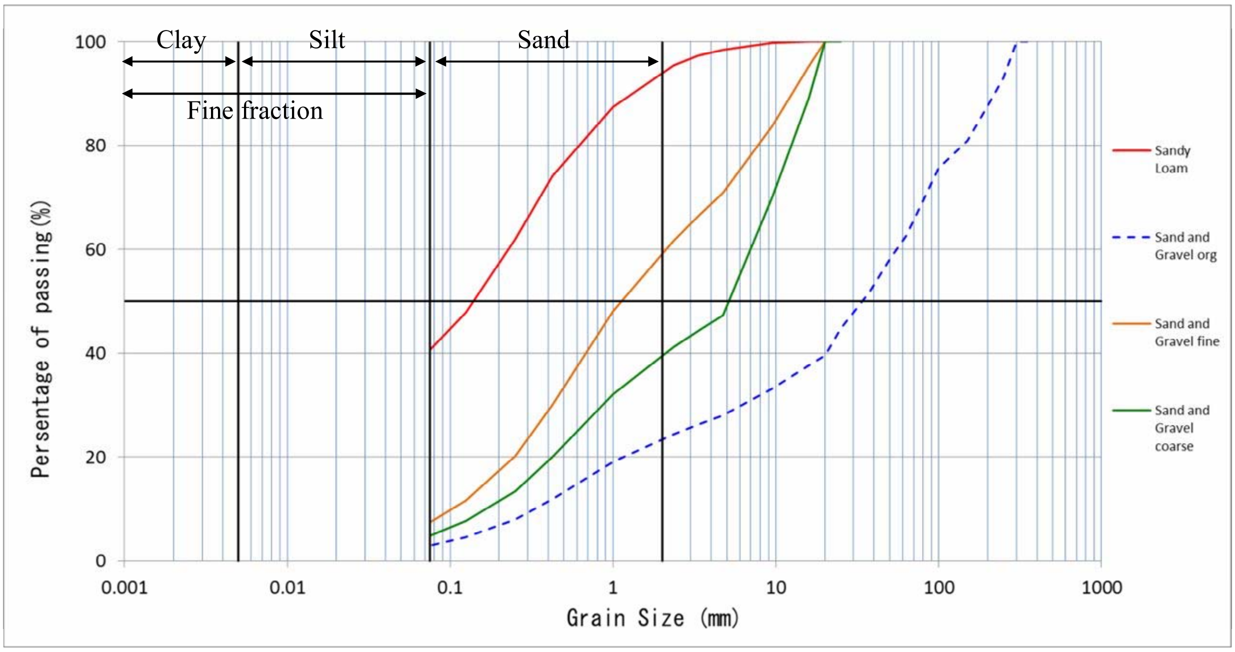


Figure 1-2-4 Grain Size Distribution

- Atterberg limit test

  Plastic Index of all specimens was increased by adding bentonite. This result was similar to the test result described above.

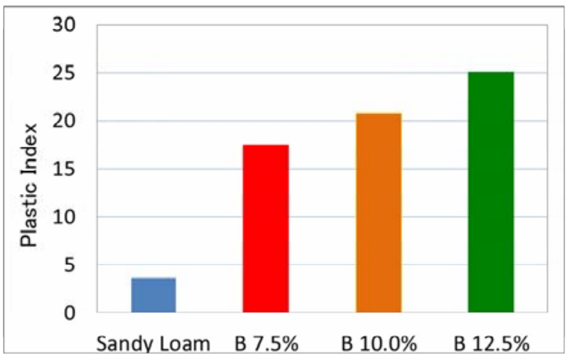
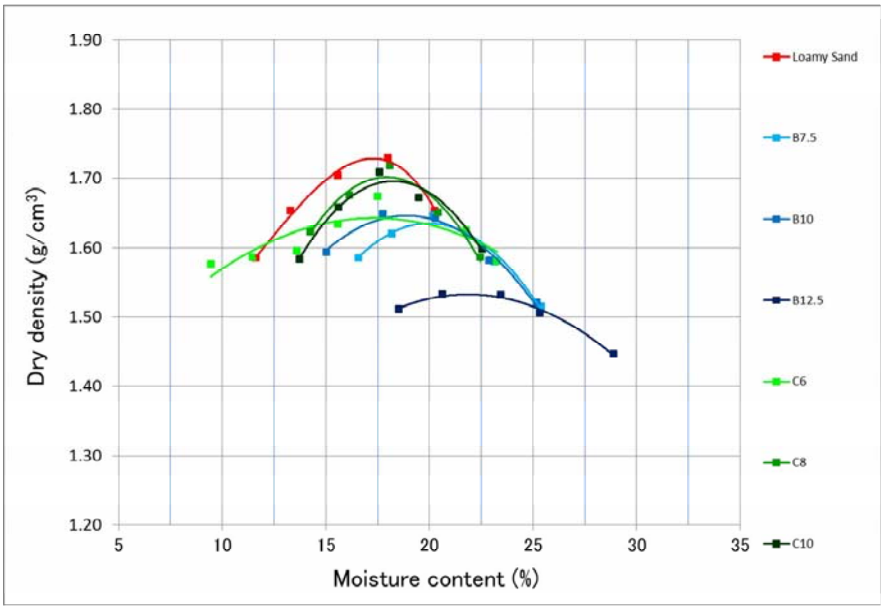


Figure 1-2-5 Effect of adding bentonite on Atterberg test

- Standard compaction test

  Maximum dry density at optimum moisture content was measured under 3layers-25blows condition. The result was shown in below. Decreasing of maximum dry density and increasing of optimum moisture content were confirmed by mixing bentonite. As described above, this seems due to the mixing of the fine particle fraction, while changes of maximum dry density and optimum moisture content were not confirmed by mixing cement.



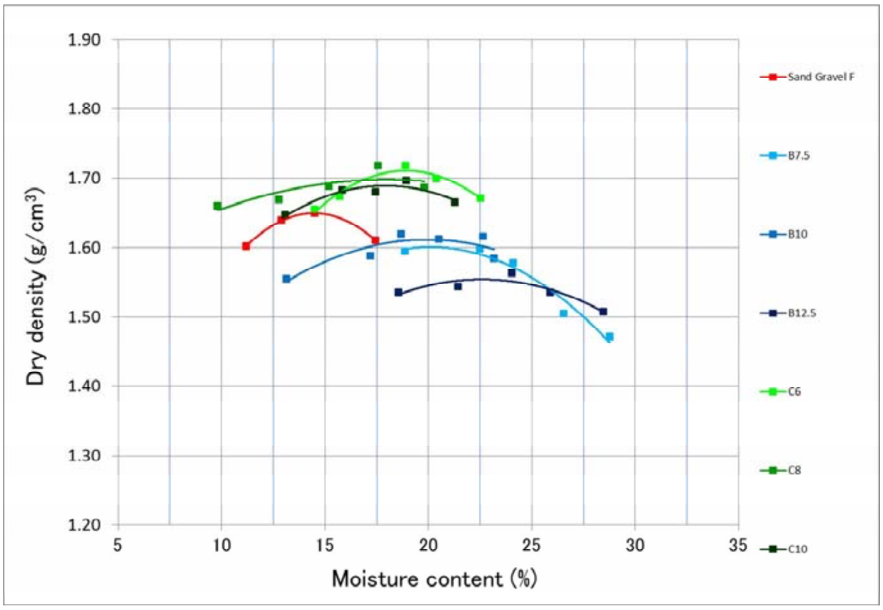


Figure 1-2-6 Effect of adding bentonite and cement on standard compaction test (1).

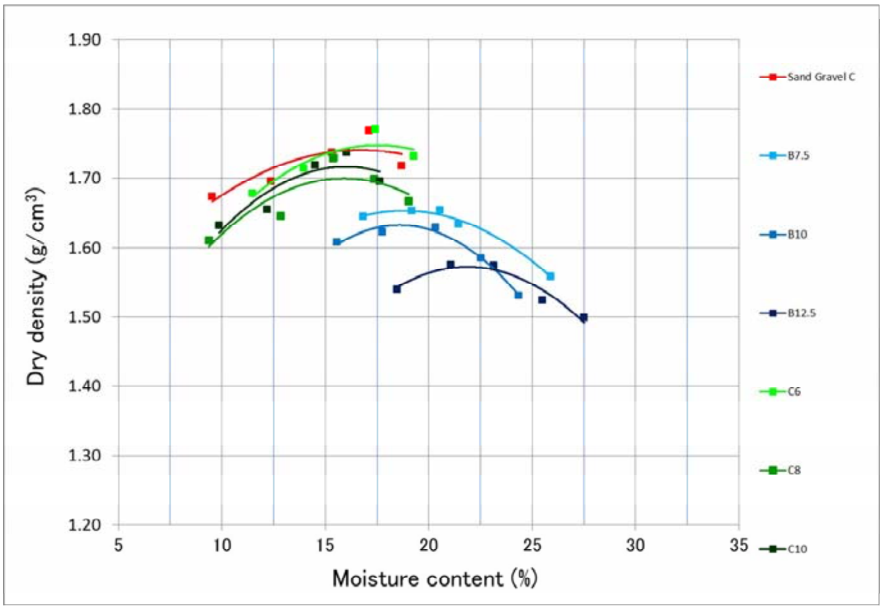


Figure 1-2-7 Effect of adding bentonite and cement on standard compaction test (2)

- ✓ Set for testing point.

Conditions of soil specimen were set for the following tests. Soil specimens were remolded to meet the following conditions in terms of "Dry Density" & "Moisture content" obtained by standard compaction test.

Point-A: Dry density condition = Maximum dry density
Moisture content condition = Optimum moisture content

Point-B: Dry density condition = Maximum dry density × 0.97 (= relative density: D-97%)
Moisture content condition = Moisture content corresponding to D-97% on the compaction curve in wet side

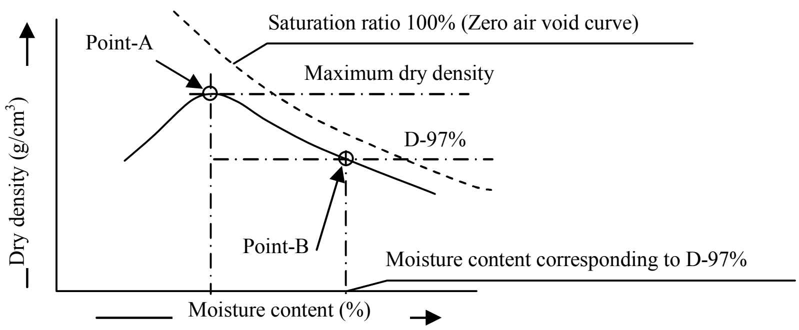


Figure 1-2-8 Set of the soil specimen condition by standard compaction test

➢ Permeability test

(1) Bentonite-soil Mixture

Permeability test for bentonite-soil mixture was conducted at two (2) testing points A and B (indicated Figure 1-2-8) per one sample.

(2)Soil Cement

Permeability test for soil cement was conducted at one (1) testing point A (indicated Figure 1-2-8 per one sample. And two (2) kinds of specimens prepared. One is "cured" for twenty-eight (28) days in a humidity chamber. Another is "Not cured" which is stand-still in atmospheric situation.

The result is shown in Figure 1-2-9. Four (4) categories, "Very Low", "Low", "Medium" and "High", are used to identify their permeability based on coefficient of permeability. At point A, permeability of all samples are mainly categorized as "Very Low". Permeability of bentonite-soil mixture and soil cement with not curing were roughly equal and soil cement with curing is indicated a one (1) order lower value. Therefore on soil cement, lower permeability is expected by a sufficient curing, but also variation, which is like six (6) and ten (10) percentage of cement mix to Sand and Gravel fine, is needed to be considered.

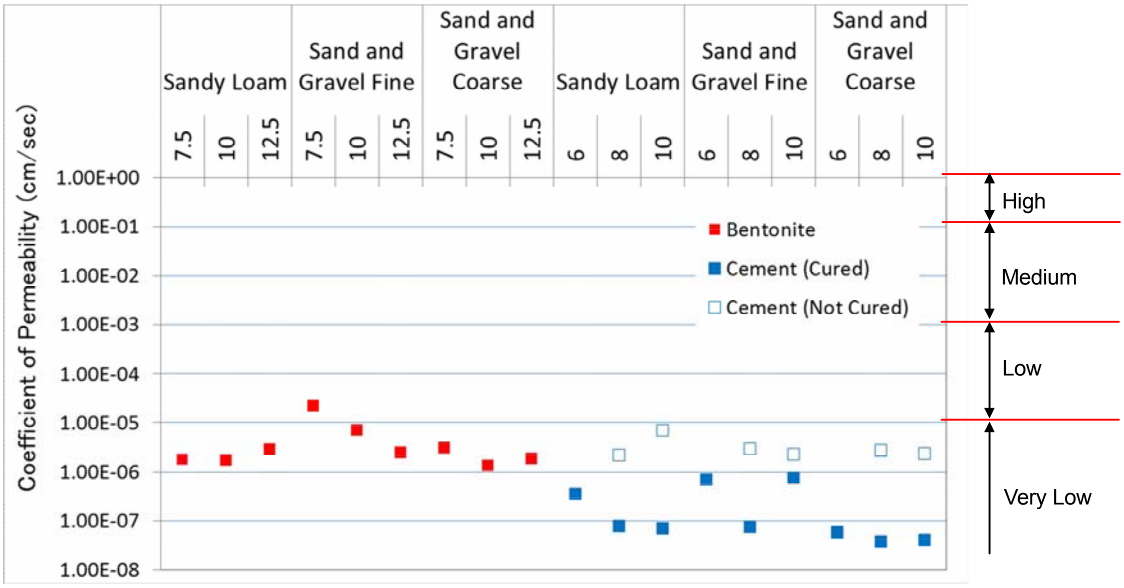


Figure 1-2-9 Result of permeability test on Point A

➢ Unconfined compression test

Unconfined compaction test was conducted to the same test point of the permeability test above. The result was shown in Figure 1-2-10. Compression stress of soil cement showed approximately ten (10) times higher value than bentonite soil. Stress of bentonite was not seen clear differences by aggregate or mixture ratio of bentonite. On the other hand, higher mixture ratio provided stronger value and Sand and gravel was stronger value than sandy loam.

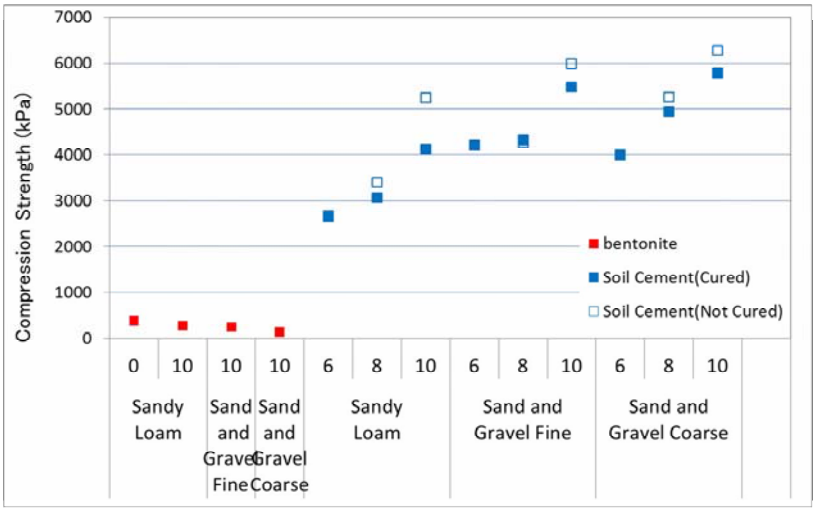


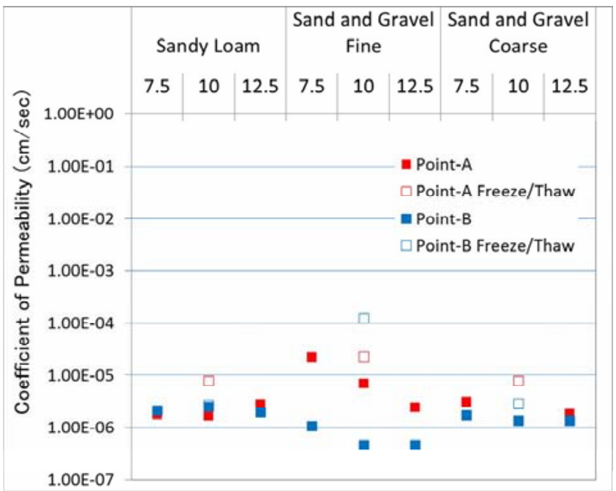
Figure 1-2-10 Result of unconfined compression test

➢ Freezing/Thawing

Permeability and unconfined compression test were conducted to grasp changes of properties of material for anti-filtration after exposed to freezing and thawing condition. After the falling head permeability test, the specimens were taken out of the testing mold and kept in a freezer for six (6) hours or more as freezing process, and then kept out from the freezer until the specimen thaws completely as thawing process. After ten (10) cycles of freezing and thawing, the specimen was set in the testing mold and provided to the test.

