REPORT

District of Summerland

Thirsk Dam Inspection
Spillway Piezometer Data Review

August 2016

ASSOCIATED ENGINEERING
QUALITY MANAGEMENT SIGN-OFF
Signature
Date AUG 18 2016

Table of Contents

1 Background

The Thirsk Arch Dam and Spillway was originally constructed by the District of Summerland in 1940/41. In 2006 the dam was raised and the spillway replaced to provide additional storage capacity. Today, the Thirsk Dam consists of three separate structures: a concrete spillway 14m high by 125m long, a 26m high concrete arch dam with low level outlet, and an earth-filled saddle dam.

The spillway is divided into 18 blocks; with each block designed to be individually stable. The highest blocks, #12 to #16 include an inspection gallery, along with a grout curtain and drains meant to reduce the hydrostatic uplift on the base of the dam. Two of the blocks, #12 & #14, each include four piezometers to help monitor the hydrostatic uplift on the underside of the base.

The piezometer data was recorded by District of Summerland staff between 2008 and 2014. The data was forwarded to Golder Associates Ltd.'s office in Kelowna for review. In their Technical Memorandum dated December 15, 2014 (Appendix D), Golder noted anomalies in the data, and recommended that Associated Engineering review the readings and determine the implications of the new hydrostatic uplift data on spillway stability.

The District of Summerland retained Associated Engineering in March, 2016 to inspect the spillway and review the piezometer data. The inspection was carried out during the 2016 freshet to ensure the lake level was near maximum during the inspection.

2 Inspection of the Spillway

Associated Engineering conducted a visual inspection of the spillway gallery on April 11, 2016, with the assistance of District staff and Dean Environmental out of Penticton, B.C. The inspection gallery was classified as a confined space according to WorkSafeBC regulations, and Dean Environmental were retained to provide safe access. The resulting safety plan included a site risk analysis, confined space procedures, forced ventilation, air quality monitoring and safety procedures.

The inspection date was planned carefully to coincide with the lake level being at or near spill elevation. Lake water levels were monitored by District staff in the weeks prior. The lake level during the inspection was approximately 100 to 200 mm below the spillway crest (See photos in Appendix A and inspection notes in Appendix B).

Observations from a visual inspection of the downstream face of the spillway and the spillway gallery were noted. The spillway was found to be generally in good condition with no specific concerns identified. The gallery drains all appeared to be operational with a very small flow rates measured at 2.4 litres/minute.

A few hairline cracks with efflorescence and minor weeping were observed in the upstream face of the gallery, however none showed any measureable leakage. None of the cracks observed impact the stability of the dam. The contraction joints were inspected between blocks and we measured the joint width as approximately 1.0 mm. This indicated that the joints are functioning as intended to relieve thermal and shrinkage stresses. The was no leakage observed in the contraction joints within the gallery, indicating that the water-stops between the blocks were functioning as designed.

The drains all appeared to be functioning, although it was noted that all had small amounts of sediment on the sides of the drain holes. We recommend cleaning them as part of a 5 year maintenance cycle.

3 Stability Calculations

3.1 SPILLWAY HYDROSTATIC UPLIFT

Blocks #12 to #18 (inclusive) were designed with upstream drains and a grout curtain to reduce the hydrostatic uplift on the base of the spillway. During construction, vibrating piezometers were installed below Blocks #12 and #14 to monitor the hydrostatic uplift. The maximum hydrostatic uplift forces measured by the piezometers, below Blocks #12 and #14, are plotted on Figures 3-1 & 3-2. The source of this data is the Golder Technical Memorandum found in Appendix D. The figures demonstrate both the design hydrostatic uplift and the maximum uplift forces for the condition with the lake level at the spillway crest (Elevation 1028.70). The uplift condition was also added to the figures, assuming that there are no drains, and that the uplift pressure is linear from the upstream face to the downstream face.

Based on this analysis, it was determined that:

- The hydrostatic uplift under Block #12 is significantly greater than the design uplift. In fact, it appears that the drains and grout curtain are ineffective under Block #12 at reducing the hydrostatic uplift.
- The hydrostatic uplift under Block #14, although slightly different in shape is about the same magnitude as the design uplift.

Increased hydrostatic uplift under the base of the blocks reduces the block stability. Therefore, we re-calculated the stability of Block #12 based on the increased hydrostatic uplift.

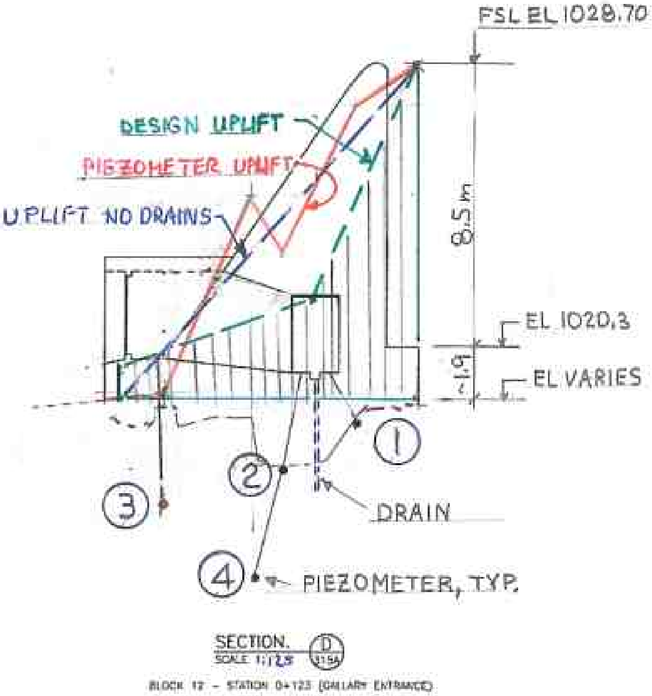


Figure 3-1 – Block 12 – Hydrostatic Uplift

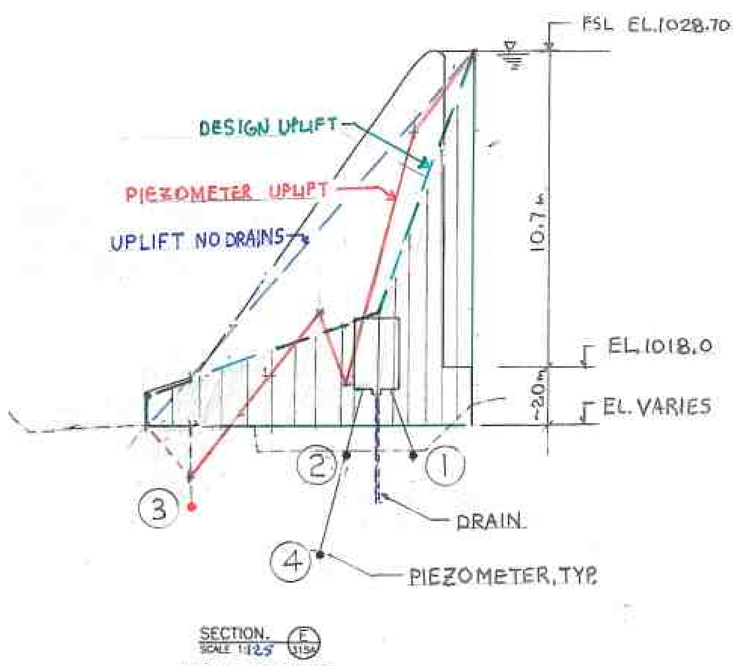


Figure 3-2 – Block 14 – Hydrostatic Uplift

3.2 SPILLWAY STABILITY ASSESSMENT

The stability of Block 12 was evaluated assuming the drains as ineffective (or plugged) in accordance with the latest Canadian Dam Association (CDA) Dam Safety Guidelines (2007) for the hydrostatic ice, flood and earthquake loading cases. We used the applied loads from the original design, but calculated the performance factors based on the plugged drain condition. The plugged drain condition is a recent addition to the 2007 CDA Guidelines.

The performance factors are a measure of the safety of the dam. They vary depending on the load case, but are indicators of the safety of the structure The following table summarizes the critical load cases and performance factors for Block #12.

Table 3-1 Calculated and Acceptable Performance factors – Block #12 - Plugged Drains(PD)

Type of Analysis	Load Combinations				
	Hydrostatic	Ice	Probable Maximum Flood (PMF)	Earthquake	Post Earthquake
Residual Sliding Factor (Note 4)	2.8 > 1.3	2.2 > 1.3	1.9 > 1.1	Note 3	2.7 > 1.1
Position of Resultant Force	75% of base in compression	75% of base in compression	Within the base	Note 3	Within the base

Notes:

1. The dam was originally conservatively designed to be stable, under the usual hydrostatic condition, assuming the rock anchors are ineffective.
2. The dam was originally designed to be stable for ice, flood and earthquake conditions assuming that the rock anchors are effective.
3. Earthquake stability is evaluated for the post-earthquake condition, assuming the drains are ineffective.
4. Friction only, ignoring cohesion.

Although not indicated in the table above, our analysis indicates that Block #12 has inadequate stability for usual hydrostatic conditions, if the anchors are ineffective (as conservatively assumed in the original design). However, Block #12 performance factors are acceptable, with plugged drains, if the rock anchors are fully effective for all load conditions including usual hydrostatic.

The highest block, Block #14, has drains that are working effectively and the stability of this block meets the original design assumptions (i.e. it is stable for the usual hydrostatic condition with no anchors and the other load conditions with anchors).

Because we do not have piezometer's results for the hydrostatic uplift under Blocks # 13, #15, & #16, we also checked the stability of all of these blocks, assuming the drains are plugged. We calculated that all of the blocks meet the current CDA performance factors for the plugged drain condition, and are therefore stable if the anchors are effective for all conditions.

4 Conclusions

We conclude that the hydrostatic uplift indicated by the piezometers in Block 12 exceeds the original design uplift assumptions. The sliding and position of the resultant force was re-calculated, and we conclude that Block 12 is well within the acceptable performance factors. Our analysis relies on the rock anchors for stability under all load combinations, and that all other blocks within the spillway gallery sections are stable based on the current CDA recommended performance factors.

Based on our findings at this time, the Thirsk Spillway Dam is safe under all load combinations assuming the rock anchors are performing as designed.

5 Recommendation

We recommend the following:

1. The District conduct anchor lift-off tests to confirm that the rock anchors are performing as designed. These tests would be supervised and evaluated by a Dam Safety Engineer.
2. The District continue to monitor the piezometers and report any anomalies to a Dam Safety Engineer.
3. The District measure and record the flow of water from the drains annually; particularly when the lake level is at or near full service level. Report any significant changes in drainage flow to a Dam Safety Engineer.
4. The District clean out the drains in the inspection gallery at 5 year intervals.

REPORT

Certification Page

This report presents our findings regarding the District of Summerland Thirsk Dam Inspection Spillway Piezometer Data Review.

Respectfully submitted,

Prepared by:	Reviewed by:
PROFESSIONAL PROVINCE OF D. B. HARRISON # 10869 BRITISH COLUMBIA ENGINEER	PROFESSIONAL PROVINCE OF BRITISH COLUMBIA ENGINEER
AUG 18/16	Aug 18 2016
Dale B. Harrison, P.Eng.	Roderick T. MacLean, P.Eng.
Senior Structural Engineer	Project Manager & Dam Safety Engineer

DBH/RM/lw

Appendix A – Spillway Photos

Photo 1
Spillway – Viewed from the East

Photo 2
Spillway Gallery - Entrance

Photo 3
Spillway Gallery - Air Intake

Photo 4
Piezometer Monitoring Station – Spillway Left Abutment

Photo 5
Spillway Drain in Gallery

Photo 6
Block 12 – Weep on Upstream Face

Photo 7
Block 12-13 Contraction Joint

Appendix B – Site Inspection Notes

INSPECTION/SITE MEETING REPORT

Associated Engineering GLOBAL PERSPECTIVE LOCAL FOCUS.

