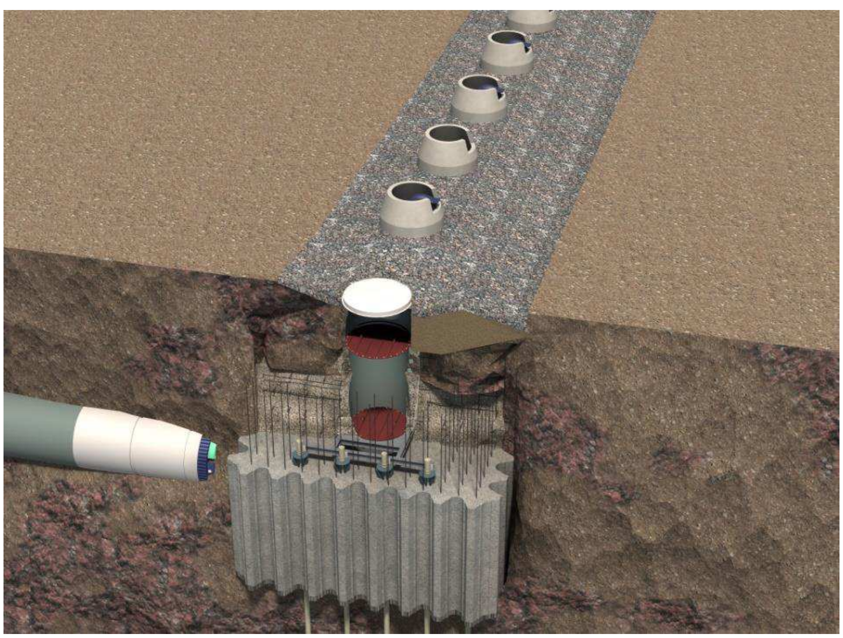
APPENDIX B
GEOTECHNICAL REPORTS

B.1: Geotechnical Data Report

Part D: Appendix B

Annacis Island WWTP New Outfall System

Vancouver Fraser Port Authority
Project and Environmental Review Application



metrovancouver
SERVICES AND SOLUTIONS FOR
A LIVABLE REGION

CDM Smith

Golder Associates

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APPENDIX B

Technical Memoranda on SPT Energy Measurements

Golder Associates

TECHNICAL MEMORANDUM

DATE September 3, 2015 **REFERENCE No.** 1532895-003-TM-Rev0

TO Yannick Wittwer
Golder Associates Ltd.

FROM V. Manmatharajan & M. Yogendrakumar **EMAIL** vmathan@golder.com

ENERGY MEASUREMENTS ON STANDARD PENETRATION TEST (SPT) HAMMER
GEOTECHNICAL INVESTIGATION – TRANSIENT MITIGATION AND OUTFALL SYSTEM
ANNACIS ISLAND, BC.

This technical memorandum presents the results of series of energy measurements carried out by Golder Associates Ltd. (Golder) during Standard Penetration Testing (SPT) as part of the geotechnical investigation for the Annacis Outfall project in Annacis Island, BC.

The energy measurements were carried out in accordance with ASTM Standard Designation D4633-10. The Force Velocity method (EFV) specified in the standard was used to compute the energy that was delivered to the SPT sampling rods during testing.

1.0 INTRODUCTION

Golder carried out the energy measurements during Standard Penetration Testing at two (2) boreholes (BH15-04 & BH15-14) during the period between July 6, 2015 and July 9, 2015. An automatic trip hammer mounted on Fraste XL-2 mud rotatory, track mounted drill rig supplied and operated by Mud Bay Drilling Co. Ltd. was used for the SPT. The SPT energy measurements were carried out at 5 ft. depth intervals.

2.0 INSTRUMENTED ROD AND HAMMER

Instrumented 0.6 m (2 ft.) subassemblies of AW and NW rods were used in the energy measurements. The AW rod assembly was used up to a depth of 15 m and the NW rod assembly was used below 15 m. The subassemblies were instrumented with two strain gauges and two accelerometers. The accelerometers that were used in the energy measurements are capable of measuring the acceleration of high impact steel (Piezo-Resistive Type). A Pile Driving Analyzer (PDA-8G version 2015-10) unit was used to record strains and accelerations for every blow.

Photographs 1 and 2 below show the automatic trip hammer on top of sampling rod and instrumented AW and NW rods at boreholes BH15-04 and BH15-14, respectively.