The result of permeability test was shown in Figure 1-2-11. By the effect of Freezing/Thawing, both permeability of bentonite-soil mixture and soil cement increased. However, it was not significant increase than curing or not.

The result of unconfined compression test was shown in Figure 1-2-12. No significant change was observed by the effect of freezing/thawing, but strength of was some part of bentonite mixture increased. This is considered because moisture inside of specimen was evaporated.



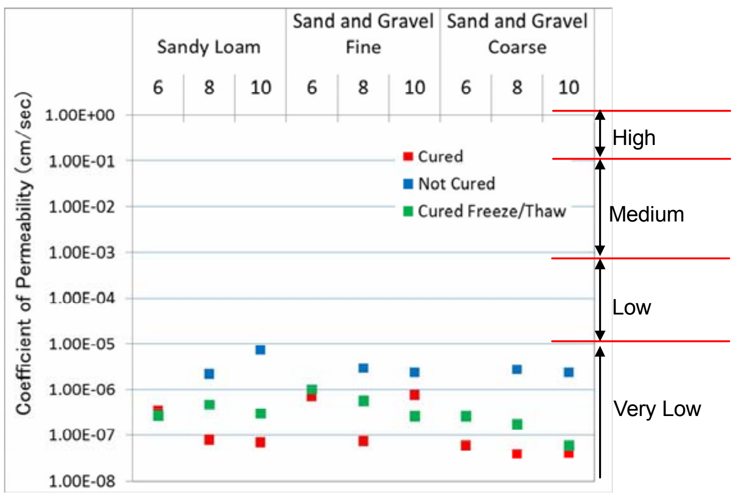


Figure 1-2-11 Result of permeability test: bentonite-soil mixture (left), soil cement (right)

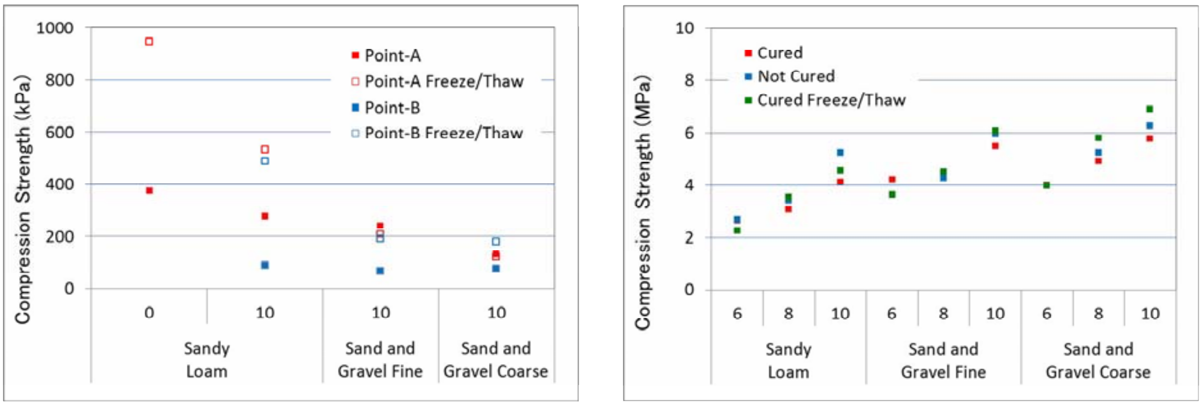


Figure 1-2-12 Result of unconfined compression test: bentonite-soil mixture (left), soil cement (right)

➢ Observation in water

Observation in water was conducted to check a behavior of bentonite-soil mixture when soaked in water. Their pictures are taken thirty (30) minutes later from soaking in water, and it was shown in Figure 1-2-13. Bentonite mixture started to decompose immediately after the specimen was soaked in water. Therefore, it was confirmed that bentonite mixture is difficult to keep the original shape in water.

Figure 1-2-13 Specimen in water after 30 minutes

➢ Slaking test

Three (3) pieces of specimen for “slaking test” were produced by cutting from the specimen cured for twenty-eight (28) days for the unconfined compression test. These specimens were more than 3kg in weight and exposed to the five (5) cycles of “dry and wet process”. The dry process was to keep specimens in the 110°C oven for 24 hours, and the wet process was to keep the specimen in water for 24 hours. After the five (5) cycles, these specimens were put into the oven for 24 hours and washed on the 9.5mm sieve with water, then measured its weight. The degree of slaking is estimated by amount of loss through these processes. The result is shown in Figre 1-2-14. The higher mixing ratio tends to provide the lower amount of loss. Sand and gravel specimens of ten (10) percentage cement mixture were generally categorized “High Durability”. It is considered that they are durable to drying and wetting process.

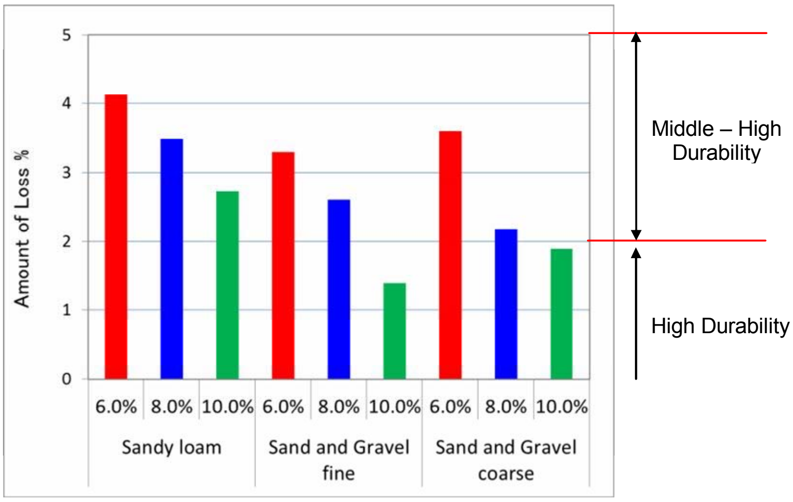


Figure 1-2-14 Amount loss after five (5) cycles of drying and wetting process

➢ Soundness of aggregate

Soundness of aggregates was measured by use of sodium sulfate. Preparing specimen was the same way of slaking test. After submerging in sodium sulfate solution for five (5) cycles, amount of loss were measured. The result was shown in Figure 1-2-15. As well as slaking test, the higher mixing ratio tends to provide the lower amount of loss. Typical criteria value of a maximum percent loss of aggregate is set twelve (12) percent. All results were less than criteria therefor it is considered that they have soundness of aggregate.

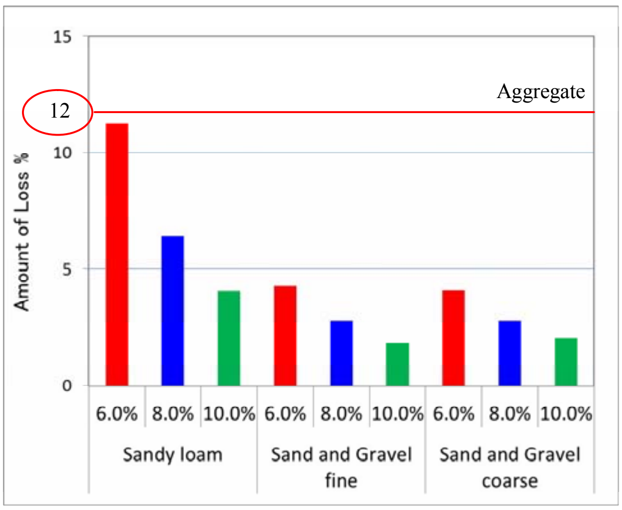


Figure 1-2-15 Amount loss after submerging in a sodium sulfate solution for five (5) cycles

- Hexavalent chromium dissolution test

Hexavalent chromium dissolution test was conducted for identifying an environmental effect with hexavalent chromium when local soil is mixed with cement material. When the ground improvement by cement was conducted, there is a possibility that hexavalent chromium distributes outside by being inhibited hydration reaction of cement. Especially, dissolution amount of hexavalent chromium is higher when volcanic cohesive soil and cement were mixed than another type of soil. Specimens cured for seven (7) days were used for the test. Test solution for measurement was made from the specimen, and amount of dissolution of hexavalent chromium were measured from the aqueous solution. The result was shown in Figure 1-2-16. All the dissolution values were over two times higher than the criteria, which is 0.05mg/L or less. Therefore, it is necessary to use adequate cement materials, such as slug cement, which reduce the dissolution of hexavalent chromium.

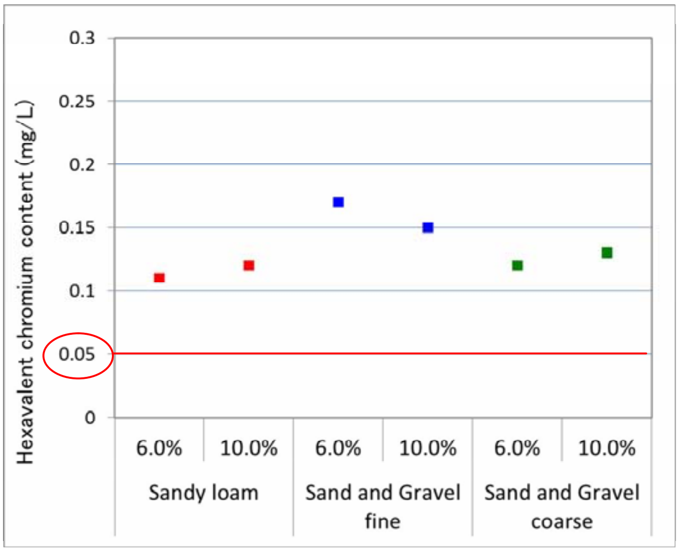


Figure 1-2-16 Result of Hexavalent chromium dissolution test

(3) Consideration on the material selection

The comparison table for selecting an optimum material, based on the soil test results, was shown in Table 1-2-3.

Table 1-2-3 Comparison table for selecting optimum material and its mixing ratio

<table>
<tr><th rowspan="4"></th><th colspan="9">Bentonite-Soil</th><th colspan="9">Soil-Cement</th></tr>
<tr><th colspan="3" rowspan="2">Sandy loam</th><th colspan="6">Sand and Gravel</th><th colspan="3" rowspan="2">Sandy loam</th><th colspan="6">Sand and Gravel</th></tr>
<tr><th colspan="3">Fine</th><th colspan="3">Coarse</th><th colspan="3">Fine</th><th colspan="3">Coarse</th></tr>
<tr><th>7.5</th><th>10</th><th>12.5</th><th>7.5</th><th>10</th><th>12.5</th><th>7.5</th><th>10</th><th>12.5</th><th>6</th><th>8</th><th>10</th><th>6</th><th>8</th><th>10</th><th>6</th><th>8</th><th>10</th></tr>
<tr><td rowspan="2">1.Permeability</td><td colspan="9">N×10$^{-6\sim-7}$
It is depending on compaction degree and type of soil.</td><td colspan="9">N×10$^{-7\sim-8}$
It is depending on the curing method
(If curing is insufficient, Permeability increases approximately 10 times.)</td></tr>
<tr><td colspan="9">△</td><td colspan="6">○</td><td colspan="3">◎</td></tr>
<tr><td rowspan="2">2.Unconfined compression</td><td colspan="9">Strength is not expected.</td><td colspan="9">It is depending on amount of cement and type of soil.</td></tr>
<tr><td colspan="9">×</td><td colspan="3">○</td><td colspan="6">◎</td></tr>
<tr><td rowspan="2">3.Freezing and Thawing</td><td colspan="9">Permeability increases depending on a type of soil(Sand and gravel Fine)
Strength increases by moisture evaporating.</td><td colspan="9">Permeability increases slightly.
No strength change</td></tr>
<tr><td colspan="9">○</td><td colspan="9">○</td></tr>
<tr><td rowspan="2">4.Observation in water</td><td colspan="9">Specimen decomposed within 30 minutes</td><td colspan="9">No change</td></tr>
<tr><td colspan="9">×</td><td colspan="9">◎</td></tr>
<tr><td rowspan="2">5.Slaking</td><td colspan="9">Probably decomposed because of the result of observation in water</td><td colspan="9">10% mix of sand and gravel is categorized “High Durability”, the others are “Middle-High Durability.</td></tr>
<tr><td colspan="9">×</td><td colspan="5">○</td><td>◎</td><td colspan="2">○</td><td>◎</td></tr>
<tr><td rowspan="2">6.Soundness of aggregate</td><td colspan="9">-</td><td colspan="9">All the result was less than criteria (12% of amount loss). Most of samples were less than 5% of amount loss.</td></tr>
<tr><td colspan="9">-</td><td colspan="3">○</td><td colspan="6">◎</td></tr>
<tr><td rowspan="2">7.Hexavalent chromium</td><td colspan="9">Not detected</td><td colspan="9">Exceeding the criteria(0.05mg/L)</td></tr>
<tr><td colspan="9">◎</td><td colspan="9">×</td></tr>
<tr><td>Total</td><td colspan="9">△</td><td colspan="3">○</td><td colspan="6">◎</td></tr>
</table>

georisk

GEORISK SCIENTIFIC RESEARCH COMPANY CJSC

SOIL INVESTIGATION AND LABORATORY TEST IN YEGHVARD RESERVOIR AREA

Report

YEREVAN, 2015

1-2. Test-pit excavation survey for impervious materials

(1) Findings

・The thickness of top soil ranges from 0.5m to 1.0m approximately, and the latter case is predominant. It takes on greyish black which comes from organic material.

・Soil layer of silty sand with scarce cohesion to sandy silt with cohesion a little, which would be classified into SM in the unified soil classification system, is predominant in the soil so called "loamy sand or sandy loam".

・The soil layer of volcanic sandy silt/clay, which seems to be called "loam" in the Soviet investigation era and of which characteristics is its light unit weight, appeared on rare occasions.

・Any sedimentation formation could not be seen clearly in the soil layer. A soil clod with macro-porous vacant holes which suggested the eolian sediment formation was found only one time, and the alternation of thin deposits which suggested the aqueous sediment formation was found also only one time.

・The soils on the test-pit wall were dried up except for the test-pit excavated in well-cultivated area or excavated in a vacant lot of borrow pit where the ground level was about 4 m below the ground surface around.

・The location of test-pit 15TP-10 was shifted toward north by 100m approximately because of the rock formation appearing at the depth of 0.5m in excavation. This rock formation seems to be lava layer, which would be cracky so that considerations shall be requested in the reservoir planning.