OWNER:	District of Summerland	PROJECT NO.:	20162249.001	REPORT NO.:	
PROJECT:	Thirsk Dam Piezometer Inspection	FILE NO.:	20162249.001 A.01	SHEET:	1 OF 2
COMPONENT:	Spillway	DATE:	June 7, 2016		
LOCATION:	Summerland, BC	ISSUE COPIES TO:			
ASSOCIATED ENGINEERING REP.:	Dale Harrison, P. Eng.	PROJ. MGR.:	Rod MacLean, P.Eng.		
OTHERS PRESENT:		OWNER CONTACT:	District of Summerland – Devon Van der Meulen		
		CONTRACTOR:			
		OTHER:			

PROJECT REPORT Progress/Status/Conformance To Design/Workmanship/Comments/Recommendations

Item	Description	Depth Measurement from Base (m)
1	1.6 m from end – Leak – DS of trench	7.6
2	Negligible flow	7.6
3	Minor flow	7.6
4	Minor flow – Some sediment	5.8-6.8
5	Minor flow – Some sediment at 6.8 m	7.8+
6	Minor sediment	7.6+
7		7.8+
8	Water draining in – 3 inches low. Water drains through crack and disappears	7.8+
9	Working	7.8+
Drain		
10	6.5 Silt encountered	7.8+
11	Note yellow film in Photo	7.8+
Piezometers	1.1 m from 11 (Block 14)	
12	Clear water	7.8+
Block Joint	Blocks 14-15 – Grout flaking – Minor spalling from joint repair	
13	Clear water	7.8+
14	Minor resistance at 6.5 m	7.8+
15	Clear water	7.8+

Item	Description	Depth Measurement from Base (m)
Block Joint	Blocks 15-16 (slope rise starts)	
16	Appears to be plugged (sandy) – no flow	6.7
17	Not reported	
18		7.8+
19	Sand at 7.2 m – red slime in between – minor flow	7.2
20	Red slime	7.8 m
Joint 16-17	Good shape – Minor crack beside it (300 mm). Exposed rebar	
Joint 15-16	Effervescence on ceiling – Damp – Appears OK	
Block 15	Upstream Face – Mini crack - Staining	
Joint 14-15	OK – Effervescence – Minor crack near Piezometer – Minor crack in ceiling. Stain color (reddish)	
Joint 13-14	OK – Minor crack – B13 (every 10 ft)	
Block Joint 13	Good – 1.4m N, minor cracking, effervescence, staining	
Joint 12-13	Crack gauge used – 1.5-2mm crack – weeping. On curve up – crack End – Crack + condensation	
Drain	Drain Flow = 2.4 l/min	

Inspection completed at 2 pm.
Spillway 150 mm from spilling. Splash noted.

Appendix C - Calculations

CONCRETE GRAVITY DAM

Project Summerland- Thirsk Spillway - Block 12 Case: Existing Spillway with Plugged Drains

ASSUMES - Height of Block = 8.9 m + 1.5 m base = 10.4 m above heel rotation point, based on DWG 303-R2 & 304-R2
Note : Check Usual, Ice & PMF, Quake should not be any different!

Ref.: Bureau of Reclamation, "Design of Small Dams,1986
US Army Corps of Engineers,

CDA, "Dam Safety Guidelines, 2007

Rev 2: revised height to work with foundation slope
Rev. 3: revised method of calc slope effectiveness
New - Rev1- Added parapet (NEEDS CHECKING)
Rev 4: July 21-16 - Added iteration for hydrostatic uplift for ICE & PMF

INPUT GEOMETRY

Reservoir water depth	h_water_re	9	m
Normal tailwater depth	n_tail	1	
Flood water depth	h_flood_ref	10.9	m
Flood tailwater depth	h_tail	2	
Height of dam	h_ref	8.9	m
Width at top of dam	w_top	0.7	m
Silt height from u/s base	h_silt	2	m
Foundation slope	f_slope	0	fraction
depth of key	h_key	1	m
width of key	w_key	2	m
Distance x to key	x_key	6	m
Slope of back face	s_down	0.70	H/V
Slope of upstream face	s_up	0.0	H/V
Distance to drain from heel	x_drain	3.0	m
Heel projection	w_heel	1.0	m
Base height @ toe	h_toe	1.5	m
Toe width	w_toe	1.55	
Parapet	h_parapet	0.0	

INPUT LOADING DATA

Hor. gnd. accel./gravity	pga	0.22	
Vert. gnd. accel./gravity	v	0.11	
Horizontal ice force	ice	146	kn/m

INPUT MATERIAL PROPERTIES

Density of Concrete	g_con	22.6	kN/m^3
Density of rock	g_rock	26	kN/m^3
Density of Water	g_wat	9.81	kn/m^3
equiv. fluid pressure	silt	13.3	kn/m^3
Friction rock/conc interface	fr_cr	1.00	
Friction rock/rock interface	fr_rr	1	
Residual cohesion rock/rock	c_rr	500	
Peak cohesion concrete/rock	c_cr	100	kPa
Residual cohesion conc/rock	coh_r	0	kPa
Concrete comp. strength	F'c	20	MPa
Rock bearing capacity		1000	kPa
Rock internal angle	phi	38	degree
Rankine Passive coefficient, no coh	K_p	4.2	
shear key capacity/m depth	key	630	kn/m^2
Dowels	D	0	kn/m
Anchor working load	P	340	kn/m
Anchor dist. To upstream heel	anch_dist	0.5	
Anchor slope	s_ancho	0	degree
Hydrodyanmic pressure Coeff	C_dyn	0.74	
Drain Efficiency as decimal	E	0	

Note: removed otm on key due to assumed failure wedge, moment on u/s base is local effect only

CALCULATED GEOMETRY

Segment		A	B	C	D	base	Key	Gallery	Parapet
width	w	0.7	6.2	9.5	0.0	9.5	2.0	1.5	0.7
height	h	8.9	8.9	0.0	8.9	1.5	1.0	2.4	0
area	A	6.2	27.7	0.0	0.0	14.2	2.0	-3.6	0.0

Width at top of base	w_tbase	6.93	m
Height of water above heel	h_water	10.5	m
Width at underside of base of dam	w_bott	9.5	m
Foundation slope height	h_slope	0.00	m
Overall height @ upstream face	h_dam	10.4	m
Concrete volume	V_conc	46.6	cm/m
Height of water above heel	h_flood	12.4	m
Base height @heel	h_heel	1.5	m

Gallery Height	h_gallery	2.4	m
Gallery Width	w_gallery	1.5	m
Gallery distance to heel	x_gallery	2.5	m
Gallery floor	y_gallery	0.5	m

Note: does silt act on front of base ????

Note:sloping base friction is non-conservative-fix, includes all vertical forces on resistance side
Note:check Jan 28/05 against Shane's spreadsheet for non-sloping base condition no vertical on quake

PERFORMANCE FACTORS

		Construction			Usual- with Anchors			Unusual (PD) - no anchor			Ice - Unusal -PD			PMF Flood			Earthquake			Post-Earthquake		
Peak Sliding					**4.56**	>	**3**	**3.52**	>	**3**	**3.60**	>	**2**	**3.22**	>	**1.3**	**2.60**	>	**1.3**	**3.99**	>	**2**
Residual Sliding					**2.83**	>	**1.5**	**2.21**	>	**1.5**	**2.2**	>	**1.3**	**1.94**	>	**1.1**	**1.58**	>	**1.0**	**2.65**	>	**1.1**
Eccentricty		1.65	<	2.37	**-0.10**	<	**1.58**	**4.60**	<	**2.37**	**1.51**	<	**2.37**	**1.06**	<	**4.74**	**1.67**	<	**4.74**	**0.00**		
Bearing	**U/S**	**301**	<	1000	103	<	1000	0	<	1000	4	<	1000	28	<	1000	-5	<	1000	87	<	1000
	D/S	-7			91	<	1000	1011	<	1000	**189**	<	1000	143	<	1000	**175**	<	1300	**86**	<	1000

USUAL LOADING (NO ICE) - (DL + HYDROSTATIC+ SILT+ UPLIFT)-

Dead Load	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Segment A	141	8.1			1145
Segment B	627	5.7			3573
Segment C	0	6.3			0
Segment D	0	8.5			0
Gallery	-81	6.2			-507
Key	26	2.5			63
Base	321	4.74			1523
Parapet	0	9.13			0
Subtotal	1033	5.61			5798
Key passive			630		0
Resistance without anchors	**1033**	5.61	**630**		**5798**
Anchor Load	340	8.98	0		3053
Resistance with anchors	**1373**	6.45	**630**		**8851**
Hydrostatic Lateral					
Rectangular surcharge			-10	5	-53
Triangular			-531	3.5	-1839
Front slope	0	8.48			0
Heel of base	78	8.98			705
Total	**78**		**-541**		**-1187**
Hydrostatic Uplift					
Rectangular	-93	4.74	0	0.0	-441
Upstream Triangle to Drain	-44	8.48	0	0.0	-375
Upstream Rectangle to Drain	-191	7.98	0	0.0	-1525
D/S Triangle Drain to toe	-206	4.32	0	0.0	-892
Total	**-535**	6.05	**0**		**-3233**
Silt	2	9.48	**-7**	0.7	12 kN-m
Driving Forces	**-455** kN		**-548** kN		**-4408**
Total, without anchors	**578**	2.4	**-548**		**1390**
Total, with anchors	**918**		**82**		**4443**

Safety Factors		No anchors	Anchors		Target	
Peak Sliding		**3.52**	**4.56**	>	***3***	
Residual Sliding		**2.21**	**2.83**	>	***1.5***	
Overturning		1.32	2.01			
Eccentrity		**2.34**	**-0.10**	<	**1.58**	
Stresses	U/S	**-29**	**103**	<	**0**	
	D/S	**160**	**91**	<	**1000**	
Compression area		0.76	1.00			kPa
Stresses	D/S(0 tension)	**160**		<	**1000**	kPa
						kPa

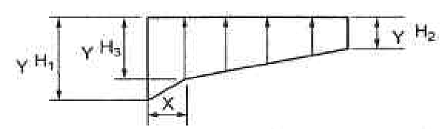
	No anchors		Anchors	
	No dowels	dowels	No dowels	Dowels
Residual Sliding Resistance	**1208**	1208	1548	1548
Cohesion	721	721	948	948
Peak Sliding Resistance	1929	1929	2496	2496

Note: base slope included in resistance

	Driving		
Resolve Orthogonal to sloping ba	Perp	Parallel	
No Anchors	578	548	548
Anchors	918	548	

resolve frame of r	**578**	1.06
tan(phi+slope an	**578**	1.06

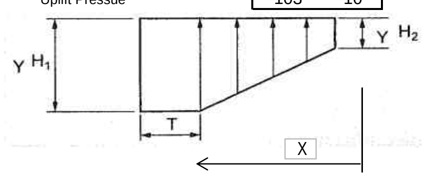
	Upstream	Drain	Toe
Uplift Pressue	-103	-74	-10



Hydrostatic Uplift (drains blocked)

	Uplift (kn)	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Rectangular	-10	-93	4.74	0	0	-441
Rectangular to Crack Depth	-93	-746	5.48	0	0.0	-4086
D/S Triangle Drain to toe		-69	0.99	0	0.0	-68
Total	**-103**	**-908**	**5.06**	**0**		**-4595**
Silt		2	9.48	**-7**	0.7	12 kN-m
Driving Forces		**-827** kN		**-548** kN		**-5770** kN-m
Total, without anchors		**206**		**82**		**28**
Total, with anchors		**546**		**82**		**3081**

	Upstream	Toe
Uplift Pressue	-103	-10



Safety Factors		No Anchors- Cracked Base			
		Actual		Target	
Peak Sliding		**3.52**	>	***3***	
Residual Sliding		**2.21**	>	***1.5***	
Overturning		1.32			
Eccentrity		**4.60**	<	**2.37**	
Stresses	U/S	**0**	<	**0**	
	D/S	**1011**	<	**1000**	kPa
Ratio Compression area to B		0.04			