(2) Test-pit logs and photos

Test Pit ; 15TP–1

Depth (m)	Color	Classification etc.	Moisture content	Cohesion
	greyish black	Top soil		
0.5				
	dark blown	clayey silt	low	a little
1.0				
	blown	clayey sand	low	a little
1.5				
2.0				
2.5				
	blown	loamy sand	low	little
		light weight		
3.0		small clods covered by black skin–like material seemed to be caused through agglutination phenomenon		
3.5				
4.0				

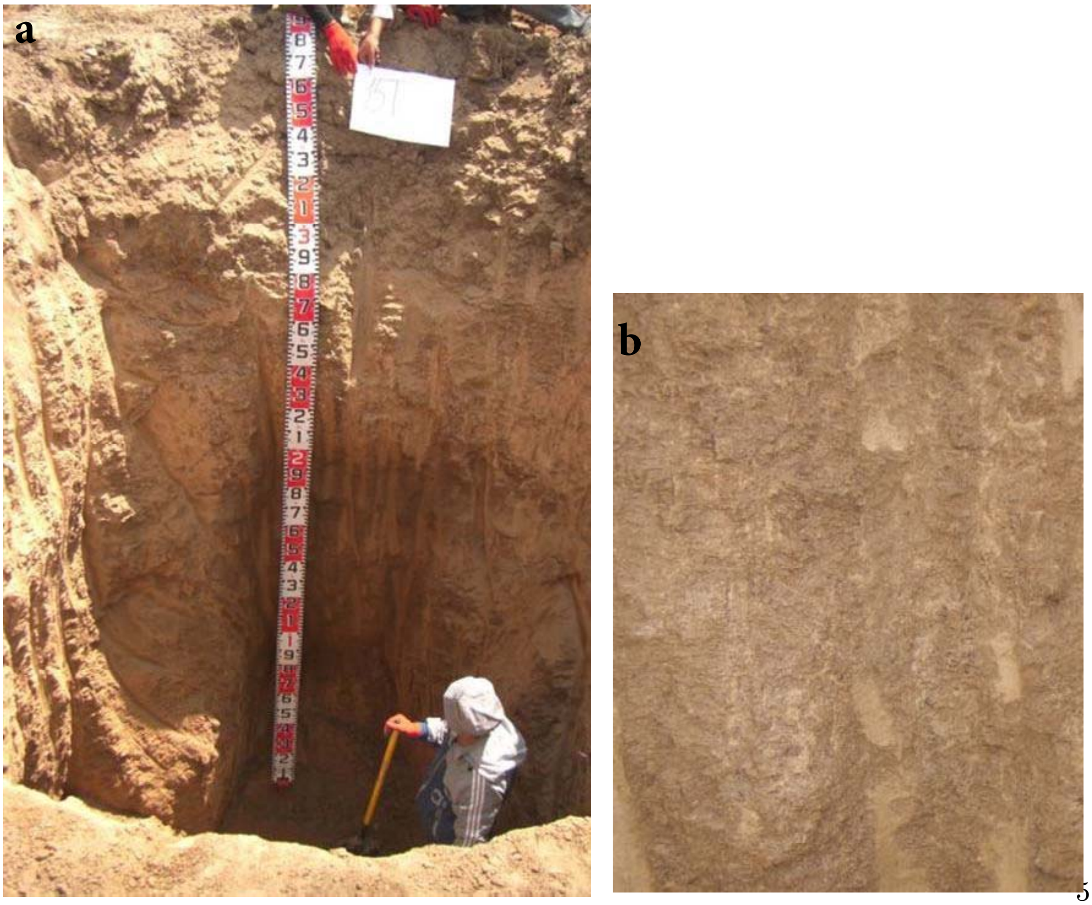


Figure 2. a) 15 test-pit 1 **b)** wall of test-pit 1

(3) Field permeability test

[Pit Method]

Testing process

a) The ground surface where the test is going to be carried out shall be finished flat.

b) Water shall be scattered at/around the testing position for making the soil layer saturated.

c) A cylindrical hole with the size of 20 cm in diameter and 21 cm in height shall be excavated into the soil layer.

d) A scale/indicator shall be installed vertically in the hole and small sized gravels shall be poured into the hole to maintain the pit wall and fix the scale.

e) Depth of water poured into the hole shall be 20 cm.

f) The water surface shall be kept constant by pouring water; and the water volume poured into shall be measured every 1 minute or 2 minutes.

g) Repeat the above measurement till the water volume poured into becomes constant.

Photos

Figure 13. Pit excavation

[Cylinder Method]

Testing process

a) The ground surface on the terrace where the test is going to be carried out shall be finished flat.

b) Water shall be scattered at/around the testing position for making the soil layer saturated.

c) A soil column, 15 cm tall and 18 cm in diameter, shall be scraped out on the ground.

d) A cylindrical pipe, 36 cm long and 20 cm in diameter, shall be set over the soil column to cover it to the bottom.

e) Stuff bentonite powder with water into the slit between the column surface and the inner surface of the cylinder.

f) A scale/indicator shall be installed vertically in the vacant space on the soil column and small sized gravels shall be poured into the space to fix the scale.

g) Pour water into the space on the soil column to the depth of 20 cm.

h) The water surface shall be kept constant by pouring water; and the water volume poured into shall be measured every 1 minute or 2 minutes.

i) Repeat the above measurement till the water volume poured into becomes constant.

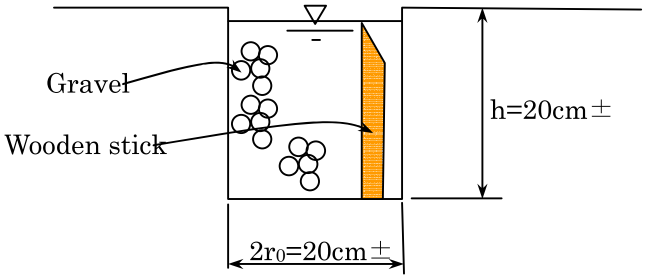
Photos

Figure 17. Scraping out and shaping of the soil column

Results of the field permeability test

Calculation formula

[Pit method]

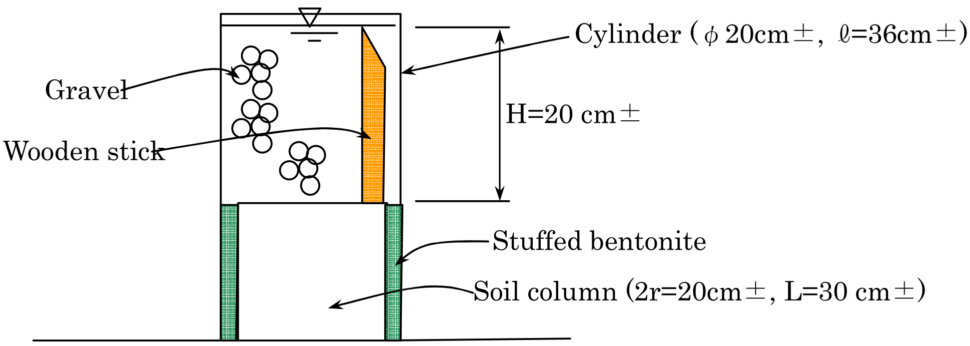


$$k = \frac{Q}{2\pi h^2}\left[\ln\left\{\frac{h}{r_0} + \left(\frac{h^2}{r_0^2}+1\right)^{1/2}\right\} - \left(\frac{r_0^2}{h^2}+1\right)^{1/2} + \frac{r_0}{h}\right]$$

Here; k : In-situ permeability coefficient (cm/sec)
Q : Constant seepage quantity (cm^3/sec)
h : Water depth in the test hole (cm)
r_0 : Radius of the test hole (cm)

(Source; Design standard "Dam", Department of Agriculture and Fishery, Japan)

[Cylinder method]



$k = Q/((L/H) \cdot 3.142 \cdot r^2)$

Here; k : In-situ permeability coefficient (cm/sec)
Q : Constant seepage quantity (cm^3/sec)
H : Water depth on the soil column (cm)
r : Radius of the soil column (cm)
L : length of the soil column (cm)

Findings

The permeability coefficients by the pit method, the values of 10^{-3} cm/sec class, are larger apparently by 2 to 5 times than the ones, the values of 10^{-4} cm/sec class, by the cylinder method.

Summary of the field permeability test results

Test Name	Permeability coefficient (cm/sec)		Hori./Verti.
	Horizontal (Pit method)	Vertical (Cylinder method)	
15TP-1,UP	1.72E−04	8.44E−05	2.03
15TP-1,Down	1.26E−03	2.51E−04	5.01
15TP-2,UP	2.47E−03	3.22E−04	7.67
15TP-2,Down	1.28E−03	4.35E−04	2.94
15TP-3,UP	2.10E−03	3.25E−04	6.46
15TP-3,Down	2.31E−03	3.09E−04	7.47
15TP-4,UP	4.94E−04	2.95E−04	1.67
15TP-4,Down	7.06E−04	1.40E−04	5.04
15TP-5,UP	1.54E−03	4.02E−04	3.82
15TP-5,Down	5.76E−03	3.32E−04	17.35
15TP-6,UP	9.22E−04	4.26E−04	2.16
15TP-6,Down	1.10E−03	4.80E−04	2.29
15TP-7,UP	4.12E−04	2.15E−04	1.91
15TP-7,Down	3.55E−04	3.71E−04	0.95
15TP-8,UP	2.47E−03	2.88E−04	8.59
15TP-8,Down	2.63E−04	2.76E−04	0.95
15TP-9,UP	1.30E−03	3.37E−04	3.87
15TP-9,Down	1.87E−03	1.19E−03	1.57
15TP-10,UP	1.92E−03	8.62E−04	2.23
15TP-10,Down	4.07E−03	1.04E−03	3.91

Calculation table of the permeability coefficient (pit method);

Test Pit ; 15TP−1, UP

Trial No.	poured Q (cm^3)	time passed		unit Q (cm^3/sec)	h ; water depth	r ; hole radius	k (cm/sec)
		minit	second				
1	200	4	30	0.74	19.2	10	2.56E−04
2	200	5	23	0.62	19.2	10	2.14E−04
3	200	5	40	0.59	19.2	10	2.03E−04
4	200	6	42	0.50	19.2	10	1.72E−04
5	200	6	43	0.50	19.2	10	1.72E−04

Test Pit ; 15TP−1, Down

Trial No.	poured Q (cm^3)	time passed		unit Q (cm^3/sec)	H ; water depth	r ; hole radius	k (cm/sec)
		minit	second				
1	200	0	10	20.00	19.2	10	6.92E−03
2	200	0	40	5.00	19.2	10	1.73E−03
3	200	0	57	3.51	19.2	10	1.21E−03
4	200	0	54	3.70	19.2	10	1.28E−03
5	200	0	55	3.64	19.2	10	1.26E−03

1. INTRODUCTION

According to Contract for "soil investigation and laboratory test in Yeghvard reservoir area" in 01 July 2015 between "Georisk" Scientific Research Company CJSC and SANYU CONSULTANTS INC., our specialists carried out the laboratory tests of soil samples. In Report No.1 (21 August 2015) the results of physical soil tests for 29 samples (19 samples + 10 samples from soil survey in the spare borrow area) were presented (Table 1).

Table 1. Physical soil test's results for 29 samples

N	**Sample No.**	**Moisture content, %**	**Specific gravity**	**Liquid limit, %**	**Plastic limit, %**	**Plasticity index, %**	**Particle less than 0.075 mm, %**
1.	T-1d W	**19.50**	**2.59**	28.5	24.5	**4.0**	82.60
2.	T-1up W	**13.11**	**2.64**	22.5	17.1	**5.4**	64.20
3.	T-2d W	**17.83**	**2.55**	28.6	25.3	**3.3**	65.90
4.	T-2up W	**16.48**	**2.58**	33.9	23.9	**10.0**	92.10
5.	T-3d W	**8.97**	**2.66**	**Non-plastic**			51.20
6.	T-3up W	**15.15**	**2.57**	30.0	20.2	**9.8**	55.10
7.	T-4d W	**28.73**	**2.55**	**Non-plastic**			69.20
8.	T-4up W	**22.56**	**2.57**	**Non-plastic**			64.00
9.	T-5d W	**12.30**	**2.67**	**Non-plastic**			48.50
10.	T-5up W	**8.01**	**2.63**	21.9	17.5	**4.4**	64.00
11.	T-6d W	**14.63**	**2.60**	**Non-plastic**			49.06
12.	T-6up W	**8.51**	**2.64**	20.1	16.8	**3.3**	69.45
13.	T-7d W	**25.56**	**2.49**	34.1	29.5	**4.6**	89.27
14.	T-7up W	**25.20**	**2.58**	30.2	27.6	**2.6**	77.83
15.	T-8d W	**13.38**	**2.64**	24.5	20.5	**4.0**	86.36
16.	T-8up W	**19.12**	**2.59**	38.5	22.2	**16.3**	96.53
17.	T-9up W	**10.28**	**2.60**	25.0	20.0	**5.0**	85.85
18.	T-10d W	**12.37**	**2.52**	**Non-plastic**			58.56
19.	T-10up W	**8.08**	**2.53**	23.8	20.0	**3.8**	46.47
20.	Au-1	**24.90**	**2.57**	36.3	23.4	**12.9**	73.12
21.	Au-2	**14.22**	**2.63**	35.0	21.9	**13.1**	81.26
22.	Au-3	**12.68**	**2.64**	27.5	18.8	**8.7**	70.86
23.	Au-4	**12.17**	**2.51**	25.5	20.1	**5.4**	51.61
24.	Au-5	**13.23**	**2.57**	37.2	20.3	**16.9**	92.24
25.	Au-6	**14.19**	**2.56**	30.3	19.7	**10.6**	70.64
26.	Au-7	**20.76**	**2.59**	30.0	21.2	**8.8**	48.95
27.	Au-8	**14.61**	**2.58**	31.1	19.7	**11.4**	89.63
28.	Au-9	**8.39**	**2.50**	**Non-plastic**			34.80
29.	Au-10	**15.87**	**2.63**	29.9	18.1	**11.8**	91.06

9. APPENDIX B (The results of Permeability, Direct shear, Consolidation and Triaxial tests)

Point	Sample name	Standard Compaction		Permeability			Direct shear test				Consolidation test						Triaxial test					
																			(UU)		CU-bar	
				Specimen condition		Result	Specimen condition		Result		Specimen condition		% of settlement				Specimen condition		Result		Result	
		OMC, %	ρ_{dmax}, t/m³	ρ_d, t/m³	M.C., %	K, cm/sec	ρ_d, t/m³	M.C., %	C, KN/m²	φ, °	ρ_d, t/m³	M.C., %	50 KPa	100 KPa	200 KPa	400 KPa	ρ_d, t/m³	M.C., %	C, KN/m²	φ, °	C, KN/m²	φ, °
A point	T-1d	26.0	1.53	1.53	26.0	**4.3×10^{-7}**	1.53	26.0	**12.7**	**23.3**	-	-	-	-	-	-	-	-	-	-	-	-
	T-2up	23.0	1.56	1.56	23.0	**3.2×10^{-7}**	1.56	23.0	**7.5**	**22.3**	-	-	-	-	-	-	-	-	-	-	-	-
	T-4d	24.8	1.41	1.41	24.8	**2.9×10^{-6}**	1.41	24.8	**11.9**	**23.4**	-	-	-	-	-	-	-	-	-	-	-	-
	T-5d	19.2	1.66	1.66	19.2	**2.3×10^{-6}**	1.66	19.2	**7.9**	**24.8**	-	-	-	-	-	-	-	-	-	-	-	-
	T-10up	18.2	1.66	1.66	18.2	**5.2×10^{-7}**	1.66	18.2	**23.9**	**25.5**	-	-	-	-	-	-	-	-	-	-	-	-
B point	T-1d	26.0	1.53	1.48	29.0	**3.5×10^{-7}**	1.48	29.0	**11.4**	**24.3**	1.48	29.0	**3.29**	**4.45**	**5.56**	**7.68**	1.48	29.0	**12**	**10.2**	**26**	**24.7**
	T-2up	23.0	1.56	1.51	26.0	**4.7×10^{-7}**	1.51	26.0	**6.5**	**21.0**	1.51	26.0	**2.22**	**3.24**	**5.09**	**7.29**	1.51	26.0	**13**	**16.7**	**34**	**23.7**
	T-4d	24.8	1.41	1.37	29.0	**2.0×10^{-6}**	1.37	29.0	**8.6**	**22.4**	1.37	29.0	**2.38**	**3.25**	**5.50**	**6.67**	1.37	29.0	**13**	**24.7**	**35**	**27.9**
	T-5d	19.2	1.66	1.61	22.0	**1.7×10^{-6}**	1.61	22.0	**7.7**	**24.8**	1.61	22.0	**2.30**	**3.16**	**4.77**	**7.29**	1.61	22.0	**3**	**17.2**	**10**	**33.8**
	T-10up	18.2	1.66	1.61	21.0	**1.9×10^{-6}**	1.61	21.0	**15.6**	**23.9**	1.61	21.0	**2.04**	**3.25**	**4.87**	**6.97**	1.61	21.0	**8**	**25.2**	**28**	**30.1**
C point	T-1d	26.0	1.53	1.40	19.0	**1.3×10^{-5}**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T-2up	23.0	1.56	1.37	17.8	**2.8×10^{-6}**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T-4d	24.8	1.41	1.33	23.0	**1.1×10^{-5}**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T-5d	19.2	1.66	1.64	15.5	**1.1×10^{-5}**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	T-10up	18.2	1.66	1.54	13.5	**2.9×10^{-5}**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

GEORISK SCIENTIFIC RESEARCH
COMPANY CJSC

INVESTIGATION AND LABORATORY TEST TO THE EXISTING EMBANKMENT IN YEGHVARD RESERVOIR

Report

YEREVAN, January, 2016

2. In-situ investigation and test

2-1. Test-pit excavation

(1) Findings

・The maximum grain size of cobbles is about 40 cm.