Trial Crack Depth, T_trial **8.00** m ⟷ Crack length, T **9.073** m

ICE LOADING - (DL + HYDROSTATIC+ SILT+ ICE+UPLIFT)-

Dead Load		V (kN)	x (m)	H (kn)	y (m)	M (kn-m)	
Segment A		141	8.1			1145	
Segment B		627	5.7			3573	
Segment C		0	6.3			0	
Segment D		0	8.5			0	
Gallery		-81	6.2			-507	
Key		26	2.5			63	
Base		321	4.74			1523	
Parapet		0	9.13			0	
Subtotal		**1033**	5.61			5798	
Key passive(residual)				630		0	
Anchor Load		340	8.98	0		3053	
Resistance with anchors		**1373**	6.45	**630**		**8851**	
Hydrostatic Lateral							
Rectangular surcharge				-10	5	-53	
Triangular				-531	3.5	-1839	
Front slope	0	0	8.48			0	
Heel		78	8.98			705	
Total		**78**		**-541**		**-1187**	
Hydrostatic Uplift	Uplift (kn)						
Rectangular	-93	-93	4.74	0	0	-441	
Upstream Triangle to Drain		-44	8.48	0	0.0	-375	
Upstream Rectangle to Drain		-191	7.98	0	0.0	-1525	
D/S Triangle Drain to toe		-206	4.32	0	0.0	-892	
Total	**-93**	**-535**	**6.05**	**0**		**-3233**	
Silt		2	9.48	**-7**	0.7	12	kN-m
Ice				**-146**	10.1	**-1475**	
Driving Forces		**-455** kN		**-694** kN		**-5883**	kN-m
Total, with anchors		**918**		**-64**		**2968**	

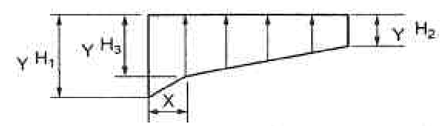
Safety Factors

	No dowels	Dowels		Target	
Peak Sliding	**3.60**	**0.00**	>	***3***	
Residual Sliding	**2.23**	**0.00**	>	***1.5***	
Overturning	1.50				
Eccentrity	**1.51**		<	**1.58**	
Stresses U/S	**4**		<	**0**	
D/S	**189**		<	**1000**	
Compression area	1.00				kPa

Crack length, T 0.000 **0.0**

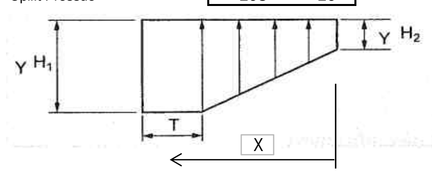
	Un-cracked Anchors	Cracked Anchors
Residual Sliding Resistance	1548	1548
Cohesion	948	948
Peak Sliding Resistance	2496	2496

	Upstream	Drain	Toe
Uplift Pressue	-103	-74	-10



Hydrostatic Uplift (drains blocked)	Uplift (kn)	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)	
Rectangular	-10	-93	4.74	0	0	-441	
Rectangular to Crack Depth	-93	0	9.48	0	0.0	0	
D/S Triangle Drain to toe		-442	6.32	0	0.0	-2792	
Total	**-103**	-535	**6.05**	**0**		**-3233**	
Silt		2	9.48	**-7**	0.7	12	kN-m
Ice				**-146**	10.1	**-1475**	
Driving Forces		**-455** kN		**-694** kN		**-5883**	kN-m
Total, with anchors		**918**		**-64**		**2968**	

	Upstream	Toe
Uplift Pressue	-103	-10



Safety Factors

	Actual		Target	
Peak Sliding	**3.60**	>	***3***	
Residual Sliding	**2.23**	>	***1.5***	
Overturning	1.50			
Eccentrity	**1.51**	<	**1.58**	
Stresses U/S	**4**	<	**1000**	
D/S	**189**	<	**1000**	kPa
Ratio Compression area to Ba	**1.00**			

Trial Crack Depth, T_trial_ice **0.00** m ⟷ Crack length, T **0.000** m

PMF- FLOOD LOADING (DL + HYDROSTATIC + SILT + FLOOD UPLIFT)

Dead Load	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Segment A	141	8.1			1145
Segment B	627	5.7			3573
Segment C	0	6.3			0
Segment D	0	8.5			0
Gallery	-81	6.2			-507
Key	26	2.5			63
Base	321	4.74			1523
Parapet	0	9.13			0
Total	**1033**	5.61			**5798**
Anchors	**340**	8.98	0		**3053**
Key passive			630	0.00	**0**
Resistance with anchors	**1373**		**630**		**8851**
Hydrostatic Lateral					
Rectangular surcharge			-204	5.2	-1061
Triangular			-531	3.5	-1839
Front slope	0	8.48			0
Heel	107	8.98			960
Total	**107**	8.98	**-735**		**-1940**
Hydrostatic Uplift					
Rectangular	-186	4.74	0	0.00	-882
Upstream Triangle to Drain	-48	8.48	0	0.0	-411
Upstream Rectangle to Drain	-209	7.98	0	0.0	-1670
D/S Triangle Drain to toe	-226	4.32	0	0.0	-976
Total	**-670**	5.88	**0**		**-3938**
Silt	2	9.48	**-7**	0.7	12
Driving Forces	**-561** kN		**-742** kN		**-5866** kN-m
Total Forces	**812**		**-112**		**2985**

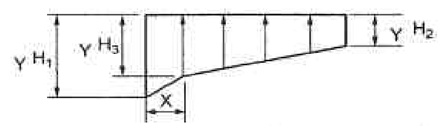
Safety Factors

	Actual		Target	
Peak Sliding	**3.22**	>	***2***	
Residual Sliding	**1.94**	>	***1.3***	
Overturning	1.51			
Eccentrity Overturning	**1.06**	<	**1.58**	
Stresses U/S	**28**	<	**0**	kPa
D/S	**143**	<	**1000**	kPa
Compression area	**1.00**			

	Anchors	Cracked- Anchors
Residual Sliding Resistance	1442	1442
Cohesion	948	948
Peak Sliding Resistance	2390	2390

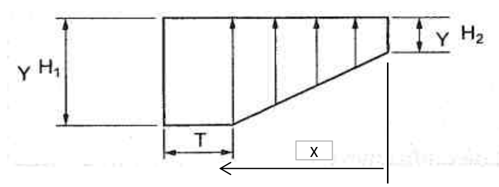
	Upstream	Drain	Toe
Uplift Pressue	-122	-89	-20

	Crest	Heel
Hydrostatic Pressure	20	122



Hydrostatic Uplift(drains blocked-cracked)	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Rectangular	-186	4.74	0	0.00	-882
Rectangular to Crack Depth	0	9.48	0	0.0	0
D/S Triangle, Crack to Toe	-484	6.32	0	0.0	-3056
Total	**-670**	5.88	**0**		**-3938**
Silt	2	9.48	**-7**	0.7	12
Driving Forces	**-561** kN		**-742** kN		**-5866** kN-m
Total Forces	**812**		**-112**		**2985**

	Upstream	Toe
Uplift Pressue	-122	-20



Safety Factors

	Actual		Target	
Peak Sliding	**3.22**	>	***2***	
Residual Sliding	**1.94**	>	***1.3***	
Overturning	1.51			
Eccentrity	**1.06**	<	**4.74**	
Stresses U/S	**28**	<	**0**	kPa
D/S	**143**	<	**1000**	kPa
Ratio Compression area to B	**1.00**			

Trial Crack Depth, T_tri_fld **0.0** m

Crack Depth, T_flood **0.00** m

NOTES					
	x is measured from toe of dam to centroid of mass	U	Uplift on base	U_{PQ} Uplift, post earthquake	U_F Uplift for flood condition
	positive sign = upstream force				
	force is in kN/m	Ignored lateral pressure differences across key assuming downstream of grout curtain and drains			
	moment is in kN-m/m	tailwater beneficial effect not included.			
	internal shear strength at lift joints=.17*sqrt(F'c)/2	for ice loading case set water at crest of dam			
	Cohesion concrete/rock applies to peak sliding only	USBR-Small Dams section 8.22 for earthquake analysis & CDSA - 1995 Dam Guidelines commentary.			
	cohesion taken on area of compression	Uplift pressure is correct without sine & cosine			
	residual cohesion=0, unless tested otherwise, max 100kPa	Used submerged weight of key, and ignored uplift on key			
	Propogate crack at base to depth of 0 tension	See US Governement dam guidelines for alternate method of anlyzing			
	earthquake assumes no dynamic amplification of dam, acts as rigid block	earthquake. Only review post-earthquake condition for stability, and			

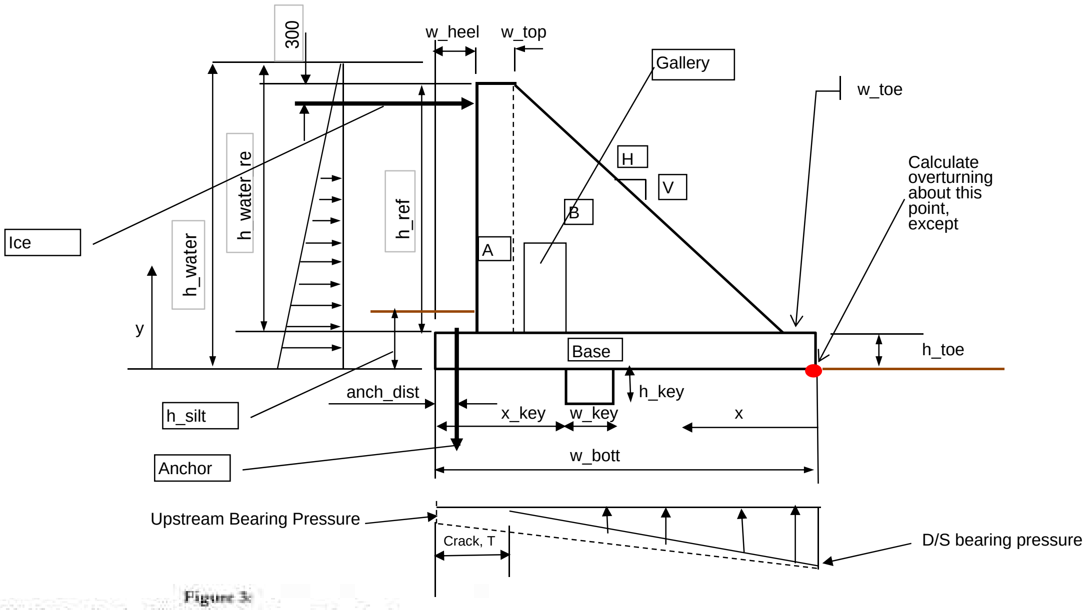


Figure 3:
Uplift Distribution With Effective Foundation Drainage

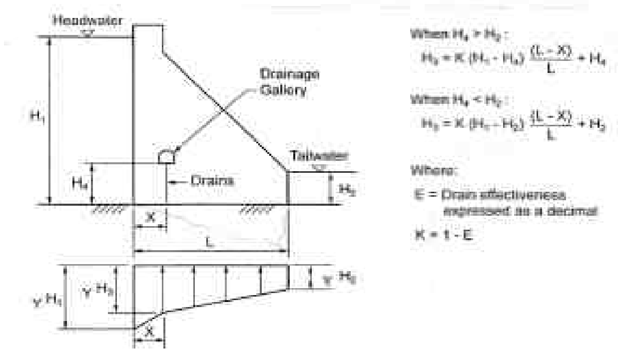
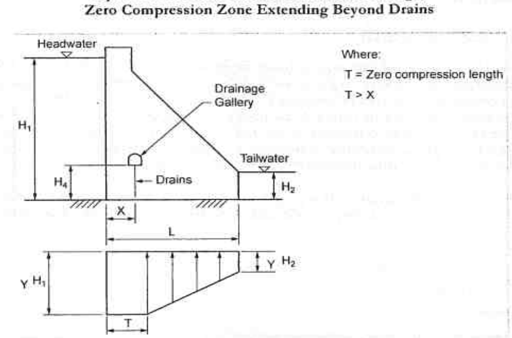