・The rock category of cobbles and gravels is basalt.

・The quality of cobbles is hard and not weathered so that the metallic sound is emitted from them by the hit of an iron hammer.

・The compacted layers are rich with fine particles composed of sand and silt that fills up almost completely and densely voids among gravels and cobbles.

(2) Test-pit photos

Figure 2. Test-pit No. 14

Figure 3. Test-pit No. 15

Figure 4. Test-pit No. 16

2-1. Wet density test

(1) Field measurement

Number of hole	Weigh of digged material (kg)	Volume of poured water (kg)	density
Test-pit No. 14	156.2	80.1	1.95
Test-pit No. 15	203.6	108.3	1.88
Test-pit No. 16	237.2	114.6	2.07

(2) Estimation of the compaction degree by the relative density, D value

Test-pit No. 14

Item	Calculation formula	Value	unit	Note
① Total volume of the excavated material		80,100	cm3	
② Total weight of the excavated material		156.2	kg	
③ Weight of the coarse portion	②×(100−65.25*)/100	54.3	kg	*passing percentage of −37mm
④ Weight of the fine portion	②−③	101.9	kg	
⑤ Bulk density of the coarse portion		2.25		
⑥ Volume of the coarse portion	③/⑤×1000	24124.2	cm3	
⑦ Volume of the fine portion	①−⑥	55,975.8	cm3	
⑧ Wet density of the fine portion	④×1000/⑦	1.82	g/cm3	
⑨ moisture content of the fine portion		9.5	%	
⑩ Dry density of the fine portion	⑧/(1+⑨/100)	1.66	g/cm3	
⑪ Maximum dry density in the compaction test		1.77	g/cm3	
⑫ Compaction degree (relative density D value)	⑩/⑪×100	93.9	%	

Test-pit No. 15

Item	Calculation formula	Value	unit	Note
① Total volume of the excavated material		108,300	cm3	
② Total weight of the excavated material		203.6	kg	
③ Weight of the coarse portion	②×(100−59.5*)/100	82.5	kg	*passing percentage of −37mm
④ Weight of the fine portion	②−③	121.1	kg	
⑤ Bulk density of the coarse portion		2.17		
⑥ Volume of the coarse portion	③/⑤×1000	37999.1	cm3	
⑦ Volume of the fine portion	①−⑥	70,300.9	cm3	
⑧ Wet density of the fine portion	④×1000/⑦	1.72	g/cm3	
⑨ moisture content of the fine portion		11.48	%	
⑩ Dry density of the fine portion	⑧/(1+⑨/100)	1.55	g/cm3	
⑪ Maximum dry density in the compaction test		1.65	g/cm3	
⑫ Compaction degree (relative density D value)	⑩/⑪×100	93.7	%	

Test-pit No. 16

Item	Calculation formula	Value	unit	Note
① Total volume of the excavated material		114,600	cm3	
② Total weight of the excavated material		237.2	kg	
③ Weight of the coarse portion	②×(100−61.48*)/100	91.4	kg	*passing percentage of −37mm
④ Weight of the fine portion	②−③	145.8	kg	
⑤ Bulk density of the coarse portion		2.35		
⑥ Volume of the coarse portion	③/⑤×1000	38880.6	cm3	
⑦ Volume of the fine portion	①−⑥	75,719.4	cm3	
⑧ Wet density of the fine portion	④×1000/⑦	1.93	g/cm3	
⑨ moisture content of the fine portion		7.81	%	
⑩ Dry density of the fine portion	⑧/(1+⑨/100)	1.79	g/cm3	
⑪ Maximum dry density in the compaction test		1.95	g/cm3	
⑫ Compaction degree (relative density D value)	⑩/⑪×100	91.6	%	

(3) Results of the field permeability test
Calculation formula

$$k = \frac{Q}{2\pi h^2}\left[\ln\left\{\frac{h}{r_0}+\left(\frac{h^2}{r_0^2}+1\right)^{1/2}\right\}-\left(\frac{r_0^2}{h^2}+1\right)^{1/2}+\frac{r_0}{h}\right]$$

Here; k : In-situ permeability coefficient (cm/sec)
Q : Seepage quantity (cm^3/sec)
h : Water depth in the test hole (cm)
r_0 : Radius of the test hole (cm)

(Source; Design standard "Dam", Department of Agriculture and Fishery, Japan)

Table1 TP-14

Trial N	poured Q (cm^3)	Time passed		Unit Q (cm^3)	H ; water depth	r ; hole radius	k ; (cm/sec)
		minute	second				
1	31000	2	22	218.3099	40	56	0.007471
2	31000	3	0	172.2222	40	56	0.005894
3	31000	3	2	170.3297	40	56	0.005829
4	31000	3	5	167.5676	40	56	0.005735
5	31000	3	1	171.2707	40	56	0.005861

Table2 TP-15

Trial N	poured Q (cm^3)	Time passed		Unit Q (cm^3)	H ; water depth	r ; hole radius	k ; (cm/sec)
		minute	second				
1	12600	34	34	6.075217	42	57.5	0.000193

Table3 TP-16

Trial N	poured Q (cm^3)	Time passed		Unit Q (cm^3)	H ; water depth	r ; hole radius	k ; (cm/sec)
		minute	second				
1	35750	63	0	9.457672	55	60	0.000215
2	3575	5	0	11.91667	55	60	0.000271

(4) Findings

・Any pinhole did not appear on the bottom surface of the test hole.

2-4. Measurement of the repose angle

(1) Measurement method

・ The excavated sand-and-gravel was mounded up naturally by the backhoe.

・ The inclination of the mound slope was measured by the tablet clinometer in such a manner as shown below.

Figure 8. Measurement of the repose angle

(2) Measurement result

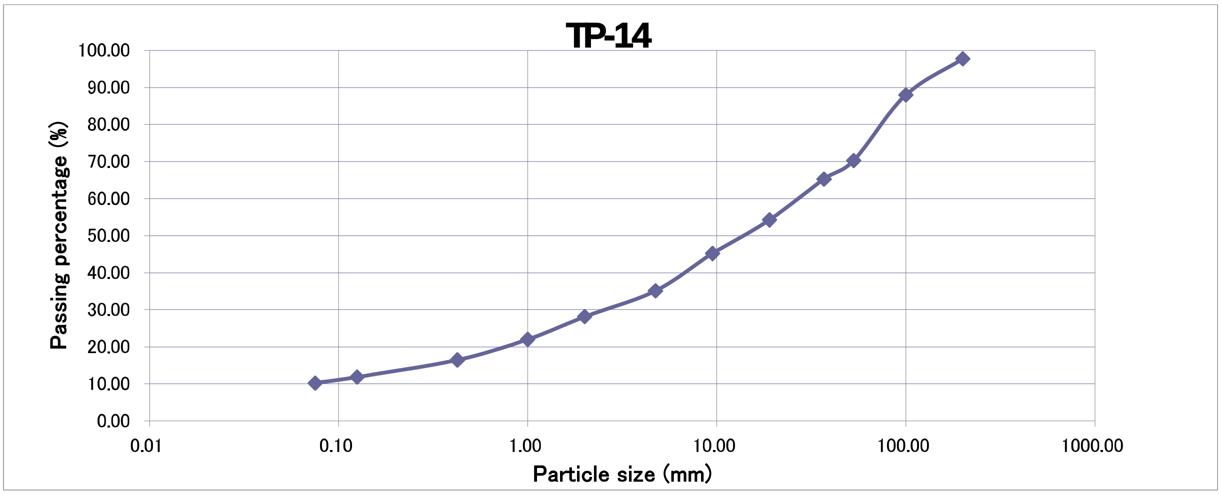
- Test-pit number 14 the repose angle is 36.8^0
- Test-pit number 15 the repose angle is 40.1^0
- Test-pit number 16 the repose angle is 41.2^0

5-4. Sieving test

TP-14

Sample weight (kg) 299.3

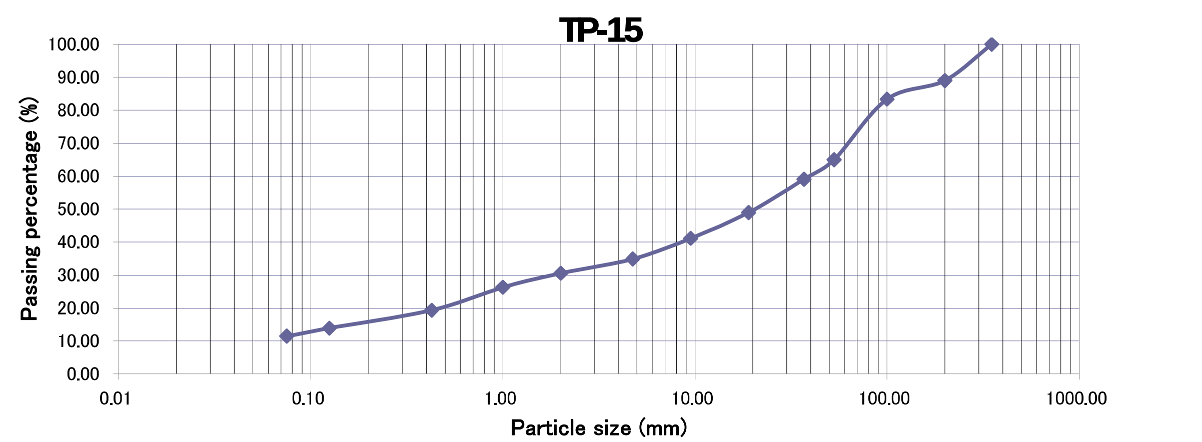
Sieve #	Retained		Comulative		
	Ret weight	Ret perc %	Com weight	Com perc %	Pass perc %
200.00	7.00	2.34	7.00	2.34	97.66
100.00	29.00	9.69	36.00	12.03	87.97
53.00	53.00	17.71	89.00	29.74	70.26
37.00	15.00	5.01	104.00	34.75	65.25
19.00	33.00	11.03	137.00	45.77	54.23
9.50	27.00	9.02	164.00	54.79	45.21
4.75	30.00	10.02	194.00	64.82	35.18
2.00	21.16	7.07	215.16	71.89	28.11
1.00	18.30	6.11	233.46	78.00	22.00
0.425	16.60	5.55	250.06	83.55	16.45
0.125	13.70	4.58	263.76	88.13	11.87
0.075	5.00	1.67	268.76	89.80	10.20
sum	268.76	89.80			



TP-15

Sample weight (kg) 337

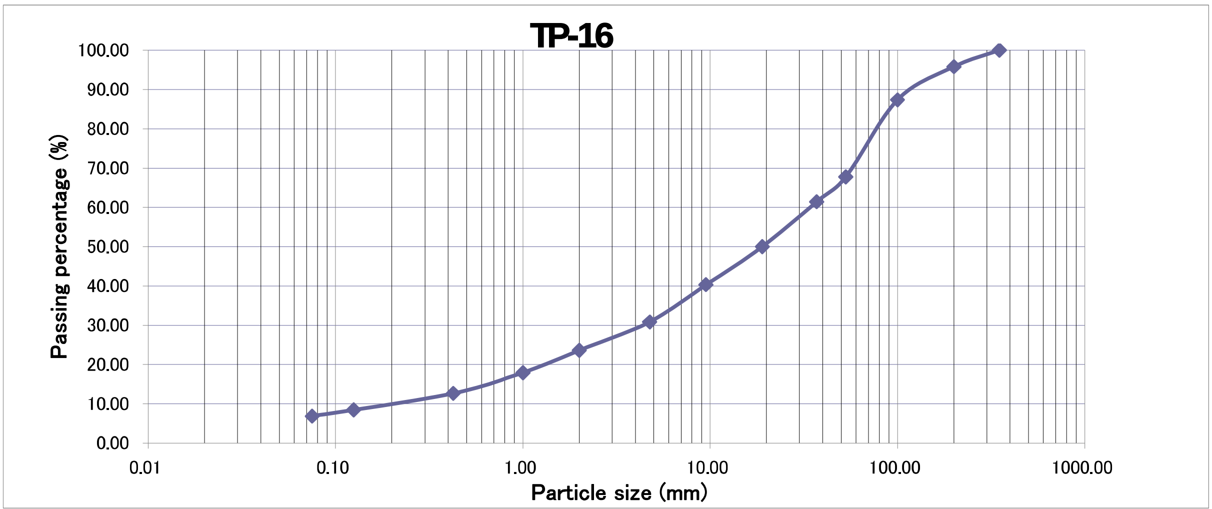
Sieve #	Retained		Comulative		
	Ret weight	Ret perc %	Com weight	Com perc %	Pass perc %
350.00					100.00
200.00	37.00	10.98	37.00	10.98	89.02
100.00	19.00	5.64	56.00	16.62	83.38
53.00	62.00	18.40	118.00	35.01	64.99
37.00	20.00	5.93	138.00	40.95	59.05
19.00	34.00	10.09	172.00	51.04	48.96
9.50	26.50	7.86	198.50	58.90	41.10
4.75	21.00	6.23	219.50	65.13	34.87
2.00	14.45	4.29	233.95	69.42	30.58
1.00	14.40	4.27	248.35	73.69	26.31
0.425	23.50	6.97	271.85	80.67	19.33
0.125	18.30	5.43	290.15	86.10	13.90
0.075	8.10	2.40	298.25	88.50	11.50
sum	298.25	88.50			



TP-16

Sample weight (kg) 506.2

	Retained		Comulative		
Sieve #	Ret weight	Ret perc %	Com weight	Com perc %	Pass perc %
350.00					100.00
200.00	21.00	4.15	21.00	4.15	95.85
100.00	43.00	8.49	64.00	12.64	87.36
53.00	99.00	19.56	163.00	32.20	67.80
37.00	32.00	6.32	195.00	38.52	61.48
19.00	58.00	11.46	253.00	49.98	50.02
9.50	49.00	9.68	302.00	59.66	40.34
4.75	48.00	9.48	350.00	69.14	30.86
2.00	36.70	7.25	386.70	76.39	23.61
1.00	28.50	5.63	415.20	82.02	17.98
0.425	26.90	5.31	442.10	87.34	12.66
0.125	21.20	4.19	463.30	91.53	8.47
0.075	8.10	1.60	471.40	93.13	6.87
sum	471.40	93.13			



6. APPENDIX

THE SUMMARIZED TEST RESULTS OF TOP SOIL SAMPLES

N	Sample No.	Ignition loss test	Standard compaction test		Direct shear test	
		Organic matter	Maximum dry density	Optimum moisture content	Cohesion, C,	Friction angle, φ
		%	g/cm^3	%	KPa	degrees
1.	Ts1	3.76	1.58	22.5	24.1	14.8
2.	Ts2	4.68	1.41	25.9	10.0	22.4
3.	Ts3	5.01	1.57	22.0	7.1	23.4

THE SUMMARIZED TEST RESULTS OF SAND-GRAVEL MIX

N	Sample No.	Moisture content	Specific gravity	Modified compaction test	
				Maximum dry density	Optimum moisture content
		%	-	g/cm^3	%
1.	TP 14 (fine portion)	9.50	2.59	1.77	16.0
2.	TP 15 (fine portion)	11.48	2.53	1.65	17.2
3.	TP 16 (fine portion)	7.81	2.64	1.95	12.7

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"C-LAB" LLC testing laboratory
Accreditation Certificate N 005/T-005

C-lab
CONSTRUCTION LABORATORY

REPUBLIC OF ARMENIA

"C-LAB" LLC TESTING LABORATORY

Customer: SANYU CONSULTANTS INC.