Figure 5:
Uplift Distribution Cracked Base with Drainage,
Zero Compression Zone Extending Beyond Drains



CONCRETE GRAVITY DAM

Project Summerland- Thirsk Spillway - Block 14 Case: Existing Spillway with Working Drains

ASSUMES - Height of Block = 11.2 m + 1.5 m base = 12.7 m above heel rotation point, based on DWG 303-R2 & 304-R2

Ref.: Bureau of Reclamation, "Design of Small Dams,1986
US Army Corps of Engineers,

CDA, "Dam Safety Guidelines, 2007

Rev 2: revised height to work with foundation slope
Rev. 3: revised method of calc slope effectiveness
New - Rev1- Added parapet (NEEDS CHECKING)
Rev 4: July 21-16 - Added iteration for hydrostatic uplift for ICE & PMF

INPUT GEOMETRY

Reservoir water depth	h_water_re	**11.3**	m
Normal tailwater depth	n_tail	1	
Flood water depth	h_flood_ref	12.1	m
Flood tailwater depth	h_tail	2	
Height of dam	h_ref	11.2	m
Width at top of dam	w_top	0.7	m
Silt height from u/s base	h_silt	2	m
Foundation slope	f_slope	0	fraction
depth of key	h_key	1	m
width of key	w_key	2	m
Distance x to key	x_key	6	m
Slope of back face	s_down	0.70	H/V
Slope of upstream face	s_up	0.0	H/V
Distance to drain from heel	x_drain	3.0	m
Heel projection	w_heel	1.0	m
Base height @ toe	h_toe	1.5	m
Toe width	w_toe	1.55	
Parapet	h_parapet	0.0	

INPUT LOADING DATA

Hor. gnd. accel./gravity	pga	0.22	
Vert. gnd. accel./gravity	v	0.11	
Horizontal ice force	ice	146	kn/m

INPUT MATERIAL PROPERTIES

Density of Concrete	g_con	22.6	kN/m^3
Density of rock	g_rock	26	kN/m^3
Density of Water	g_wat	9.81	kn/m^3
equiv. fluid pressure	silt	13.3	kn/m^3
Friction rock/conc interface	fr_cr	1.00	
Friction rock/rock interface	fr_rr	1	
Residual cohesion rock/rock	c_rr	500	
Peak cohesion concrete/rock	c_cr	100	kPa
Residual cohesion conc/rock	coh_r	0	kPa
Concrete comp. strength	F'c	20	MPa
Rock bearing capacity		1000	kPa
Rock internal angle	phi	38	degree
Rankine Passive coefficient, no coh	K_p	4.2	
shear key capacity/m depth	key	630	kn/m^2
Dowels	D	0	kn/m
Anchor working load	P	340	kn/m
Anchor dist. To upstream heel	anch_dist	0.5	
Anchor slope	s_ancho	0	degree
Hydrodyanmic pressure Coeff	C_dyn	0.74	
Drain Efficiency as decimal	E	**0.67**	

Note: removed otm on key due to assumed failure wedge, moment on u/s base is local effect only

CALCULATED GEOMETRY

Segment		A	B	C	D	base	Key	Gallery	Parapet
width	w	0.7	7.8	11.1	0.0	11.1	2.0	1.5	0.7
height	h	11.2	11.2	0.0	11.2	1.5	1.0	2.4	0
area	A	7.8	43.9	0.0	0.0	16.6	2.0	-3.6	0.0

Width at top of base	w_tbase	8.54	m
Height of water above heel	h_water	12.8	m
Width at underside of base of dam	w_bott	11.1	m
Foundation slope height	h_slope	0.00	m
Overall height @ upstream face	h_dam	12.7	m
Concrete volume	V_conc	66.8	cm/m
Height of water above heel	h_flood	13.6	m
Base height @heel	h_heel	1.5	m

Gallery Height	h_gallery	2.4	m
Gallery Width	w_gallery	1.5	m
Gallery distance to heel	x_gallery	2.5	m
Gallery floor	y_gallery	0.5	m

Note: does silt act on front of base ????

Note:sloping base friction is non-conservative-fix, includes all vertical forces on resistance side

Note:check Jan 28/05 against Shane's spreadsheet for non-sloping base condition no vertical on quake

PERFORMANCE FACTORS

		Construction			Usual- with Anchors			Unusual (PD) - no anchor			Ice - Unusal -PD			PMF Flood			Earthquake			Post-Earthquake		
Peak Sliding					**3.99**	>	**3**	**3.57**	>	**3**	**2.97**	>	**2**	**3.46**	>	**1.3**	**2.22**	>	**1.3**	**3.12**	>	**2**
Residual Sliding					**2.62**	>	**1.5**	**2.20**	>	**1.5**	**1.8**	>	**1.3**	**2.24**	>	**1.1**	**1.47**	>	**1.0**	**2.06**	>	**1.1**
Eccentricty		1.85	<	2.77	**0.25**	<	**1.85**	**1.81**	<	**2.77**	**2.32**	<	**2.77**	**1.06**	<	**5.55**	**2.23**	<	**5.55**	**0.76**		
Bearing	**U/S**	**334**	<	1000	116	<	1000	0	<	1000	28	<	1000	83	<	1000	-25	<	1000	55	<	1000
	D/S	0			153	<	1000	206	<	1000	**242**	<	1000	171	<	1000	**268**	<	1300	**132**	<	1000

USUAL LOADING (NO ICE) - (DL + HYDROSTATIC+ SILT+ UPLIFT)-

Dead Load	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)	
Segment A	177	9.7			1726	
Segment B	992	6.8			6724	
Segment C	0	7.4			0	
Segment D	0	10.1			0	
Gallery	-81	7.8			-638	
Key	26	4.1			105	
Base	376	5.55			2085	
Parapet	0	10.74			0	
Subtotal	1490	6.71			10001	
Key passive			630		0	
Resistance without anchors	**1490**	6.71	**630**		**10001**	
Anchor Load	340	10.59	0		3601	
Resistance with anchors	**1830**	7.43	**630**		**13602**	
Hydrostatic Lateral						
Rectangular surcharge			-12	6	-79	
Triangular			-791	4.2	-3349	
Front slope	0	10.09			0	
Heel of base	101	10.59			1070	
Total	**101**		**-804**		**-2358**	
Hydrostatic Uplift						
Rectangular	-109	5.55	0	0.0	-603	
Upstream Triangle to Drain	-132	10.09	0	0.0	-1330	
Upstream Rectangle to Drain	-84	9.59	0	0.0	-802	
D/S Triangle Drain to toe	-113	5.39	0	0.0	-608	
Total	**-437**	7.65	**0**		**-3343**	
Silt	2	11.09	**-7**	0.7	15	kN-m
Driving Forces	**-334** kN		**-811** kN		**-5687**	
Total, without anchors	**1155**	3.7	**-811**		**4315**	
Total, with anchors	**1495**		**-181**		**7915**	

Hydrostatic Uplift (drains blocked)

	Uplift (kn)	V	x	H	y	M	
Rectangular	-10	-109	5.55	0	0	-603	
Rectangular to Crack Depth	-116	0	11.09	0	0.0	0	
D/S Triangle Drain to toe		-642	7.39	0	0.0	-4746	
Total	**-126**	**-751**	**7.13**	**0**		**-5349**	
Silt		2	11.09	**-7**	0.7	15	kN-m
Driving Forces		**-648** kN		**-811** kN		**-7692**	kN-m
Total, without anchors		**842**		**-181**		**2309**	
Total, with anchors		**1182**		**-181**		**5909**	

Safety Factors

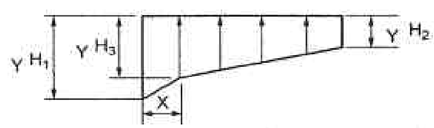
		No anchors	Anchors		Target	
Peak Sliding		**3.57**	**3.99**	>	***3***	
Residual Sliding		**2.20**	**2.62**	>	***1.5***	
Overturning		1.76	2.39			
Eccentrity		**1.81**	**0.25**	<	**1.85**	
Stresses	U/S	**2**	**116**	<	**0**	
	D/S	**206**	**153**	<	**1000**	
Compression area		1.00	1.00			kPa
Stresses	D/S(0 tension)	**206**		<	**1000**	kPa

	No anchors		Anchors		
	No dowels	dowels	No dowels	Dowels	kPa
Residual Sliding Resistance	**1785**	1785	2125	2125	
Cohesion	1109	1109	1109	1109	
Peak Sliding Resistance	2894	2894	3234	3234	

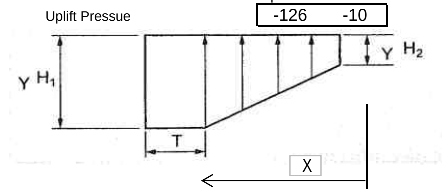
Note: base slope included in resistance

	Driving			
Resolve Orthogonal to sloping ba	Perp	Parallel		
No Anchors	1155	811	811	100
Anchors	1495	811		
resolve frame of r	**1155**	1.43		
tan(phi+slope an	**1155**	1.43		

	Upstream	Drain	Toe
Uplift Pressue	-126	-38	-10



	Upstream	Toe
Uplift Pressue	-126	-10



Safety Factors **No Anchors- Cracked Base**

		Actual		Target	
Peak Sliding		**3.57**	>	***3***	
Residual Sliding		**2.20**	>	***1.5***	
Overturning		1.76			
Eccentrity		**2.80**	<	**2.77**	
Stresses	U/S	**0**	<	**0**	
	D/S	**205**	<	**1000**	kPa
Ratio Compression area to B		0.74			

Trial Crack Depth, T_trial **0.00** m Crack length, T **2.861** m

ICE LOADING - (DL + HYDROSTATIC+ SILT+ ICE+UPLIFT)-

Dead Load		V (kN)	x (m)	H (kn)	y (m)	M (kn-m)	
Segment A		177	9.7			1726	
Segment B		992	6.8			6724	
Segment C		0	7.4			0	
Segment D		0	10.1			0	
Gallery		-81	7.8			-638	
Key		26	4.1			105	
Base		376	5.545			2085	
Parapet		0	10.74			0	
Subtotal		**1490**	6.71			10001	
Key passive(residual)				630		0	
Anchor Load		340	10.59	0		3601	
Resistance with anchors		**1830**	7.43	**630**		**13602**	
Hydrostatic Lateral							
Rectangular surcharge				-12	6	-79	
Triangular				-791	4.2	-3349	
Front slope	0	0	10.09			0	
Heel		101	10.59			1070	
Total		**101**		**-804**		**-2358**	
Hydrostatic Uplift	Uplift (kn)						
Rectangular	-109	-109	5.55	0	0	-603	
Upstream Triangle to Drain		-132	10.09	0	0.0	-1330	
Upstream Rectangle to Drain		-84	9.59	0	0.0	-802	
D/S Triangle Drain to toe		-113	5.39	0	0.0	-608	
Total	**-109**	**-437**	**7.65**	**0**		**-3343**	
Silt		2	11.09	**-7**	0.7	15	kN-m
Ice				**-146**	12.4	**-1810**	
Driving Forces		**-334** kN		**-957** kN		**-7497**	kN-m
Total, with anchors		**1495**		**-327**		**6105**	

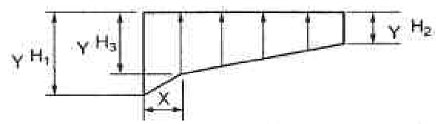
Safety Factors

	No dowels	Dowels		Target	
Peak Sliding	**3.38**	**0.00**	>	***3***	
Residual Sliding	**2.22**	**0.00**	>	***1.5***	
Overturning	1.81				
Eccentrity	**1.46**		<	**1.85**	
Stresses U/S	**28**		<	**0**	
D/S	**242**		<	**1000**	
Compression area	1.00				kPa

Crack length, T 0.000 **0.0**

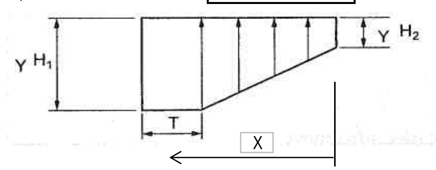
	Un-cracked Anchors	Cracked Anchors
Residual Sliding Resistance	2125	1735
Cohesion	1109	1109
Peak Sliding Resistance	3234	2844

	Upstream	Drain	Toe
Uplift Pressue	-126	-38	-10



Hydrostatic Uplift (drains blocked)	Uplift (kn)	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)	
Rectangular	-10	-109	5.55	0	0	-603	
Rectangular to Crack Depth	-116	-153	10.43	0	0.0	-1594	
D/S Triangle, Crack to Toe		-565	6.51	0	0.0	-3683	
Total	**-126**	**-827**	**7.11**	**0**		**-5880**	
Silt		2	11.09	**-7**	0.7	15	kN-m
Ice				**-146**	12.4	**-1810**	
Driving Forces		**-724** kN		**-957** kN		**-10034**	kN-m
Total, with anchors		**1105**		**-327**		**3568**	

	Upstream	Toe
Uplift Pressue	-126	-10



Safety Factors

	Actual		Target	
Peak Sliding	**2.97**	>	***3***	
Residual Sliding	**1.81**	>	***1.5***	
Overturning	1.36			
Eccentrity	**2.32**	<	**1.85**	
Stresses U/S	**0**	<	**1000**	
D/S	**228**	<	**1000**	kPa
Ratio Compression area to Ba	**0.87**			

Trial Crack Depth, T_trial_ice **1.320** m ⟷ Crack length, T **1.406** m

PMF- FLOOD LOADING (DL + HYDROSTATIC + SILT + FLOOD UPLIFT)

Dead Load	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Segment A	177	9.7			1726
Segment B	992	6.8			6724
Segment C	0	7.4			0
Segment D	0	10.1			0
Gallery	-81	7.8			-638
Key	26	4.1			105
Base	376	5.545			2085
Parapet	0	10.74			0
Total	**1490**	6.71			**10001**
Anchors	**340**	10.59	0		**3601**
Key passive			630	0.00	**0**
Resistance with anchors	**1830**		**630**		**13602**

Hydrostatic Lateral	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Rectangular surcharge			-112	6.4	-712
Triangular			-791	4.2	-3349
Front slope	0	10.09			0
Heel	119	10.59			1257
Total	**119**	10.59	**-903**		**-2804**

Hydrostatic Uplift	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Rectangular	-218	5.55	0	0.00	-1207
Upstream Triangle to Drain	-130	10.09	0	0.0	-1308
Upstream Rectangle to Drain	-82	9.59	0	0.0	-788
D/S Triangle Drain to toe	-111	5.39	0	0.0	-598
Total	**-540**	7.22	**0**		**-3900**
Silt	2	11.09	**-7**	0.7	15
Driving Forces	**-420** kN		**-910** kN		**-6689** kN-m
Total Forces	**1410**		**-280**		**6912**

Hydrostatic Uplift(drains blocked-cracked)	V (kN)	x (m)	H (kn)	y (m)	M (kn-m)
Rectangular	-218	5.55	0	0.00	-1207
Rectangular to Crack Depth	0	11.09	0	0.0	0
D/S Triangle Crack to toe	-631	7.39	0	0.0	-4665
Total	**-849**	6.92	**0**		**-5872**
Silt	2	11.09	**-7**	0.7	15
Driving Forces	**-728** kN		**-910** kN		**-8661** kN-m
Total Forces	**1101**		**-280**		**4941**

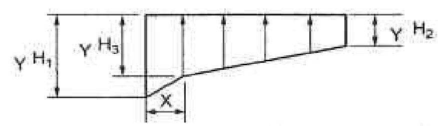
Safety Factors

	Actual		Target	
Peak Sliding	**3.46**	>	***2***	
Residual Sliding	**2.24**	>	***1.3***	
Overturning	2.03			
Eccentrity Overturning	**0.64**	<	**1.85**	
Stresses U/S	**83**	<	**0**	kPa
D/S	**171**	<	**1000**	kPa
Compression area	**1.00**			

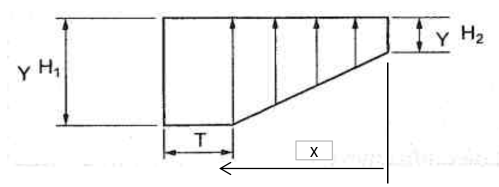
	Anchors	Cracked- Anchors
Residual Sliding Resistance	2040	1731
Cohesion	1109	1109
Peak Sliding Resistance	3149	2840

	Upstream	Drain	Toe
Uplift Pressue	-133	-47	-20

	Crest	Heel
Hydrostatic Pressure	9	133



	Upstream	Toe
Uplift Pressue	-133	-20



Safety Factors

	Actual		Target	
Peak Sliding	**3.12**	>	***2***	
Residual Sliding	**1.90**	>	***1.3***	
Overturning	1.57			
Eccentrity	**1.06**	<	**5.55**	
Stresses U/S	**42**	<	**0**	kPa
D/S	**172**	<	**1000**	kPa
Ratio Compression area to B	**1.00**			

Trial Crack Depth, T_tri_fld **0.00** m ⟷ Crack Depth, T_flood **0.00** m

NOTES

x is measured from toe of dam to centroid of mass
positive sign = upstream force
force is in kN/m
moment is in kN-m/m
internal shear strength at lift joints=.17*sqrt(F'c)/2
Cohesion concrete/rock applies to peak sliding only
cohesion taken on area of compression
residual cohesion=0, unless tested otherwise, max 100kPa
Propogate crack at base to depth of 0 tension
earthquake assumes no dynamic amplification of dam, acts as rigid block

U Uplift on base U_{PQ} Uplift, post earthquake U_F Uplift for flood condition

Ignored lateral pressure differences across key assuming downstream of grout curtain and drains
tailwater beneficial effect not included.
for ice loading case set water at crest of dam
USBR-Small Dams section 8.22 for earthquake analysis & CDSA - 1995 Dam Guidelines commentary.
Uplift pressure is correct without sine & cosine
Used submerged weight of key, and ignored uplift on key
See US Governement dam guidelines for alternate method of anlyzing
earthquake. Only review post-earthquake condition for stability, and

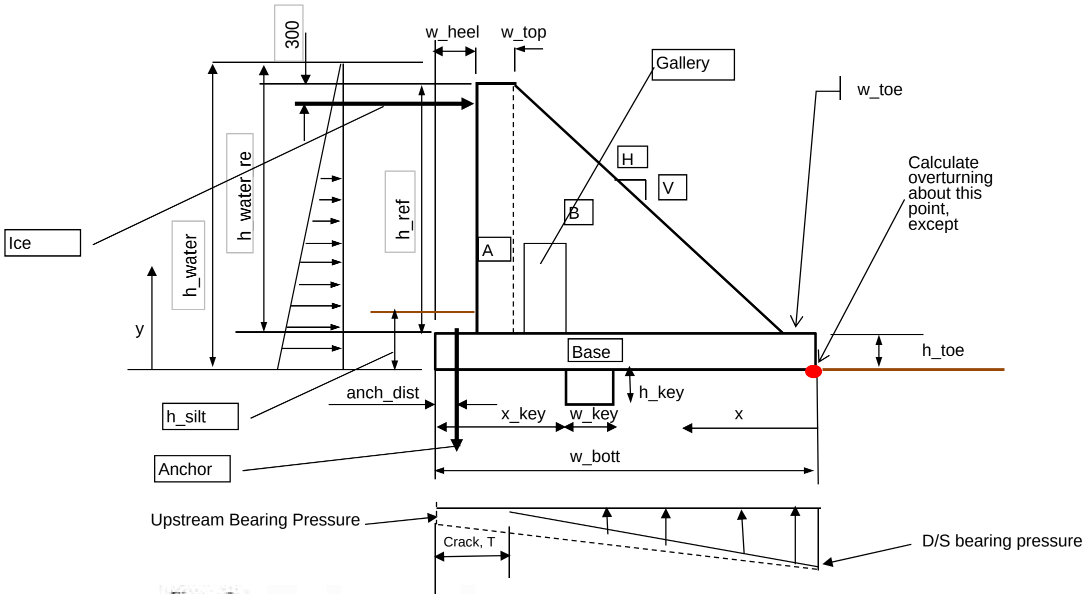


Figure 3:
Uplift Distribution With Effective Foundation Drainage

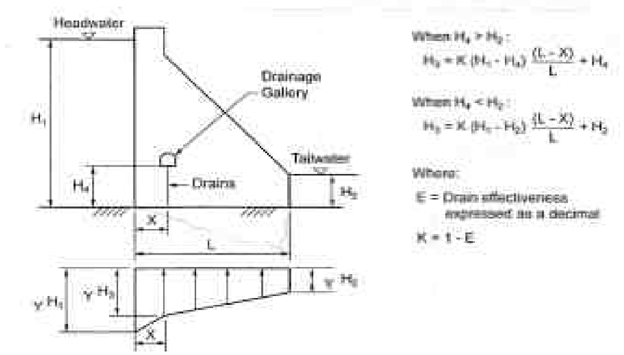
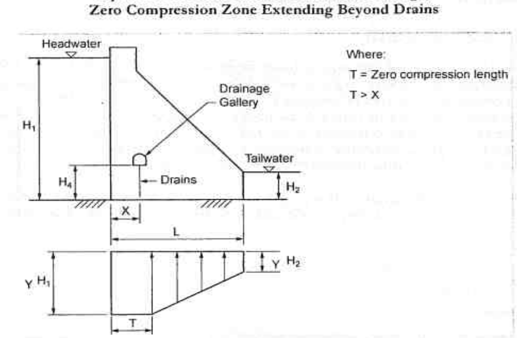


Figure 5:
Uplift Distribution Cracked Base with Drainage, Zero Compression Zone Extending Beyond Drains



Appendix D - Golder Report and Background Data

TECHNICAL MEMORANDUM

DATE December 15, 2014 **REFERENCE No.** 1418102-001-TM-Rev0

TO Shawn Hughes
District of Summerland

FROM Gerald Imada, P.Eng. **EMAIL** Gerald_Imada@golder.com

REVIEW OF VIBRATING WIRE PIEZOMETER DATA, THIRSK DAM SPILLWAY

As requested by the District of Summerland (DOS), Golder Associates Ltd. (Golder) has reviewed the vibrating wire piezometer data provided by DOS through an e-mail dated November 19, 2014. This technical memorandum provides a summary of our review.

Background Information

- Vibrating wire piezometer data for Block 12 and Block 14 was collected by DOS for the period between May, 2009 and July, 2014.
- Review of the spreadsheet data indicates that the geodetic water elevations are calculated correctly using the vibrating wire readings.
- Piezometer readings are typically taken twice per year at about the time the reservoir has reached its full storage level of 1028.70 m.
- Full storage level is typically achieved during the late May to June period, except in 2011 and 2014 when the maximum reservoir levels were recorded in July.
- Four vibrating wire piezometers are located at each of the designated Blocks.
- Block 12 is located at the north end of the gallery section at the gallery entrance at Station 0+123 and where the relief drains terminate.
- Block 14 is located near the lowest section of the spillway at Station 0+147.
- 75 mm diameter drain holes are located at 3.0 m spacing along the entire length of the gallery centre line.
- Piezometer No. 1 is located near the upstream toe of the spillway structure, mid-way between grout curtain and drain at ground surface.
- Piezometer No. 2 is located downstream of the drain holes at a distance of 1.0 m and at ground surface.
- Piezometer No. 3 is located near the downstream toe.