Contract name: Yeghvard irrigation development project in the Republic of Armenia

REPORT

"BENTONITE-SOIL" MIXTURE & "SOIL-CEMENT"
LABORATORY TEST FOR YEGHVARD RESERVOIR

Director of "C-lab" LLC __________ G. Gabrielyan

"18" May 2016

YEREVAN 2016

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Table 5. Permeability test results of "Sand/gravel fine + 10 % bentonite" mixture vs. number of blows

N	Mixture	Number of blows	Permeability, cm/sec.
1.	Sand/gravel fine + 10 % bentonite	15	$5.2 * 10^{-6}$
2.	Sand/gravel fine + 10 % bentonite	20	$2.4 * 10^{-6}$
3.	Sand/gravel fine + 10 % bentonite	25	$1.8 * 10^{-6}$

The detail results of tests are shown below:

Sand/gravel fine + 10 % bentonite (number of blows – 15 times)			
Specimen diameter, D, cm -	10.16	Compaction -	D-100
Burette area, a, cm^2 –	0.1256	Freezing/thawing -	No
Specimen area, A, cm^2 –	81.03	Test temperature, T ^{0}C -	16
Specimen length, L, cm -	11.64	Correction factor, R_T -	1.106

Measurements and calculation

Test No.	Initial Head, H_0	Final Head, H_1	Time, sec.	Hydraulic conductivity, K, cm/sec	$K_{20^oC}=K*R_T$
1	4.5	5.0	300	6.34E-06	7.01E-06
2	5.0	5.8	300	8.93E-06	9.87E-06
3	5.8	6.7	300	8.68E-06	9.59E-06
4	6.7	7.7	300	8.37E-06	9.25E-06
5	7.7	8.6	300	6.65E-06	7.35E-06
6	8.6	9.1	300	3.40E-06	3.76E-06
7	9.1	9.7	300	3.84E-06	4.25E-06
8	9.7	10.2	300	3.02E-06	3.34E-06
9	10.2	11.0	300	4.54E-06	5.02E-06
10	11.0	11.9	300	4.73E-06	5.23E-06
11	11.9	13.0	600	2.66E-06	2.94E-06
12	13.0	14.5	600	3.28E-06	3.63E-06
13	14.5	15.5	600	2.01E-06	2.22E-06
14	15.5	16.9	600	2.60E-06	2.88E-06
15	16.9	18	600	1.90E-06	2.10E-06

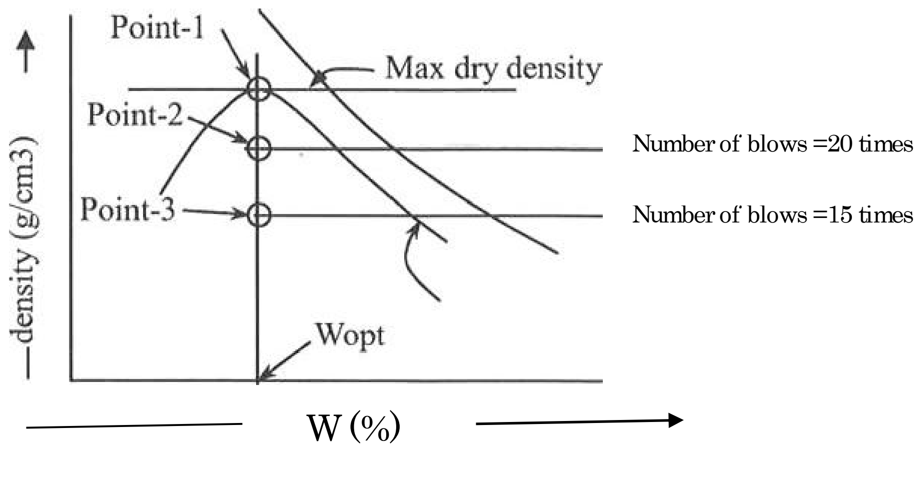
Average Hydraulic conductivity (K_{20^oC}) – $5.2 * 10^{-6}$ cm/sec

The summarized results are shown in Table 4.

Table 4. Atterberg limit results of "Soil - Bentonite" mixture

N	Mixture	Liquid limit, %	Plastic limit, %	Plasticity index, %
1.	Sandy loam + 7.5 % bentonite	34.5	17.0	17.5
2.	Sandy loam + 10 % bentonite	38.2	17.4	20.8
3.	Sandy loam + 12.5 % bentonite	43.5	18.4	25.1
4.	Sand/gravel fine + 7.5 % bentonite	39.5	39.2	0.3
5.	Sand/gravel fine + 10 % bentonite	43.5	42.2	1.3
6.	Sand/gravel fine + 12.5 % bentonite	46.5	45.0	1.5
7.	Sand/gravel coarse + 7.5 % bentonite	41.0	39.0	2.0
8.	Sand/gravel coarse + 10 % bentonite	46.0	39.3	6.7
9.	Sand/gravel coarse + 12.5 % bentonite	49.0	40.6	8.4

8.4 Falling head permeability test. The test was to know the relationship between the impervious degree and the compacted density and it was composed of three times of falling head permeability test. This test has been conducted at the beginning of the test execution; and the whole testing plan has been modified according to the result of this test.
The test points of three times of falling head permeability test are shown below. And the test has been conducted to the specimen just after being taken out of the mold.



The results of preparatory falling head permeability tests are shown in Table 5.

Table 5. Permeability test results of "Sand/gravel fine + 10 % bentonite" mixture vs. number of blows

N	Mixture	Number of blows	Permeability, cm/sec.
1.	Sand/gravel fine + 10 % bentonite	15	$5.2 * 10^{-6}$
2.	Sand/gravel fine + 10 % bentonite	20	$2.4 * 10^{-6}$
3.	Sand/gravel fine + 10 % bentonite	25	$1.8 * 10^{-6}$

The detail results of tests are shown below:

Sand/gravel fine + 10 % bentonite (number of blows – 15 times)			
Specimen diameter, D, cm -	10.16	Compaction -	D-100
Burette area, a, cm^2 –	0.1256	Freezing/thawing -	No
Specimen area, A, cm^2 –	81.03	Test temperature, T ^0C -	16
Specimen length, L, cm -	11.64	Correction factor, R_T -	1.106

Measurements and calculation

Test No.	Initial Head, H_0	Final Head, H_1	Time, sec.	Hydraulic conductivity, K, cm/sec	$K_{20^oC}=K*R_T$
1	4.5	5.0	300	6.34E-06	7.01E-06
2	5.0	5.8	300	8.93E-06	9.87E-06
3	5.8	6.7	300	8.68E-06	9.59E-06
4	6.7	7.7	300	8.37E-06	9.25E-06
5	7.7	8.6	300	6.65E-06	7.35E-06
6	8.6	9.1	300	3.40E-06	3.76E-06
7	9.1	9.7	300	3.84E-06	4.25E-06
8	9.7	10.2	300	3.02E-06	3.34E-06
9	10.2	11.0	300	4.54E-06	5.02E-06
10	11.0	11.9	300	4.73E-06	5.23E-06
11	11.9	13.0	600	2.66E-06	2.94E-06
12	13.0	14.5	600	3.28E-06	3.63E-06
13	14.5	15.5	600	2.01E-06	2.22E-06
14	15.5	16.9	600	2.60E-06	2.88E-06
15	16.9	18	600	1.90E-06	2.10E-06

Average Hydraulic conductivity (K_{20^oC}) – $5.2 * 10^{-6}$ cm/sec

10. SUMMARIZED TEST RESULTS

TEST RESULTS OF SAMPLED SOIL

N	Sample name	Moisture content, %	Specific gravity	Specific gravity & water absorption			Atterberg limits			Proctor test		Permeability, cm/sec.
				Bulk Specific Gravity	Apparent Specific Gravity	Water absorption	Liquid limit, %	Plastic limit, %	Plastic index	Max. Dry density, g/cm^3	OMC, %	
1.	Sandy loam	9.88	2.66	-	-	-	21.0	17.4	3.6	1.75	16.5	3.3E-05
2.	TP-17	9.31	2.59	2.23	2.30	2.41	Non-Plastic			1.77	14.5	-
3.	TP-18	4.69	2.59	2.35	2.41	2.06	Non-Plastic			1.56	10.5	-
4.	TP-19	16.16	2.62	2.32	2.38	1.82	33.1	20.6	12.5	1.79	17.0	-
5.	TP-20	16.77	2.60	2.32	2.40	2.42	Non-Plastic			1.83	15.8	-
6.	TP-22	11.04	2.41	1.42	1.52	15.16	Non-Plastic			1.31	17.0	3.1E-04
7.	TP-35	10.76	2.61	2.15	2.21	2.50	Non-Plastic			1.88	14.5	1.8E-04
8.	TP-41	24.79	2.75	2.17	2.36	7.14	32.2	20.9	11.3	1.59	22.7	1.5E-06
9.	TP-45	19.41	2.57	1.25	1.33	23.32	Non-Plastic			1.48	23.1	3.6E-05
10.	TP-50	22.44	2.78	2.06	2.39	12.98	Non-Plastic			1.57	24.0	1.8E-04
11.	TP-57	16.51	2.60	2.25	2.32	2.34	-	-	-	-	-	-
12.	TP-58	13.36	2.64	2.34	2.41	1.94	-	-	-	-	-	-
13.	TP-59	7.52	2.65	2.42	2.49	1.87	-	-	-	-	-	-
14.	TP-60	8.76	2.65	2.27	2.33	2.05	-	-	-	-	-	-
15.	TP-62	16.17	2.40	2.20	2.26	2.40	-	-	-	-	-	-
16.	TP-65	13.64	2.48	2.26	2.37	3.65	-	-	-	-	-	-
17.	TP-68	17.53	2.61	2.16	2.36	7.20	-	-	-	-	-	-
18.	TP-69	10.34	2.70	2.32	2.44	3.54		-	-	-	-	-
19.	Sand/gravel fine	-	-	-	-	-	Non-Plastic			1.65	14.5	5.3E-04
20.	Sand/gravel coarse	-	-	-	-	-	Non-Plastic			1.76	16.5	3.4E-05

TEST RESULTS OF “SOIL – BENTONITE” MIXTURE

N	Mixture	Compaction	Standard compaction		Permeability, cm/sec.		Unconfined compression strength, KPa		Atterberg limits			Observation in water
			Max. dry density, g/cm^3	OMC, %	Not cured	After freezing/ Thawing	Not cured	After freezing/ Thawing	LL, %	PL, %	PI	
1.	Sandy loam	D-100	1.75	16.50	3.3E-05	5.1E-04	374.5	947.2	21.0	17.4	3.6	-
2.	Sandy loam+7.5 % bentonite	D-100	1.65	20.20	1.8E-06	-	-	-	34.5	17.0	17.5	-
		D-97			2.2E-06	-	-	-				-
3.	Sandy loam+10 % bentonite	D-100	1.65	19.00	1.7E-06	7.8E-06	276.9	531.8	38.2	17.4	20.8	Destroyed after 0.5-1 hour
		D-97			2.6E-06	2.7E-06	88.1	487.8				
4.	Sandy loam+12.5 % bentonite	D-100	1.53	23.00	2.9E-06	-	-	-	43.5	18.4	25.1	-
		D-97			2.0E-06	-	-	-				-
5.	Sand/gravel fine	D-100	1.65	14.50	5.3E-04	-			Non-Plastic			-
6.	Sand/gravel fine+7.5 % bentonite	D-100	1.61	21.00	2.2E-05	-	-	-	39.5	39.2	0.3	-
		D-97			1.1E-06		-	-				-
7.	Sand/gravel fine+10 % bentonite	D-100	1.62	21.00	7.0E-06	2.3E-05	239.2	207.7	43.5	42.2	1.3	Destroyed after 0.5-1 hour
		D-97			4.7E-07	1.2E-04	66.1	192.0				
8.	Sand/gravel fine+12.5 % bentonite	D-100	1.56	24.00	2.5E-06	-	-	-	46.5	45.0	1.5	-
		D-97			4.6E-07	-	-	-				-
9.	Sand/gravel coarse	D-100	1.76	16.50	3.4E-05	-			Non-Plastic			-
10.	Sand/gravel coarse+7.5 % bentonite	D-100	1.65	19.20	3.1E-06	-	-	-	41.0	39.0	2.0	-
		D-97			1.8E-06	-	-	-				-
11.	Sand/gravel coarse+10 % bentonite	D-100	1.63	20.30	1.4E-06	7.8E-06	129.0	119.6	46.0	39.3	6.7	Destroyed after 0.5-1 hour
		D-97			1.4E-06	2.9E-06	75.5	179.4				
12.	Sand/gravel coarse+12.5 % bentonite	D-100	1.57	23.00	1.9E-06	-	-	-	49.0	40.6	8.4	-
		D-97			1.4E-06	-	-	-				-

TEST RESULTS OF "SOIL – CEMENT" MIXTURE

N	Mixture	Standard compaction		Permeability, cm/sec.			Unconfined compression strength, MPa				Degree of slaking, %	Soundness, %	Hexavalent chromium content, mg/L	
		Max. dry density, g/cm^3	OMC, %	Cured	Not cured	After freezing/ Thawing	Cured 7 day	Cured 28 day	Not cured	After freezing/ Thawing			By color comparison method	By Ion Chromatog raphy
1.	Sandy loam + 6 % cement	1.67	19.00	3.6E-07	-	2.8E-07	1.7	2.7	-	2.3	4.1	11.3	0.11	-
2.	Sandy loam + 8 % cement	1.70	18.00	8.0E-08	2.2E-06	4.7E-07	2.4	3.1	3.4	3.5	3.5	6.4	0.10	0.1144
3.	Sandy loam + 10 % cement	1.71	17.61	7.0E-08	7.2E-06	3.0E-07	3.5	4.1	5.2	4.6	2.7	4.1	0.12	-
4.	Sand/gravel fine + 6 % cement	1.72	18.92	7.2E-07	-	1.0E-06	2.2	4.2	-	3.6	3.3	4.3	0.17	-
5.	Sand/gravel fine + 8 % cement	1.72	17.58	7.6E-08	3.0E-06	5.7E-07	3.5	4.3	4.3	4.5	2.6	2.8	0.094	0.092
6.	Sand/gravel fine + 10 % cement	1.70	18.95	7.7E-07	2.4E-06	2.6E-07	2.5	5.5	6.0	6.1	1.4	1.8	0.15	-
7.	Sand/gravel coarse + 6 % cement	1.77	17.42	5.9E-08	-	2.6E-07	3.1	4.0	-	4.0	3.6	4.1	0.12	-
8.	Sand/gravel coarse + 8 % cement	1.72	16.50	3.9E-08	1.5E-05	1.7E-07	4.6	4.9	5.3	5.8	2.2	2.8	0.056	0.057
9.	Sand/gravel coarse + 10 % cement	1.74	16.00	4.1E-08	1.4E-05	6.1E-08	2.4	5.8	6.3	6.9	1.9	2.1	0.13	-
10.	TP-22 + 8 % cement	1.35	19.00	4.5E-05	-	-	1.4	-	-	-	2.1	3.6	-	-
11.	TP-35 + 8 % cement	1.88	14.62	9.0E-08	-	-	4.5	-	-	-	3.6	6.1	-	-
12.	TP-41 + 8 % cement	1.52	24.00	9.5E-08	-	-	1.5	-	-	-	7.4	8.1	-	-
13.	TP-45 + 8 % cement	1.43	19.50	6.4E-08	-	-	2.9	-	-	-	6.4	10.6	-	-
14.	TP-50 + 8 % cement	1.49	20.90	3.2E-07	-	-	3.2	-	-	-	6.8	6.9	-	-
15.	Sandy loam + 8 % slag-cement 1	1.69	18.00	-	-	-	2.0	-	-	-	-	-	0.061	0.065
16.	Sand/gravel fine+8 % slag-cement 1	1.62	19.00	-	-	-	3.6	-	-	-	-	-	0.072	0.070
17.	Sand/gravel coarse+8 % slag-cement 1	1.67	15.80	-	-	-	4.6	-	-	-	-	-	0.066	0.064
18.	Sandy loam + 8 % slag-cement 2	1.62	17.40	-	-	-	2.0	-	-	-	-	-	0.062	0.0596
19.	Sand/gravel fine+8 % slag-cement 2	1.66	21.00	-	-	-	3.0	-	-	-	-	-	0.064	0.068
20.	Sand/gravel coarse+8 % slag-cement 2	1.70	16.00	-	-	-	3.9	-	-	-	-	-	0.050	0.051
21.	Sandy loam + 10 % slag-cement 1	1.70	18.00	-	-	-	2.5	-	-	--	-	-	0.052	0.065
22.	Sand/gravel fine+10 % slag-cement 1	1.69	21.00	-	-	-	3.6	-	-	-	-	-	0.066	0.068
23.	Sand/gravel coarse+10 % slag-cement 1	1.72	19.83	-	-	-	3.3	-	-	-	-	-	0.064	0.068
24.	Sandy loam + 10 % slag-cement 2	1.66	19.50	-	-	-	2.4	-	-	-	-	-	0.058	0.059
25.	Sand/gravel fine+10 % slag-cement 2	1.67	20.50	-	-	-	3.4	-	-	-	-	-	0.076	0.081
26.	Sand/gravel coarse+10 % slag-cement 2	1.77	18.50	-	-	-	3.5	-	-	-	-	-	0.070	0.071

APPENDIX J

Conditions and Results of Dam Stability Analysis

Appendix J-1: Physical Properties

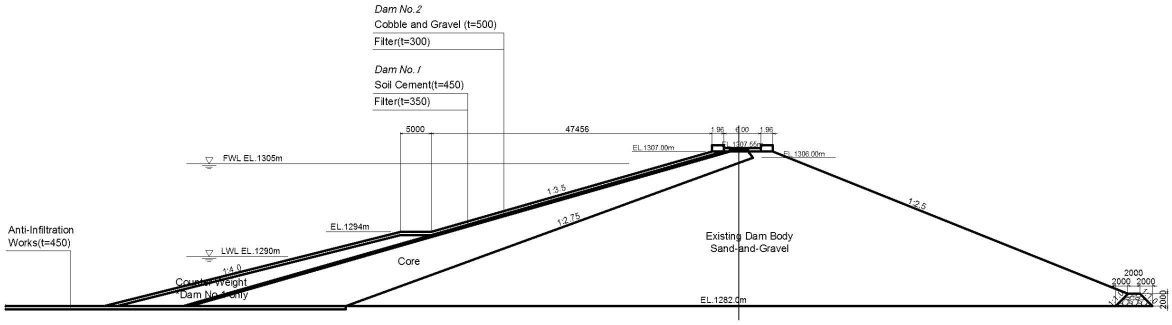


Figure J-1.1 Typical Cross Section

Table J-1.1 Physical Properties for Dam Stability Analysis

Zone	Wet Density γ_t (kN/m^3)	Saturated Density γ_{sat} (kN/m^3)	Cohesion c (kN/m^2)	Internal Friction Angle φ (Degree)
1. Core	18.99	19.19	21.40	24.30
2. Filter	19.25	20.00	0	38.00
3. Existing Dam Body*	19.30	19.97	0	38.00
4. Slope protection	22.00	22.00	0	38.00
5. Dam Crest Covering	19.30	19.97	0	33.00
6. Counter Weight	19.30	19.97	0	33.00

(1) Core zone

1) General Condition

Material can be utilized for core zone is Sandy-Loam and ten test pits are dug to collect material for laboratory tests. Location of test pits is shown in the Figure J-1.2 and materials are collected from both upper and lower side of test pits.

Figure J-1.3 shows the results of proctor test of collected core zone materials. As a result, variety of dry density and optimum moisture content extends to wide range.

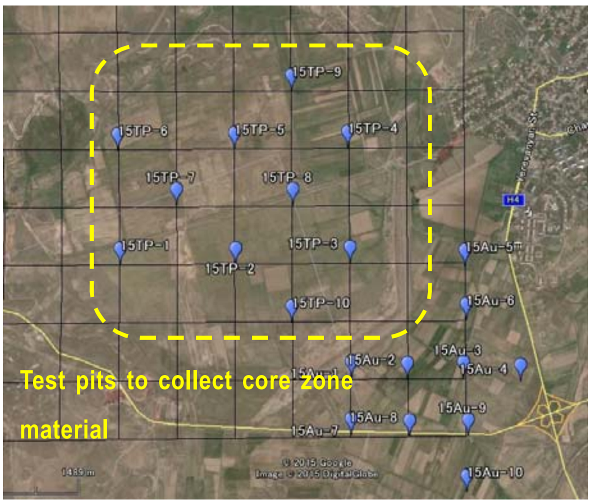


Figure J-1.2 Location of Test Pits

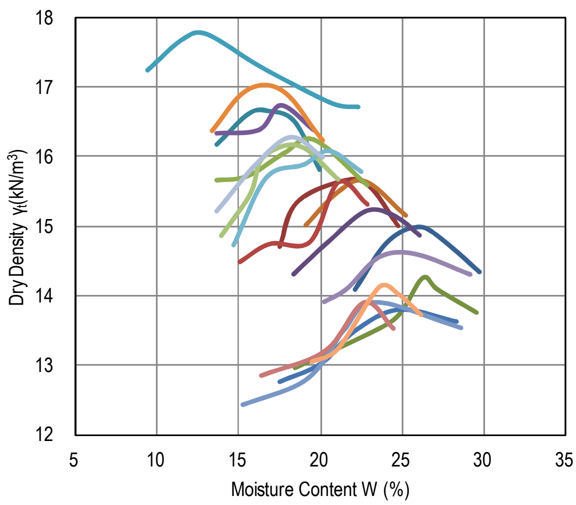
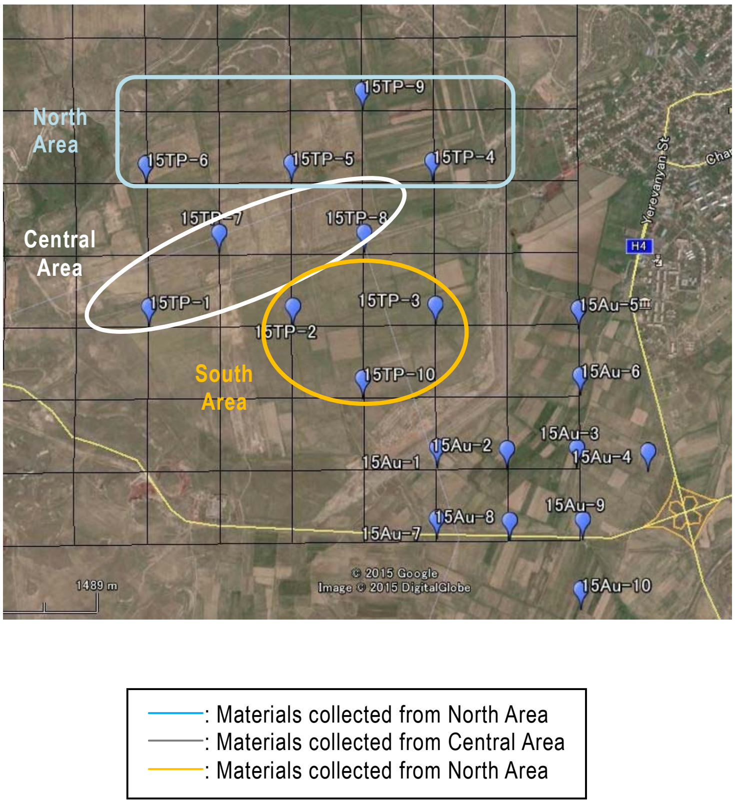


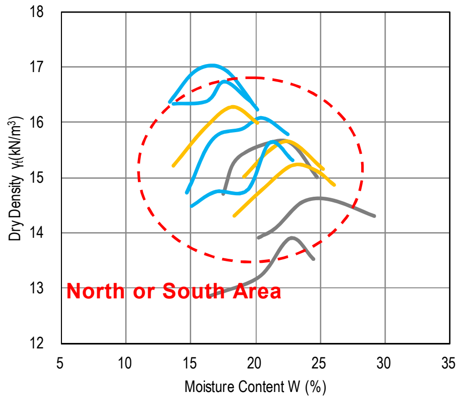
Figure J-1.3 Results of Proctor Test

However there can find a characteristic after categorizing proctor test results by collected side (upper or lower) and area as shown in the Figure J-1.4. Dry density and optimum moisture content of materials collected from lower part has wide range. On the other hand, those of materials from upper side especially collected from north or south area has narrow range. Since material is better as uniform as possible, material shall be collected from upper side of north and south area, not from the central area or lower side.

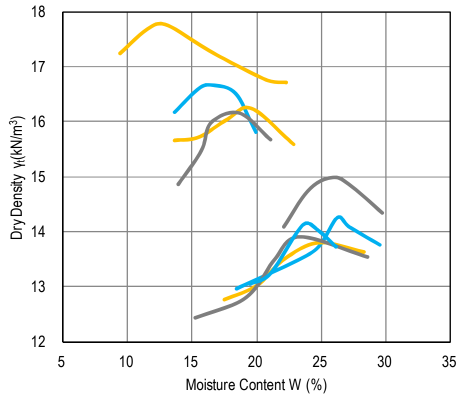
Taking into account the condition above, physical properties of core zone is examined targeting materials collected from upper side of south and north zone (TP-2, TP-3, TP-4, TP-5, TP-6,TP-9, TP-10).

Thickness of Sandy-Loam layer at central area is thick and this part acts as anti-infiltration works to reduce leakage volume. If material for core zone is collected from central area, thickness of Sandy-Loam becomes thinner and leakage volume becomes bigger. On the other hand, thickness along the edge of reservoir is thin and contribution to reduce leakage volume is very limited. Therefore collection of materials from north or south area has almost no influence to increase leakage volume. From the view point to reduce leakage volume, collection of material from north and south side is considered as better choice.





Results of Proctor Test (upper side materials)



Results of Proctor Test (Lower side materials)

Figure J-1.4 Characteristics of Proctor Tests

1) Density

Dry density with relative density 97% of maximum dry density (wet side) is selected as design value. Since relative density 97% of each collected material is different, design value is calculated by (Average) - 0.5 x (Standard Deviation) as shown in the Table J-1.2.

Table J-1.2 Design Value of Density (Core Zone)

No.	Specific Gravity Gs	Moisture Content W (%) *D value:97%	Dry Density γ_d (kN/m3) *D value: 97%	Wet Density γ_t (kN/m3)	Saturated Density γ_{sat} (kN/m3)
TP-2 U	2.58	26.35	14.84	18.75	18.90
TP-3 U	2.57	24.90	15.23	19.02	19.11
TP-4 U	2.57	23.22	15.23	18.77	19.11
TP-5 U	2.63	20.12	16.27	19.54	19.89
TP-6 U	2.64	19.38	16.46	19.65	20.04
TP-9 U	2.60	23.55	15.61	19.29	19.42
TP-10 U	2.53	21.10	15.80	19.13	19.36
(1) Average				19.16	19.41
(2) Standard Deviation				0.35	0.42
(3) Design Value (=(1)Average-0.5 x (2)Standard Deviation)				18.99	19.19

2) Shearing strength (cohesion: c and internal friction angle φ)

i) Target results

Collected materials from ten test pits are categorized into five (5) groups according to its physical specification as shown in the Table J-1.3. Triaxle CU test is conducted to representative material of each group. Target materials to exam physical properties are belonging to No.1, 2, 3 and 5. Therefore shearing strength is examined utilizing the results of triaxle CU test of these groups.

Table J-1.3 Categorization of Material

Group	Characteristics	Categorized Sample	Representative Sample (Target for Triaxle CU test)
1	Low P.I. Medium - Low percentage of 0.005mm content	1u, 2d, 5u, 6u, 10u	10u
2	Low P.I. High percentage of 0.005mm content	1d, 7u, 7d, 8d, 9u	1d
3	Medium P.I	2u, 3u, 8u	2u
4	Non Plastic Low percentage of 0.005mm content	3d, 5d, 6d	5d
5	Non Plastic Medium percentage of 0.005mm content	4u, 4d, 10d	4d

*u: material collected from upper side of test pit

*d: material collected from lower side of test pit

*Sample numbers with red letter are target to exam physical properties

ii) Evaluation of results

The maximum depth from the slope surface to bottom of core zone is about 10m. In this case, overburden stress σ_1 is around 200kN/m^2 and lateral pressure σ_3 is around 67kN/m^2 as shown in the Figure J-1.5 (density of each zone is around 20kN/m^3).

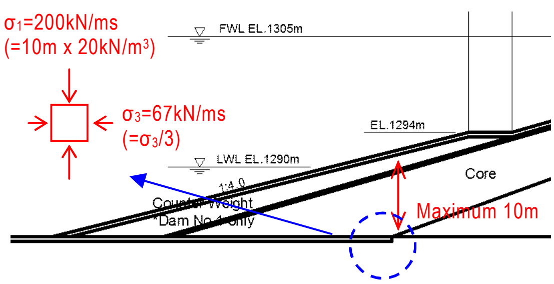


Figure J-1.5 Maximum Stress Condition

Triaxle test is conducted under lateral pressure σ_3=50, 100 and 150 kN/m^2. Generally an line enveloping all the Mohr's circle is decided as shearing strength. However in this survey, taking into account the stress condition above (maximum σ_3= around 50kN/m^2) , an line enveloping Mohr's circle under σ_3=50 and 100 kN/m^2 is selected as design value.

Table J-1.4 shows the shearing strength evaluated by Mohr's circle under σ_3=50 and 100 kN/m^2. Same as density, shearing strength of each collected material is different.

Design value is selected taking into account overburden stress condition of core zone. The range of overburden stress of core zone is about from 16kN/m2 to 200kN/m^2 as shown in the Figure J-1.6. Within this range, shearing strength of Group-1 (red line in the Figure J-1.7) is almost minimum and this value is selected as design value

Table J-1.4 Shearing Strength Evaluated by Mohr's Circle under σ_3= 50 and 100kN/m^2

Group	Cohesion c (kN/m²)	Internal Friction Angle φ (degree)
1	21.4	24.3
2	22.7	25.7
3	12.1	33.9
5	19.5	31.5

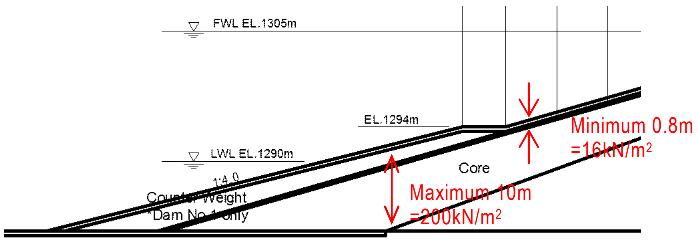


Figure J-1.6 Overburden Stress Condition of Core Zone

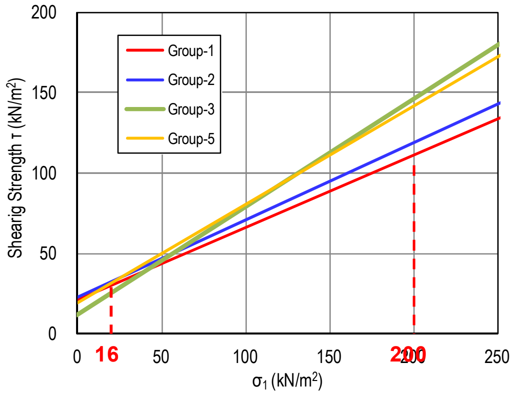


Figure J-1.7 Shearing Strength

(2) Filter zone

1) General Condition

Material for filter zone shall satisfy the following Sherard's filter criteria.

i) Maximum D_{15} size

Table J-1.5 Filter Criteria in Terms of Maximum D15 size

Soil Categorization	Base Soil Description	Percent finer than 0.075mm sieve after regraded by material which passes 4.75mm sieve	Filter criteria in terms of maximum D_{15} size
1	Fine silts and clays	more than 85% finer	D_{15}<=9 d_{85}
2	Sands, silts, clays and silty and clayey sands	40 to 85% finer	D_{15}<=0.7mm
3	Silty and clayey sands and gravels	15 to 39% finer	D_{15}<=0.7+(40-A) x (4 x d_{85}-0.7)/25
4	Sands and gravels	less than 15% finer	D_{15}<=4 or 5 d_{85}

*D_{15}: 15% grain size of filter.
*d_{85}: 85% grain size of material to be protected

ii) Maximum grain size of filter shall be 75mm.

iii) Percent finer than 0.075mm is less than 5%.

iv) D_{15} shall be more than 4 times of 85% grain size of material to be protected but not less than 0.1mm.

Red thick line in the Figure J-1.8 is average grading curve of core material and blue line is that of Sand-and-Gravel collected from test pits. To satisfy filter condition above, a model grading curve of filter is created (black line in the Figure J-1.8). This filter material is produced by sieving Sand-and-Grave.