- Piezometer No. 4 is located about 2.0 m downstream of the drain holes and about 5.0 m below the rock/concrete interface.

Geotechnical Comments and Recommendations

- Phreatic surfaces were plotted for the following reservoir operating conditions:

  1) High reservoir level using the average of the highest annual readings (see attachment showing piezometer block sections).

  2) Low reservoir level using the average of the lowest annual readings (March 24, 2010 and March 18, 2014), (see attachment showing piezometer block sections).

- Based on the average of the highest annual readings between 2009 and 2014, the average near full reservoir storage level is at an elevation of about 1028.44 m. Under this condition, the phreatic surface across the spillway structure shows a consistent upward gradient between Piezometer No. 2 and 4. The upward gradient amounts to a head of about 1.84 m or at an equivalent pressure of 18.1 kPa at Block 12. At Block 14, the upward gradient increases to a head of about 2.63 m or at an equivalent pressure of 25.8 kPa.

- Under the lower reservoir storage level of about 1019.71 m, which is based on the average of only two readings taken on March 24, 2010 and March 18, 2018), the upward hydraulic gradient between Piezometer No. 2 and 4 is still present, but at a lower head of 0.75 m (7.4 kPa) at Block 12 and 0.93 m (9.1 kPa) at Block 14.

- Under the lower reservoir storage level condition, the phreatic surface is basically coincident with the gallery drain elevation.

- Under the high reservoir storage level condition, the phreatic surface at Piezometer No. 2 (Block 14), is also coincident with the gallery drain elevation.

- Under the high reservoir storage condition, the phreatic surface at Piezometer No. 2 (Block 12) is about 3.5 m higher than the gallery drain and about 5.0 m higher at Piezometer No. 4. This would suggest that significant seepage water would be flowing through the drain hole system beneath the gallery.

- Based on the difference in head between Piezometers No. 2 and 4 for both blocks, it is apparent that the 75 mm diameter drain holes are effective in lowering the phreatic surface, but that its effectiveness is limited to a distance of about 1.0 m. As the downstream distance increases away from the drain holes, the phreatic surface also increases, especially at Block 12.

- Considering that the drain holes terminate in the vicinity of Block 12, it is reasonable to expect a higher gradient as the drainage capacity beneath the spillway structure is reduced. It is also possible that the higher head at Block 12 is associated with a less effective grout curtain system because of fractured and less competent bedrock zone.

- It is recommended that this information be submitted to Associated Engineering for their structural review of the gallery with special consideration to the upward gradient at the time when the reservoir is operating at or near its full storage level.

We trust this provides you with the information that you require. Please do not hesitate to contact the undersigned at your earliest convenience if you require additional information.

Yours truly,

GOLDER ASSOCIATES LTD.

Roger Therrien, AScT
Associate, Senior Geotechnical Technologist

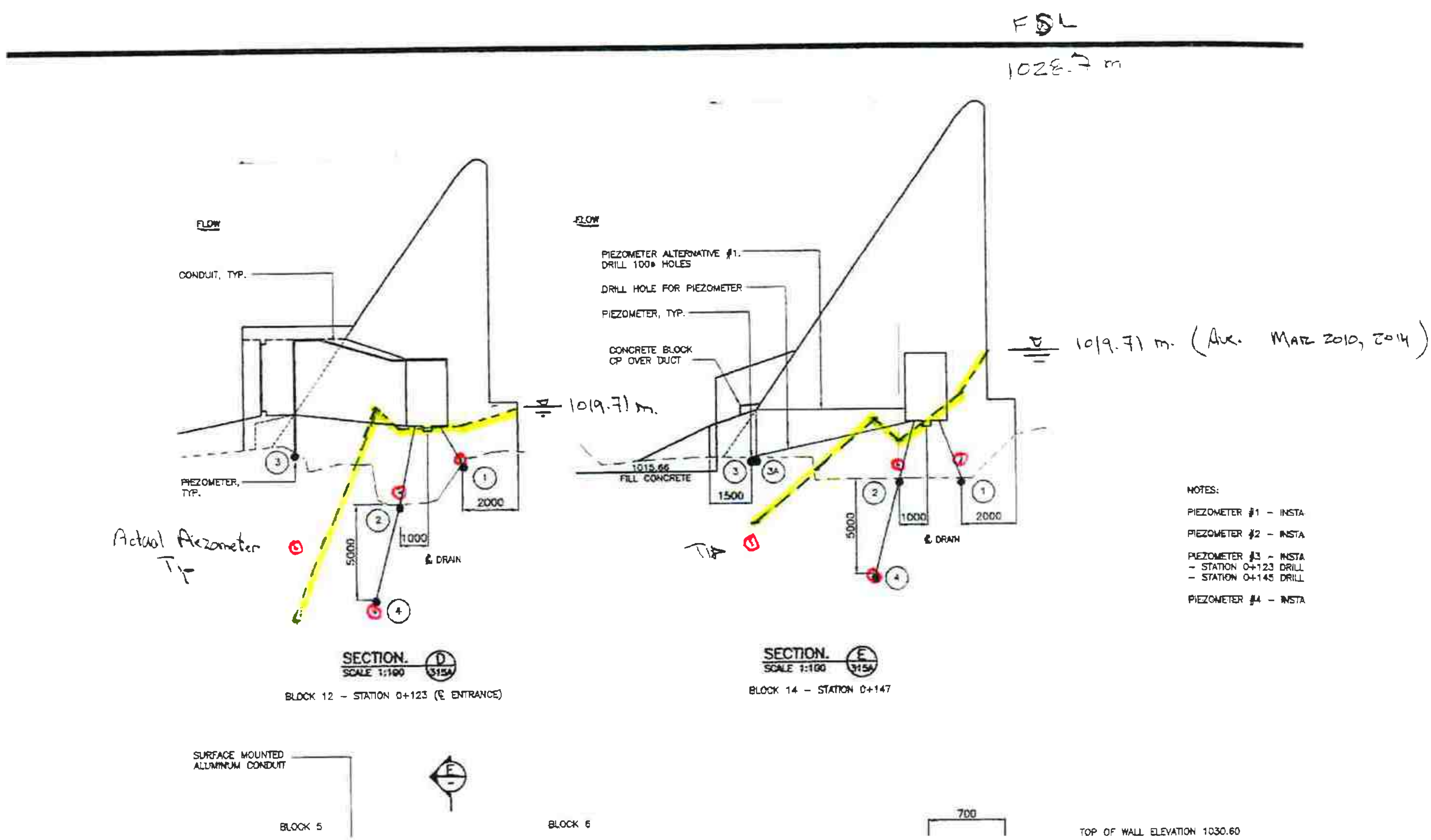
Gerald Imada, P.Eng.
Principal, Senior Geotechnical Engineer

RT/GI/kv

Attachments: Average of 2 Lowest Water Level Readings Drawing (March 24, 2010 and March 18, 2014)
Average of Highest Annual Readings Drawing (2009 to 2014)

n:\active\2014\1447\1418102 dos piezometer review summerland\07 deliverables\1418102-001-tm-rev0-vibrating wire piezometers-15dec_14.docx

Average of 2 Lowest Water Level Readings.
(March 24/10, March 18/14)



NOTES:

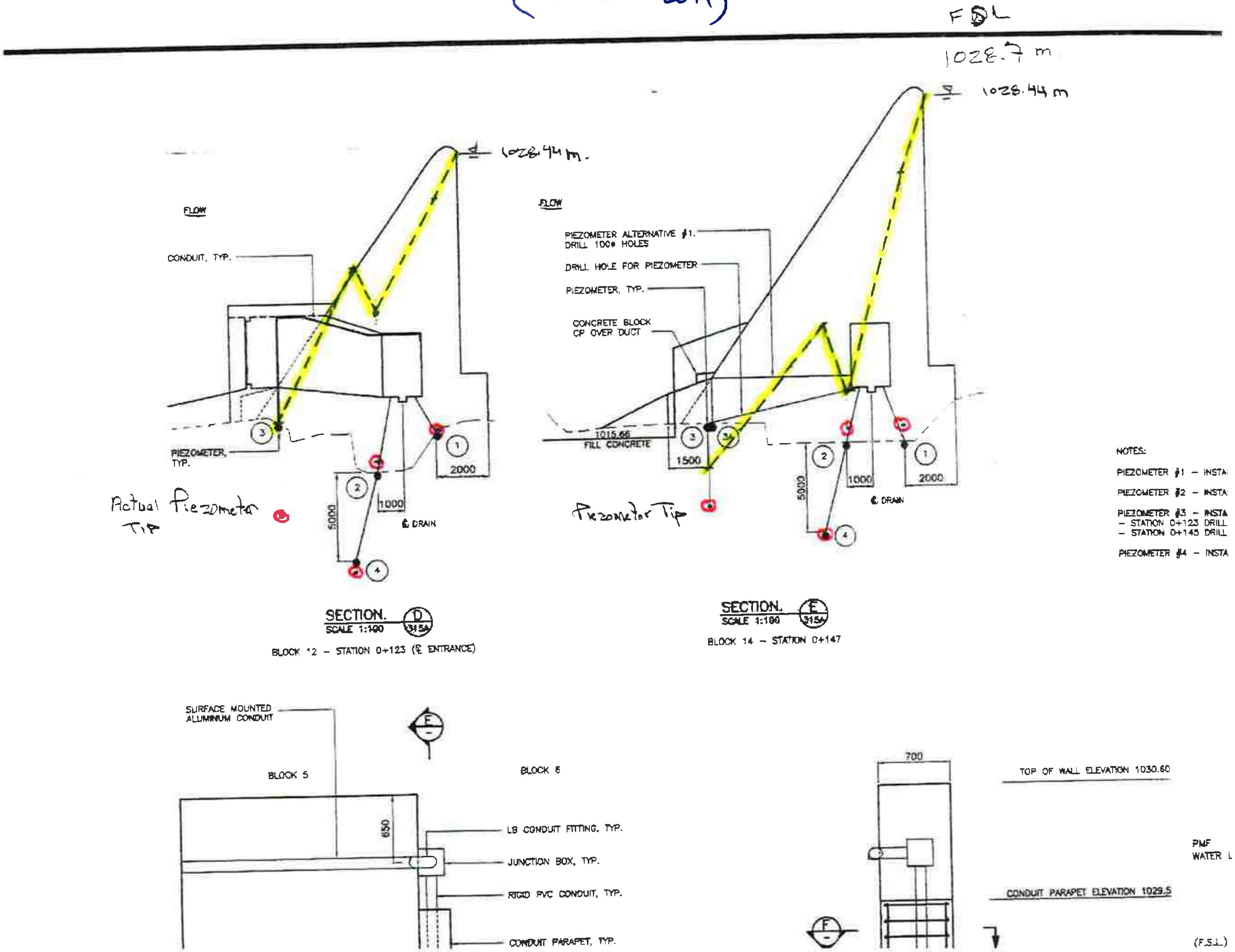
PIEZOMETER #1 - INSTA

PIEZOMETER #2 - INSTA

PIEZOMETER #3 - INSTA
- STATION 0+123 DRILL
- STATION 0+145 DRILL

PIEZOMETER #4 - INSTA

Average of highest annual readings (2009 - 2014)



District of Summerland

Thirsk Spillway Dam, Summerland, BC

Vibrating Wire Piezometer Monitoring

ENTER FIELD DATA BELOW

Note:
B_c = Current barometric pressure (in kPa)
L_c = current reading from vibrating wire piezometer (in B units)
T_c = current temperature reading from vibrating wire piezometer (in degrees Celsius)

Instructions :

1) Enter Date measurements were taken in Column A.
2) Enter Geodetic Reservoir Level (in m) at time measurements were taken in Column B.
3) Enter Barometric Pressure (in kPa) at time measurements were taken in Column C.
   - Barometric pressure information can be found on the Environment Canada Weather website for Summerland: (http://www.weatheroffice.gc.ca/city/pages/bc-54_metric_e.html).
   - If you require historical information, click on 'Historical Weather' → Climate Data Online → Search for Summerland for the appropriate date.
4) Enter all vibrating wire piezometer data within the labelled columns (Columns D through S).
5) Go to 'RESULTS' tab.