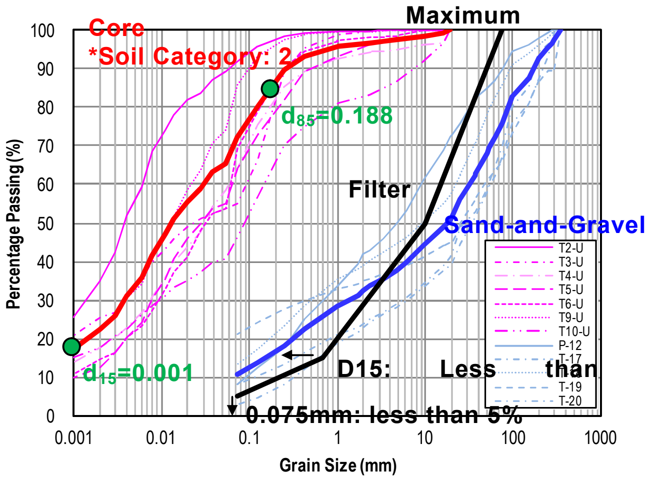


Figure J-1.8 Model Grading Curve of

2) Density

Utilizing D_{50} from model grading curve and same value of specific gravity Gs as existing dam body, 19.25 kN/m^3 is calculated as wet density and 20.00 kN/m^3 as saturated density.

3) Shearing strength (cohesion: c and internal friction angle φ)

The same values as existing dam body are applied to those of filter zone.

(3) Existing dam body

1) Density

5 test pits are dug and wet density is calculated according to the results of field density test at test pits. Also saturated density is calculated by wet density, moisture content and specific gravity. Design value is calculated by (Average) - 0.5 x (Standard Deviation) as shown in the Table J-1.6 same as core zone.

Table J-1.6 Design Value of Density (Existing Dam Body)

Location	No.	Diameter	Specific Gravity Gs	Moisture Content W (%)	Volume V (cm3)	Wet Density: Weight Wt (g)		Wet Density γt (kN/m3) (=Wt/V*9.81)	Dry Density: Weight Wd (g)		Dry Density γd (kN/m3) (=Wd/V*9.81)	Saturated Density: Weight Wsat (g)	Saturated Density γsat (kN/m3) (=Wsat/V*9.81)
Dam No.1	TPI-1	Fine	2.69	5.97	66,700	40,086.81	141,850	20.86	37,828.45	133858.64	19.69	145,457.48	21.39
		Coarse	2.34			101,763.19			96,030.19				
	TP-16	Fine	2.64	7.81	114,600	73,199.92	237,200	20.30	67,897.15	220016.70	18.83	244,166.36	20.90
		Coarse	2.35			164,000.08			152,119.54				
Dam No.2	TPI-4	Fine	2.57	7.04	79,700	50,420.37	164,450	20.24	47,104.23	153634.16	18.91	169,480.05	20.86
		Coarse	2.34			114,029.63			106,529.92				
	TP-14	Fine	2.59	9.50	80,100	54,951.16	156,200	19.13	50,183.71	142648.40	17.47	162,277.03	19.87
		Coarse	2.25			101,248.84			92,464.69				
	TP-15	Fine	2.53	11.48	108,300	70,995.32	203,600	18.44	63,684.36	182633.66	16.54	210,946.63	19.11
		Coarse	2.17			132,604.68			118,949.30				
(1) Average								19.80					20.43
(2) Standard Deviation								0.98					0.92
(3) Design Value (=(1)Average-0.5 x (2)Standard Deviation)								19.30					19.97

Fine: Diameter is 4.75mm and less

Coarse: Diameter is more than 4.75mm

2) Shearing strength (cohesion: c and internal friction angle φ)

Existing dam body consists of Sand-and-Gravel. Since Sand-and-Gravel is non-cohesive material, 0 is applied to cohesion c.

At the field, internal friction angle of disposed Sand-and-Gravel is measured. Average value is selected as internal friction angle for design. Although internal friction angle of compacted Sand-and-Gravel is bigger than disposed one, however this time values from disposed one is selected taking into consideration safety.

(4) Sand-and-Gravel zone

The same values as existing dam body are applied to those of Sand-and-Gravel zone.

Table J-1.7 Internal Friction Angle (Results of Disposed Sand-and-Gravel)

No.	φ (Degree)
1	33
2	35
3	35
4	38
5	41
6	36.8
7	40.1
8	41.2
Average	38

(5) Slope protection

1) Density

Since soil cement is planned to be adopted to slope protection, density 22kN/m^3 is selected as a design value of wet density. Also same value 22kN/m^3 is applied to saturated density because soil cement has almost no void.

2) Shearing strength (cohesion: c and internal friction angle φ)

Same values as existing dam body are applied to those of slope protection.

(5) Dam crest covering and counter weight

1) Density

The same values as existing dam body are applied to those of dam crest covering and counter weight.

2) Shearing strength (cohesion: c and internal friction angle φ)

0 for cohesion c is applied by the same reason as the other non-cohesive materials.

Dam crest covering and counter weight is act as a disposal area of Sand-and-Gravel and any type of Sand-and-Gravel can be material for these zone. Therefore minimum internal friction angle 33 degree is applied from the view point of safety.

Appendix J-2: Shape of Seepage surface

(1) Core Zone

The Fukuda method below is applied. Point B in the Figure J-2.1 is cross point of water level and core zone, B_1 is bottom width of core zone and B_2 is width of core zone at the elevation of water level. Seepage surface within core zone is shown by an arc BC which diameter is r (=1/2 (B_1+B_2)) and center is point D.

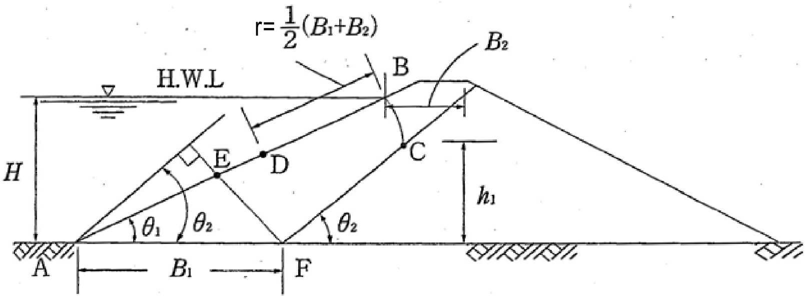
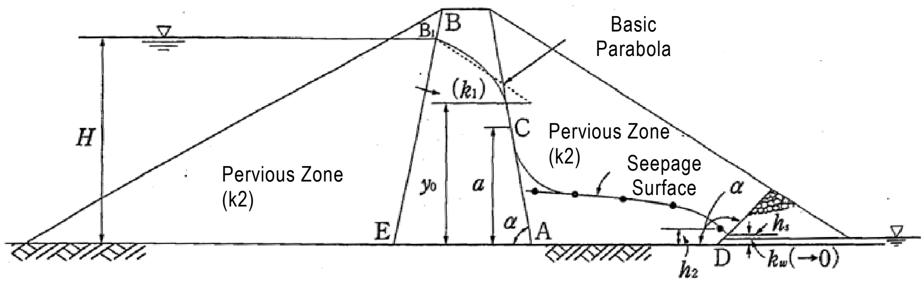


Figure J-2.1 Seepage Surface within Core Zone (Inclined Core Type)

(2) Existing Dam body or Sand-and-Gravel

The A. Casagrande method is applied. Seepage surface is shown by a parabola with its anchor at point D (edge of slope).



Where;
$h_2 = y_0 \times (k_1/k_2)$
$v^2 = 2h_2x + h_2^2$

Figure J-2.2 Seepage Surface within Pervious Zone

*Seepage surface (1) and (2) is connected by smooth line.

Appendix J-3: Calculation Method of k_Y

J-3-1 Armenian Method

k_Y varies depending on height from the basement and it is calculated according to one dimension free oscillation theory. k_Y is calculated by the formula below. Also 70% of k_Y is applied to vertical coefficinet.

$$k_Y = k\sqrt{\Sigma(\beta_i \eta_{ik})^2}$$

$\beta_i = 1 + 15T_i \quad 0 < T_i \leq 0.1$

$\beta_i = 2{,}5 \quad 0.1 < T_i \leq 0.4$

$\beta_i = 1/T_i \quad T_i > 0.4$

$T_i = 2\pi H / k_i V_s$

i	1	2	3	4
k_i	2.40	5.52	8.65	11.79

$$\eta_{ik}(x) = \frac{2I_0\left(k_i \frac{x}{H}\right)}{k_i I_1(k_i)},$$

β_i is calculated as Table J-3.1 based on dam height H=26m and average Vs of dam body 371m/s. Also due to complicated calculation of η_{ik}, calculated value is provided by the Table J-3.2.

Table J-3.1 Calculated β_i

i	i=1	i=2	i=3	i=4
k_i	2.40	5.52	8.65	11.79
T_i	0.183	0.080	0.051	0.037
β_i	2.500	2.197	1.764	1.560

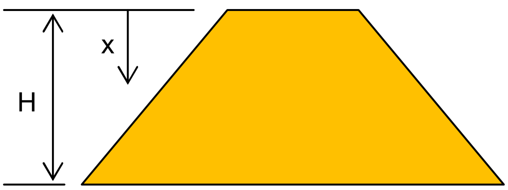


Table J-3.2 Calculated η_{ik}

i		η_{ik}			
		i=1	i=2	i=3	i=4
x/H	**0**	1.605	-1.069	0.855	-0.728
	0.1	1.578	-0.988	0.699	-0.496
	0.2	1.51	-0.766	0.324	-0.017
	0.3	1.4	-0.452	-0.081	0.281
	0.4	1.252	-0.113	-0.319	0.193
	0.5	1.074	0.173	-0.304	-0.088
	0.6	0.872	0.371	-0.101	-0.218
	0.7	0.654	0.428	0.142	-0.079
	0.8	0.43	0.362	0.255	0.133
	0.9	0.208	0.201	0.186	0.165
	1	0	0	0	0

H: Dam height (m), x: Depth from dam crest (m)

Utilizing the results above, k_Y for each elevation is calculated as shown in the Table J-3.3 and Figure J-3.1

Table J-3.3 Calculated k_Y

x/H	$(\beta_1\eta_{1k})^2$	$(\beta_2\eta_{2k})^2$	$(\beta_3\eta_{3k})^2$	$(\beta_4\eta_{4k})^2$	$\sqrt{\Sigma(\beta_i\eta_{ik})^2}$	k_Y Case-1 k=0.12	k_Y Case-2 k=0.06
0	16.100	5.514	2.274	1.290	5.018	0.602	0.301
0.1	15.563	4.710	1.520	0.599	4.732	0.568	0.284
0.2	14.251	2.831	0.326	0.001	4.172	0.500	0.250
0.3	12.250	0.986	0.020	0.192	3.667	0.440	0.220
0.4	9.797	0.062	0.316	0.091	3.204	0.384	0.192
0.5	7.209	0.144	0.287	0.019	2.768	0.332	0.166
0.6	4.752	0.664	0.031	0.116	2.359	0.283	0.142
0.7	2.673	0.884	0.063	0.015	1.907	0.229	0.114
0.8	1.156	0.632	0.202	0.043	1.426	0.171	0.086
0.9	0.270	0.195	0.108	0.066	0.800	0.096	0.048
1	-	-	-	-	-	0.120	0.060

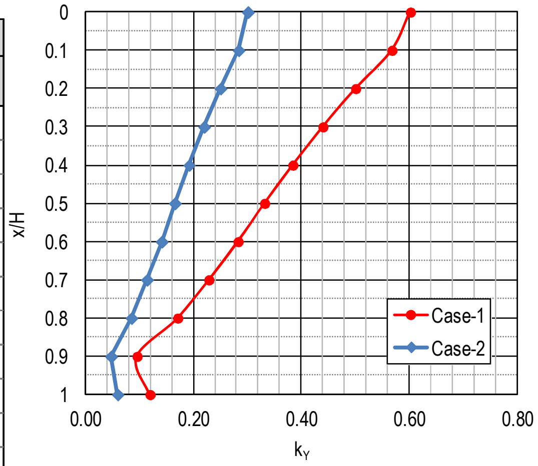


Figure J-3.1 Calculated k_Y

J-3-2 Japanese Method

k_Y is fixed value and its value is same as PGA coefficient k. This means k is applied to any part of dam body. Also same as Armenian standard, 0.7k is applied to vertical PGA coefficient.

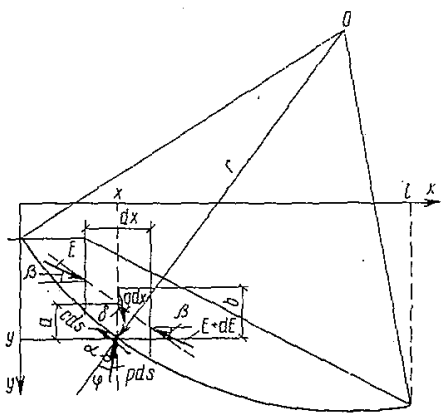
Appendix J-4: Analysis Method

J-4-1 Armenian Method

Safety Factor = R/ F

$$F_0 = r\,\Sigma Q\,[\sin(\alpha+\delta) - \frac{b}{r}\sin\delta]$$

$$R_0 = r\,[\Sigma\frac{Q\cos(\beta+\delta)\sin\varphi}{\cos(\varphi+\beta-\alpha)} + \Sigma\frac{C\cos(\beta-\alpha)\cos\varphi}{\cos(\varphi+\beta-\alpha)}]$$



J-4-2 Japanese Method

(1) Downstream Slope

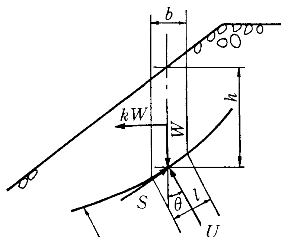
$$F_s = \frac{1 - m \cdot K}{m + K} \cdot \tan\phi' \cdot\cdot$$

Where; m: Slope angle
K: PGA coefficient
φ': Internal friction angle

(2) Upstream slope

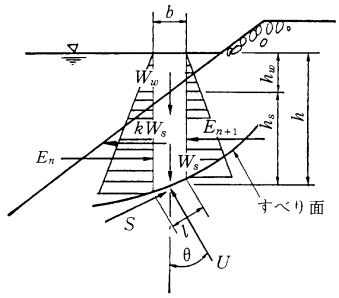
$$\text{Safety Factor} = \frac{\Sigma\{cl + (N - U - N_e)\tan\phi\}}{\Sigma(T + T_e)}$$

1) Dry part



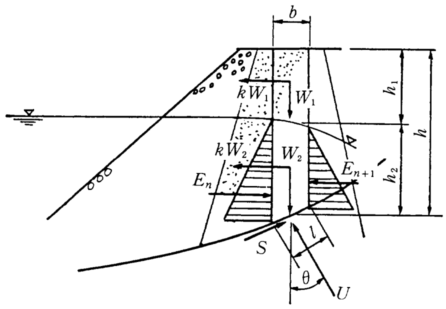
$$N = W\cos\theta = bh\gamma_t\cos\theta$$
$$N_e = kW\sin\theta = kbh\gamma_t\sin\theta$$
$$U = ul$$
$$T = W\sin\theta = bh\gamma_t\sin\theta$$
$$T_e = kW\cos\theta = kbh\gamma_t\cos\theta$$

2) Submerged part



$$N = W\cos\theta + \Delta E\sin\theta$$
$$= (W_s + W_w)\cos\theta + (E_n - E_{n+1})\sin\theta$$
$$= (\gamma_{sat}h_s + \gamma_w h_w)b\cos\theta + \gamma_w hb\sin^2\theta \,/\, \cos\theta$$
$$= \gamma_{sub}\cdot h_s b\cos\theta + \gamma_w hb \,/\, \cos\theta$$
$$N_e = kW_s\sin\theta$$
$$= k\gamma_{sat}h_s b\sin\theta$$
$$U = ul = \gamma_w hb \,/\, \cos\theta$$
$$T = W\sin\theta - \Delta E\cos\theta$$
$$= (W_s + W_w)\sin\theta - (E_n - E_{n+1})\cos\theta$$
$$= (h_s\gamma_{sat} + h_w\gamma_w)b\sin\theta - \gamma_w hb\sin\theta$$
$$= bh_s\gamma_{sub}\sin\theta$$
$$T_e = kW_s\cos\theta$$
$$= kh_s\gamma_{sat}b\cos\theta$$

3) Partly submerged part



$$N = W\cos\theta + \Delta E\sin\theta$$
$$= (W_1 + W_2)\cos\theta + (E_n - E_{n+1})\sin\theta$$
$$= (\gamma_t h_1 + \gamma_{sat}h_2)b\cos\theta + (E_n - E_{n+1})\sin\theta$$
$$N_e = (W_1 + W_2)k\sin\theta$$
$$= (h_1\gamma_t + h_2\gamma_{sat})bk\sin\theta$$
$$U = vl$$
$$T = W\sin\theta - \Delta E\cos\theta$$
$$= (W_1 + W_2)\sin\theta - (E_n - E_{n+1})\cos\theta$$
$$= (h_1\gamma_t + h_2\gamma_{sat})b\sin\theta - (E_n - E_{n+1})\cos\theta$$
$$T_e = (W_1 + W_2)k\cos\theta$$
$$= (h_1\gamma_r + h_2\gamma_{sat})bk\cos\theta$$

Appendix J-5: Results of Stability Analysis

J-5-1 Summary of Calculated Safety Factor

Table J-5.1 Summary of Calculated Safety Factor

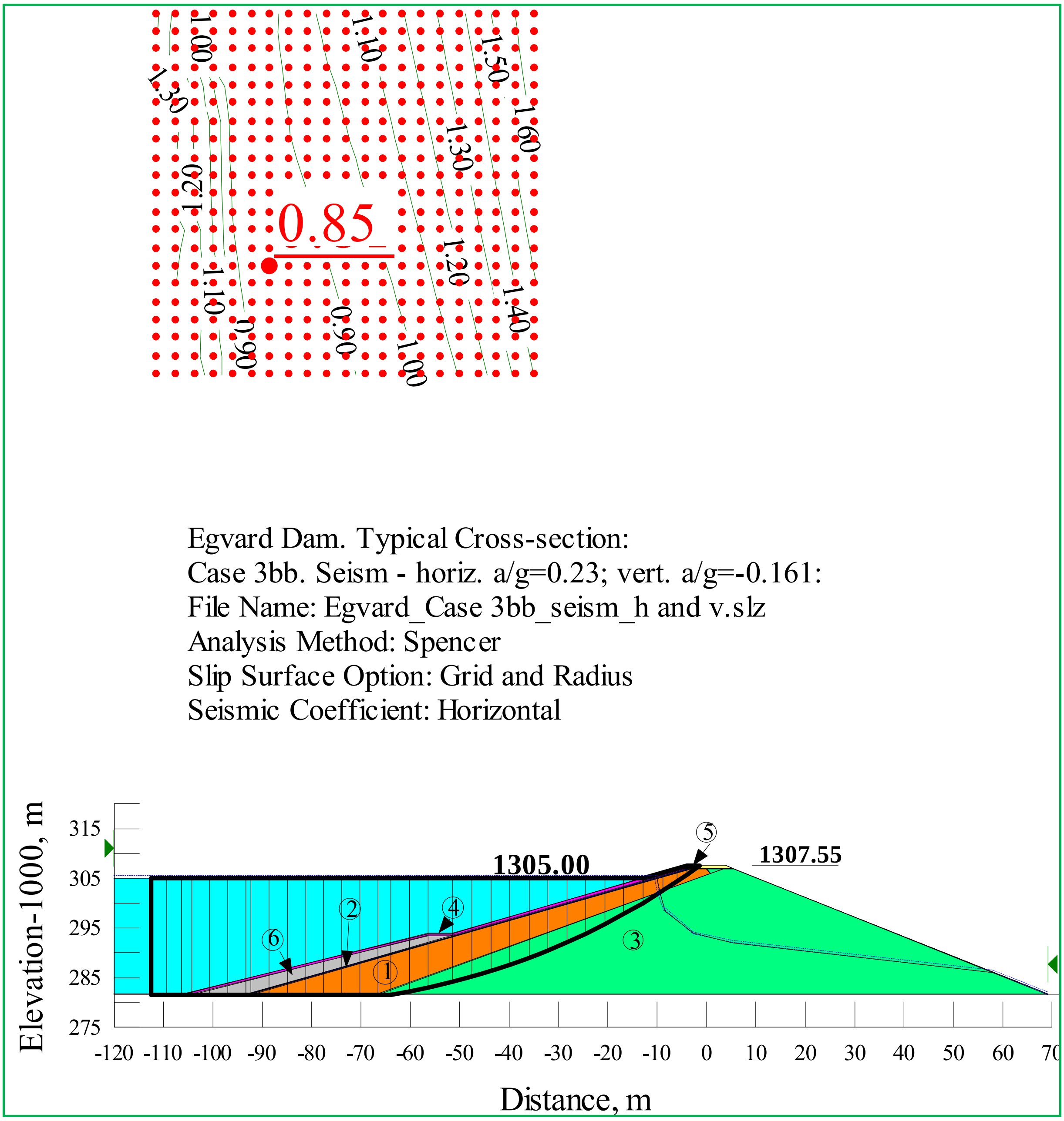
Case			Case-1	Case-2
General Condition			Normal Condition with maximum scale earthquake	Sudden water lowering with half sale earthquake
Water Level			FWL EL.1305m	FWL EL.1305m → LWL EL.1290m
PGA Coefficient k			0.120	0.060
Required Safety Factor			1.25	1.25
Calculated Safety Factor*1	Armenian Method	Upstream Slope	0.85	1.13
		Downstream Slope*2	0.70	-
	Japanese Method	Upstream Slope	1.44	1.26
		Downstream Slope*2	1.43	-

*1: Number with red letter: less than required one and blue letter: more than required one.

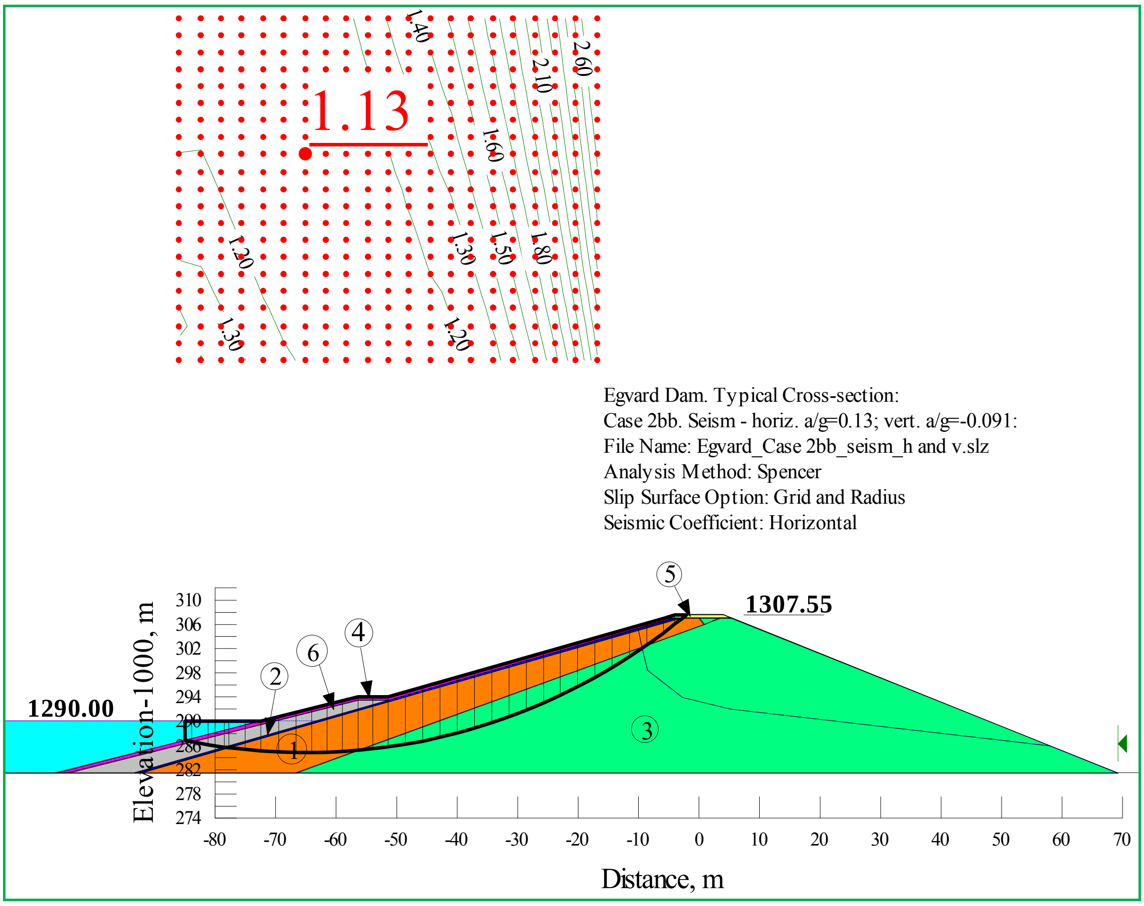
*2: Sine it is clear that calculated safety factor of case-2 is more than case-1, the calculation of case-2 is omitted.

J-5-1 Armenian Method

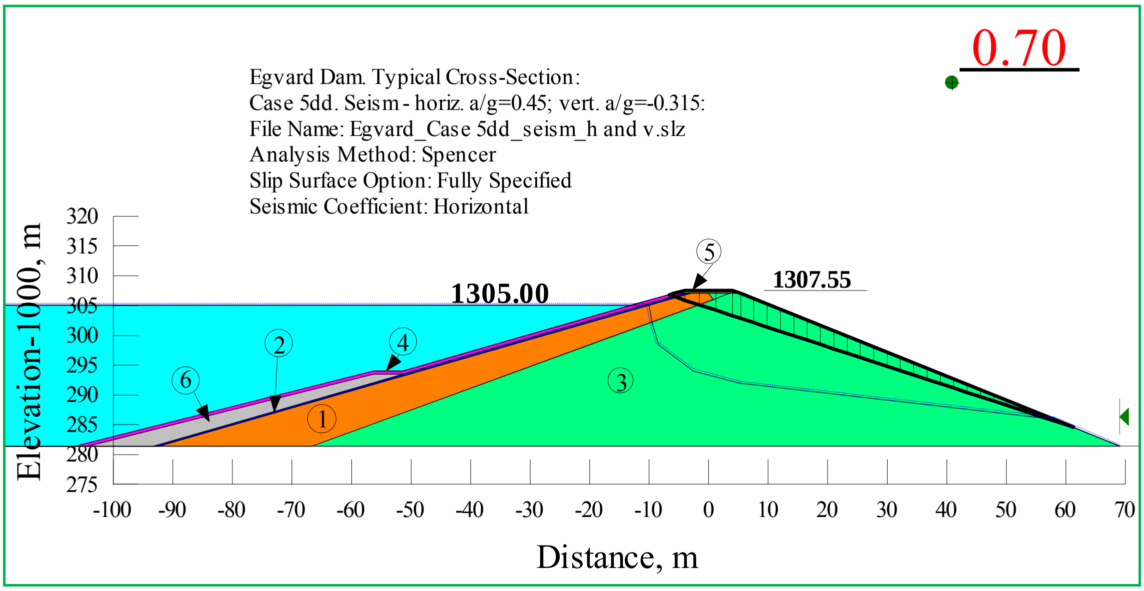
(1) Upstream slope (Case-1)



(2) Upstream slope (Case-2)

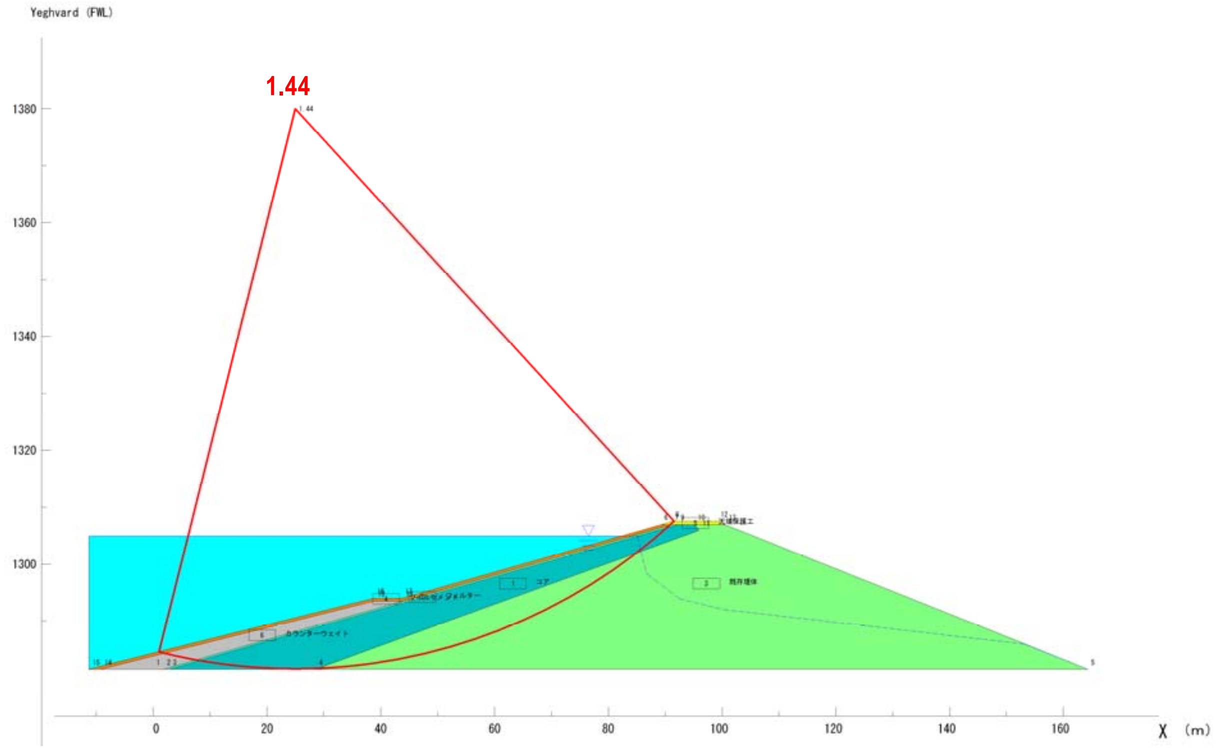


(3) Downstream slope (Case-1)

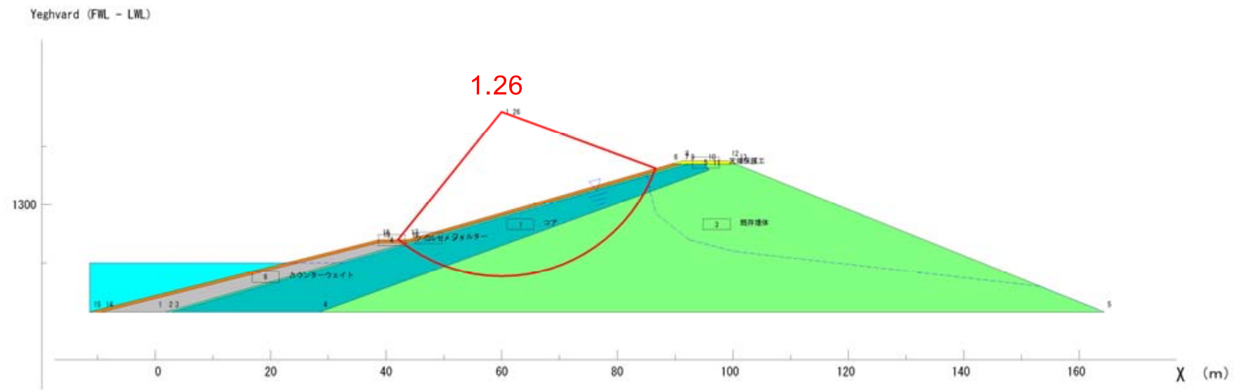


J-5-2　Japanese Method

(1) Upstream slope (Case-1)



(2) Upstream slope (Case-2)



(3) Downstream slope (Case-1)

Slope Angle					1: 2.5
PGA Coefficient			k		0.12
Density	Water		γ_w	kN/m^3	9.81
	Existing Dam Body	Wet	γ_t	kN/m^3	19.3
		Saturated	γ_{sat}	kN/m^3	19.97
		Submerged	γ_{sub}	kN/m^3	10.16
Internal Friction Angle			φ	degree	38
Safety Factor			Fs		1.43