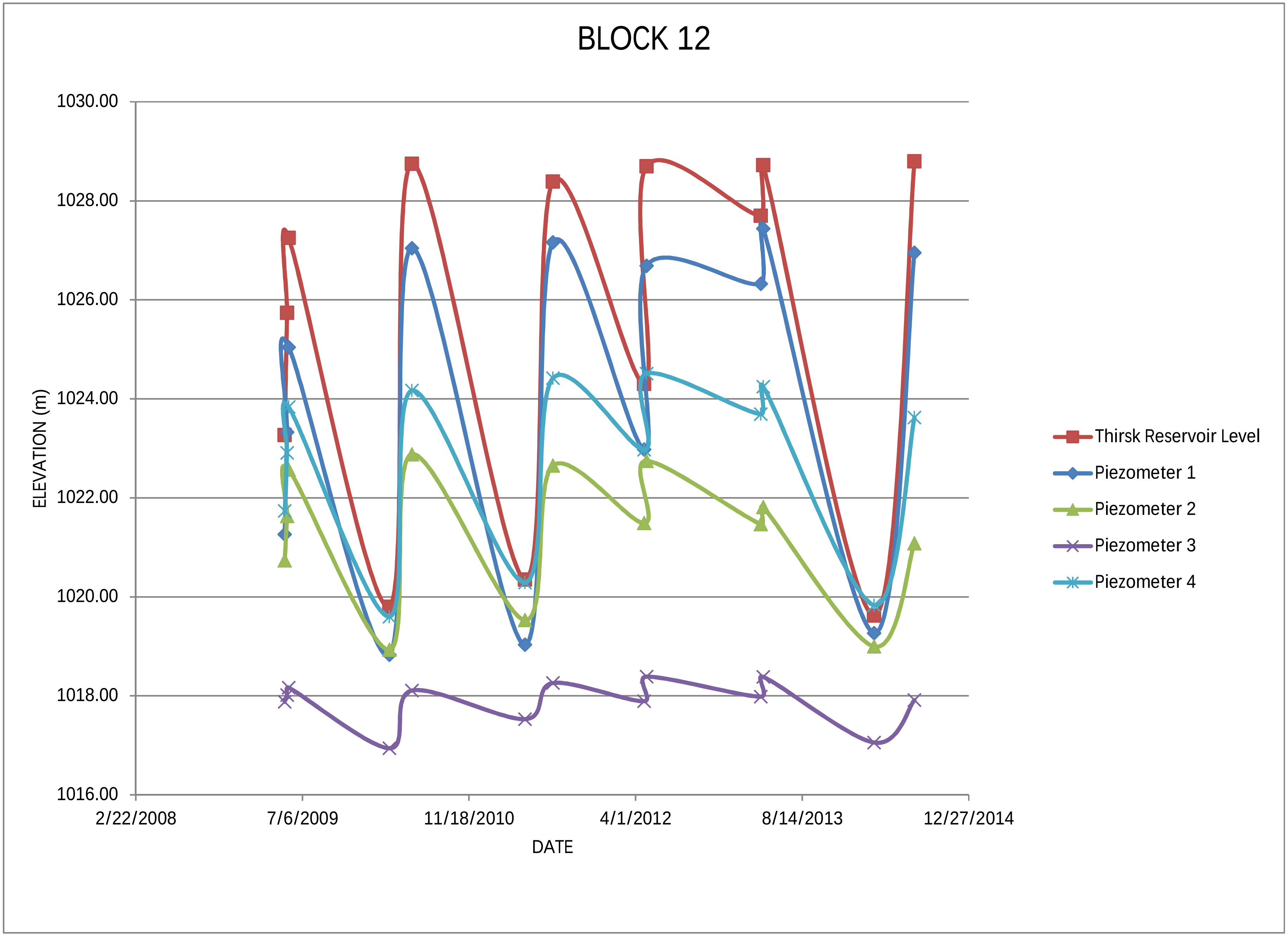
Date	Thirsk Reservoir Geodetic Water Level (m)	B_c (kPa)	Block 12								Block 14							
			Piezometer 1		*Piezometer 2*		*Piezometer 3*		*Piezometer 4*		*Piezometer 1*		*Piezometer 2*		*Piezometer 3*		*Piezometer 4*	
			L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)	L_c (B units)	T_c (°C)
5/14/2009	1023.27	95.83	8495.0	5.4	8506.8	4.8	8499.6	4.4	7774.8	6.4	8567.1	4.7	8829.6	4.3	8916.3	3.5	8292.2	5.5
5/21/2009	1025.74	96.81	8291.7	5.7	8414.3	4.9	8477.4	4.5	7649.1	6.3	8390.3	4.8	8815.1	4.4	8904.6	3.7	8239.2	5.5
5/26/2009	1027.25	96.13	8136.9	5.9	8333.4	5.0	8469.5	4.6	7564.2	6.3	8270.3	4.9	8815.3	4.5	8902.8	4.0	8209.6	5.5
3/24/2010	1019.80	101.40	8671.0	4.1	8621.5	5.0	8534.4	4.9	7929.2	6.9	8774.6	4.4	8830.3	4.6	8918.7	3.5	8346.6	6.1
5/31/2010	1028.75	101.00	7902.4	5.8	8258.1	5.4	8427.3	5.2	7482.4	6.4	8135.4	5.3	8812.4	5.0	8877.0	4.8	8158.4	5.6
5/5/2011	1020.35	97.40	8690.0	4.7	8604.0	4.7	8517.7	4.4	7901.6	6.4	8744.8	4.4	8830.8	4.4	8918.8	3.3	8337.0	5.6
7/28/2011	1028.39	97.00	7928.1	7.9	8316.2	6.2	8450.8	6.1	7498.3	6.1	8128.2	6.6	8803.4	5.9	8888.6	6.8	8169.8	5.5
4/27/2012	1024.30	97.92	8315.5	3.5	8417.7	4.2	8478.5	4.2	7631.7	6.2	8328.8	3.7	8819.3	3.9	8904.5	3.2	8235.2	5.4
5/4/2012	1028.70	97.42	7971.5	3.7	8305.7	4.2	8436.3	4.2	7484.7	6.1	8127.9	3.8	8817.3	3.9	8877.5	3.3	8163.5	5.4
4/12/2013	1027.70	97.50	8005.0	3.9	8422.8	4.9	8473.2	4.9	7564.6	6.6	8199.3	4.6	8842.5	4.4	8906.0	3.5	8202.5	5.9
4/19/2013	1028.72	97.50	7900.3	3.9	8391.0	4.9	8435.5	4.8	7509.9	6.5	8124.9	4.1	8836.8	4.3	8882.4	3.5	8166.4	5.8
3/18/2014	1019.62	102.60	8619.4	3.2	8604.2	4.8	8512.0	4.7	7894.4	6.8	8758.8	3.9	8848.0	4.3	8917.4	3.0	8329.9	6.1
7/17/2014	1028.80	101.50	7906.0	6.0	8420.2	5.4	8440.8	5.3	7531.6	6.1	8171.9	5.3	8833.5	5.0	8873.3	5.2	8167.0	5.4

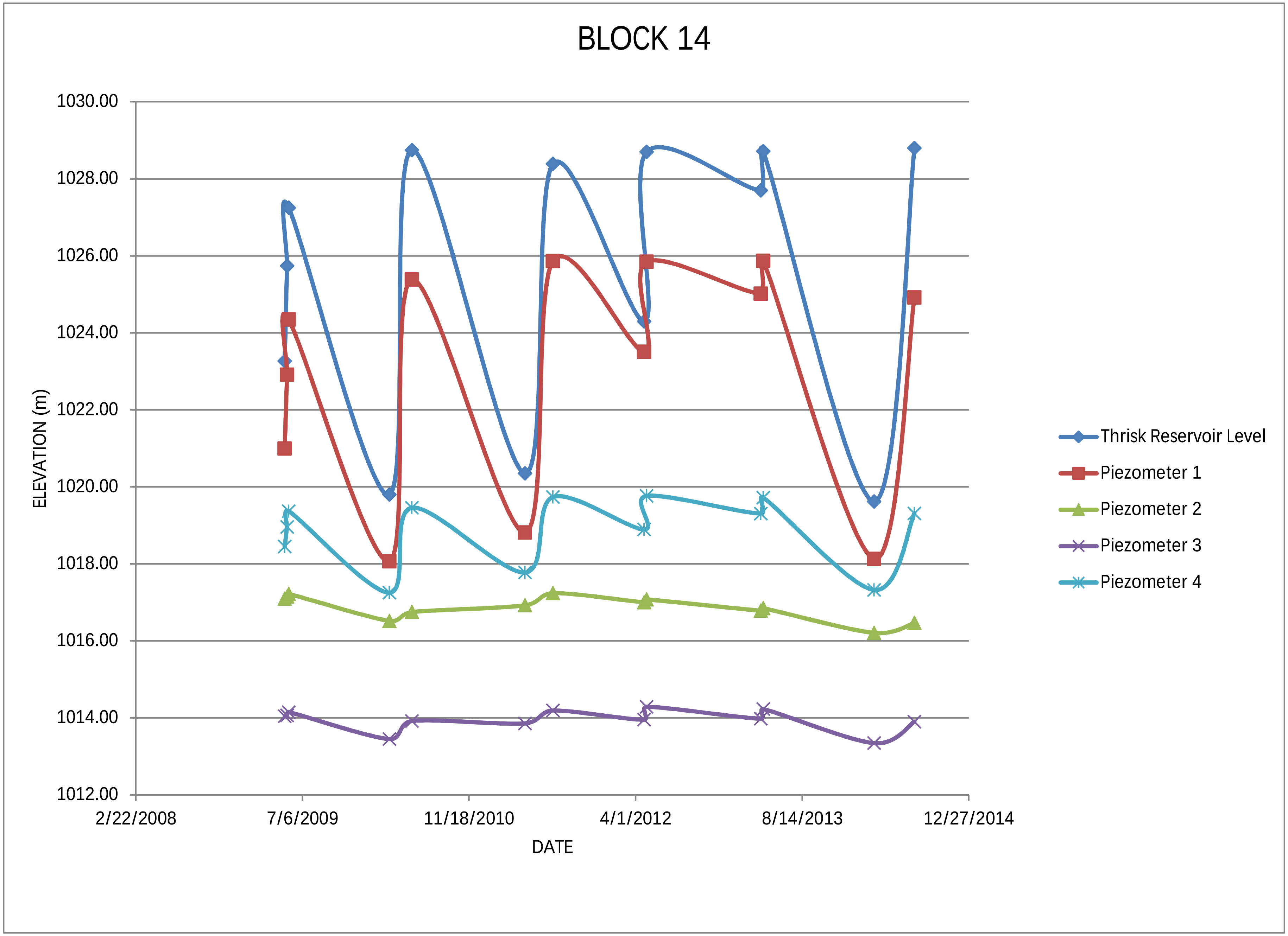
THIRSK DAM - VIBRATING WIRE PIEZOMETER RESULTS

NOTE: P = pressure (in kPa)
H_p = pressure head (in m)
H = total head (in m)

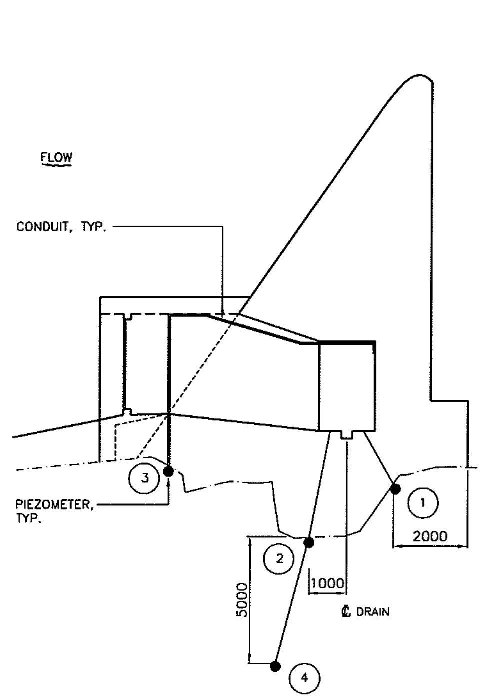
Instructions:
1) Highlight last set of results listed.
2) Drag down to update with current data and calculated pressure head and elevation head values for each piezometer. *Note: you do not need to type in anything (the spreadsheet will automatically update results).*
3) See graphs on 'Results - BLOCK 12' and 'Results - BLOCK 14'. These will now show the most

Date	Water Level (m)	Block 12								Block 14							
		Piezometer 1		*Piezometer 2*		*Piezometer 3*		*Piezometer 4*		*Piezometer 1*		*Piezometer 2*		*Piezometer 3*		*Piezometer 4*	
		H_p (m)	H (m)	H_p (m)	H (m)	H_p (m)	H (m)	H_p (m)	H (m)	H_p (m)	H (m)	H_p (m)	H (m)	H_p (m)	H (m)	H_p (m)	H (m)
5/14/2009	1023.27	3.56	1021.26	4.14	1020.74	3.28	1017.88	9.33	1021.73	5.40	1021.00	1.60	1017.10	1.34	1014.04	7.05	1018.45
5/21/2009	1025.74	5.63	1023.33	5.03	1021.63	3.41	1018.01	10.51	1022.91	7.31	1022.91	1.65	1017.15	1.36	1014.06	7.56	1018.96
5/26/2009	1027.25	7.34	1025.04	5.97	1022.57	3.57	1018.17	11.44	1023.84	8.75	1024.35	1.72	1017.22	1.45	1014.15	7.97	1019.37
3/24/2010	1019.80	1.13	1018.83	2.33	1018.93	2.34	1016.94	7.20	1019.60	2.47	1018.07	1.02	1016.52	0.75	1013.45	5.85	1017.25
5/31/2010	1028.75	9.35	1027.05	6.28	1022.88	3.51	1018.11	11.77	1024.17	9.78	1025.38	1.25	1016.75	1.22	1013.92	8.06	1019.46
5/5/2011	1020.35	1.33	1019.03	2.93	1019.53	2.93	1017.53	7.89	1020.29	3.21	1018.81	1.42	1016.92	1.16	1013.86	6.38	1017.78
7/28/2011	1028.39	9.46	1027.16	6.05	1022.65	3.66	1018.26	12.02	1024.42	10.26	1025.86	1.74	1017.24	1.49	1014.19	8.34	1019.74
4/27/2012	1024.30	5.28	1022.98	4.89	1021.49	3.29	1017.89	10.57	1022.97	7.91	1023.51	1.50	1017.00	1.25	1013.95	7.49	1018.89
5/4/2012	1028.70	8.99	1026.69	6.15	1022.75	3.79	1018.39	12.11	1024.51	10.25	1025.85	1.57	1017.07	1.59	1014.29	8.37	1019.77
4/12/2013	1027.70	8.62	1026.32	4.87	1021.47	3.38	1017.98	11.29	1023.69	9.42	1025.02	1.28	1016.78	1.28	1013.98	7.91	1019.31
4/19/2013	1028.72	9.74	1027.44	5.21	1021.81	3.78	1018.38	11.85	1024.25	10.27	1025.87	1.35	1016.85	1.53	1014.23	8.32	1019.72
3/18/2014	1019.62	1.57	1019.27	2.40	1019.00	2.46	1017.06	7.43	1019.83	2.53	1018.13	0.71	1016.21	0.64	1013.34	5.92	1017.32
7/17/2014	1028.80	9.25	1026.95	4.48	1021.08	3.31	1017.91	11.22	1023.62	9.32	1024.92	0.97	1016.47	1.20	1013.90	7.91	1019.31


BLOCK 12
1030.00
1028.00
1026.00
1024.00
1022.00
1020.00
1018.00
1016.00
ELEVATION (m)
2/22/2008
7/6/2009
11/18/2010
4/1/2012
8/14/2013
12/27/2014
DATE
Thirsk Reservoir Level
Piezometer 1
Piezometer 2
Piezometer 3
Piezometer 4

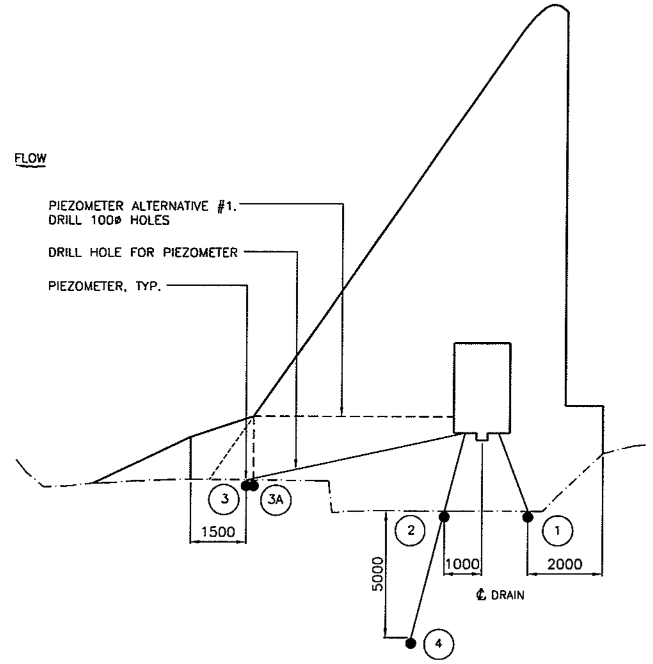


BLOCK 14
1030.00
1028.00
1026.00
1024.00
1022.00
1020.00
1018.00
1016.00
1014.00
1012.00
ELEVATION (m)
2/22/2008
7/6/2009
11/18/2010
4/1/2012
8/14/2013
12/27/2014
DATE
Thrisk Reservoir Level
Piezometer 1
Piezometer 2
Piezometer 3
Piezometer 4



SECTION. D/315A
SCALE 1:200

BLOCK 12 – STATION 0+123 (GALLARY ENTRANCE)



SECTION. E/315A
SCALE 1:200

BLOCK 14 – STATION 0+145

NOTES:

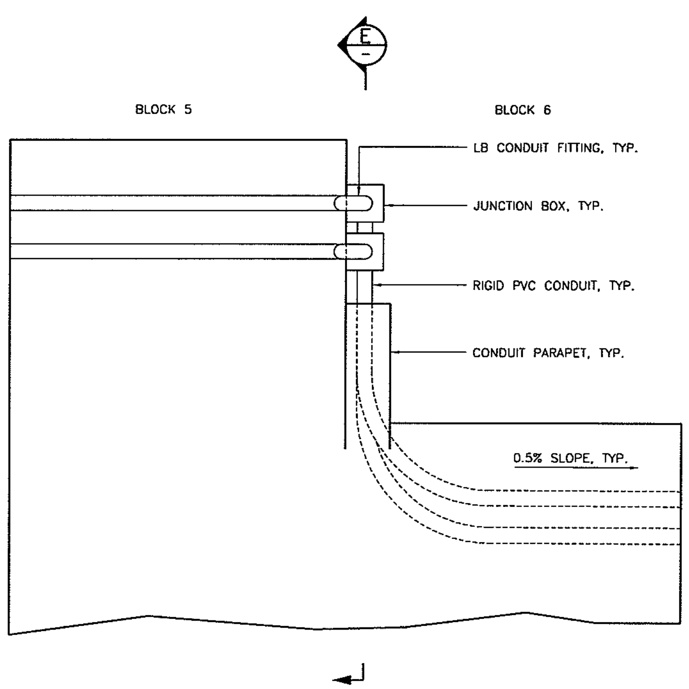
PIEZOMETER #1 – INSTALL MID-WAY BETWEEN GROUT CURTAIN & DRAIN AT GROUNDLINE.

PIEZOMETER #2 – INSTALL ±1.0m DOWNSTREAM OF DRAIN NEAR GROUNDLINE.

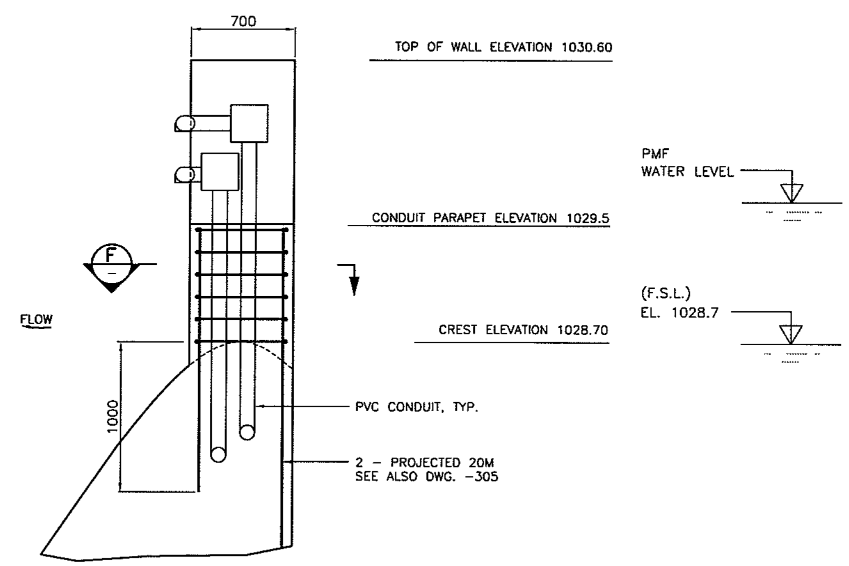
PIEZOMETER #3 – INSTALL NEAR DOWNSTREAM TOE.
– STATION 0+123 DRILL DOWN THROUGH ENTRANCE
– STATION 0+145 DRILL AS STEEP AS POSSIBLE TOWARDS TOE.

PIEZOMETER #4 – INSTALL ±5.0m BELOW THE ROCK/ CONCRETE INTERFACE.

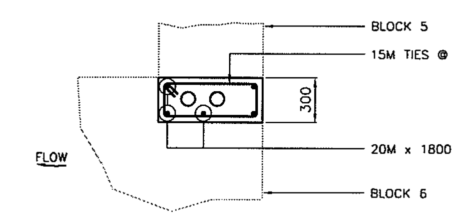
ALTERNATIVE #1 (PIEZOMETER #3A) – FOR PIEZOMETER #3 AT STATION 0+145 IT MAY NOT BE PRACTICAL TO DRILL A FLAT HOLE TOWARDS THE TOE. ALTERNATIVELY, DRILL TWO (2) INTERSECTING HOLES FROM THE TOE & GROUT/ CONCRETE COVER AFTER INSTALLATION.



DETAIL 1/315A
SCALE 1:25



SECTION. E
SCALE 1:25



SECTION. F
SCALE 1:25

NO.	DATE	ENG.	BY	SUBJECT
1	06/11/21	SC	WR	GENERAL REVISION
0	06/10/12	SC	WR	ISSUED FOR CONSTRUCTION

REVISIONS

VERIFY SCALES
BAR IS 20mm ON ORIGINAL DRAWING
0 — 20mm
IF NOT 20mm ON THIS SHEET, ADJUST SCALES ACCORDINGLY

Associated Engineering

PROJECT No.	012143		
SCALE	AS SHOWN		
DRAWN	WAYNE RILEY		05/02/02
DESIGNED	SHANE COOK		04/09/26
CHECKED	DALE HARRISON		
APPROVED			
DATE		INITIAL	

DISTRICT OF SUMMERLAND

THIRSK RESERVOIR EXPANSION

THIRSK SPILLWAY
CONDUIT ELEVATION & DETAILS – SHEET 2

DRAWING NUMBER	REV. NO.	SHEET
2143–ABR–315B	1	