Photograph 1: SPT Hammer on top of AW subassembly at Borehole BH15-04

Photograph 2: SPT Hammer on top of NW subassembly at Borehole BH15-14

3.0 ENERGY MEASUREMENTS & ETR CALCULATIONS

The energy transfer ratio (ETR) (*i.e.*, efficiency) was computed based on the maximum energy transferred to the sampling rod (EFV) and theoretical maximum potential energy (PE). The following equation is used to calculate the ETR:

$$ETR = EFV / PE$$

The energy transferred to the sampling rod (EFV) was calculated using the time-varying functions of measured force F (t) and Velocity v (t) as shown in the equation below:

$$EFV = max [\int F (t)\ v (t)\ dt]$$

For the SPT, the maximum potential energy (PE) is taken as 0.47 kNm, which is equivalent to a 0.62 kN (140 lbs) of hammer weight falling a distance of 0.76 m (30 inches).

4.0 SUMMARY OF THE RESULTS

Tables 1 and 2 summarize the results of energy measurements including blow counts, statistical average and standard deviation of ETR and the maximum of ETR computed carried out during the penetration testing at different depth intervals. Photograph 3 shows a typical force and velocity plot with time for a blow at BH15-04. Figures 1 to 2 show the variation of energy transfer ratio (ETR) with blow numbers at each depth.

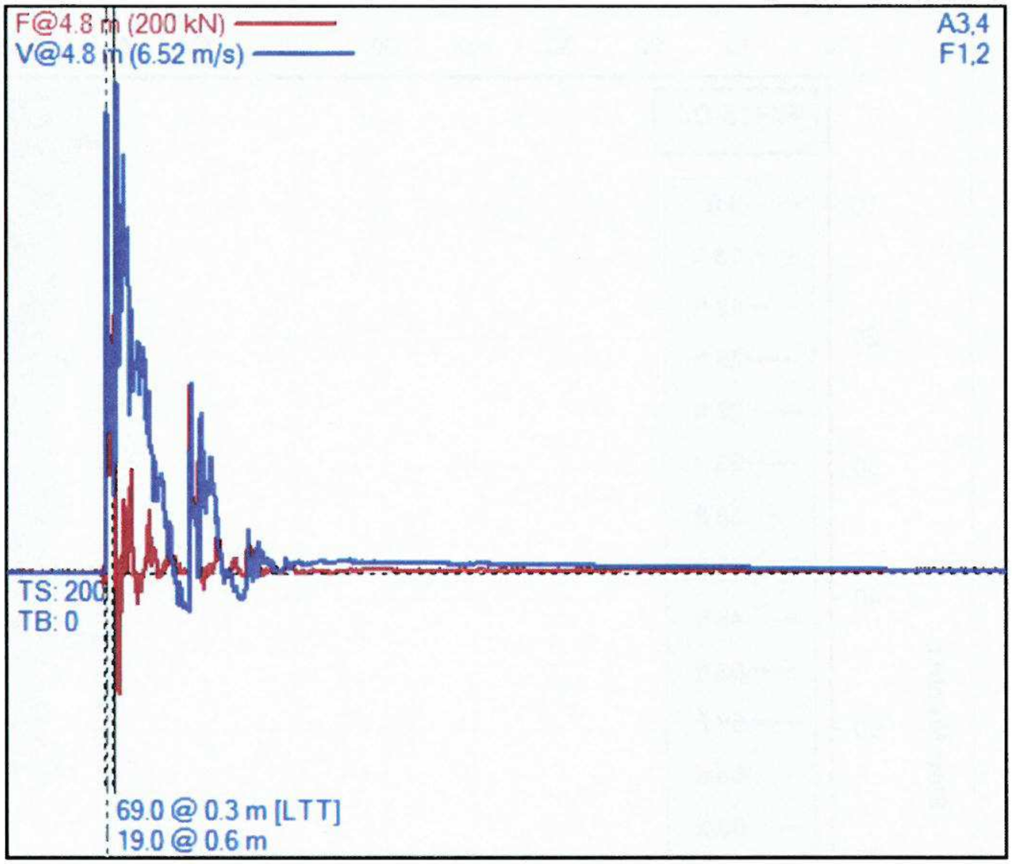
Table 1: Standard Penetration Testing (SPT) - Results at Borehole BH15-04

Depth Range	Depth Range	Blow Counts	Energy Transfer Ratio (ETR) (%)		
(ft.)	(m)	(for 6 inches)	Average	Std. Dev.	Maximum
8 -10	2.43 – 3.03	5/5/4/2	91.2	2.8	95.2
13 -15	3.96 – 4.56	1/1/1/1	89.0	1.9	90.8
18 - 20	5.49 – 6.09	2/1/2/1	87.7	4.9	92.5
23 - 25	7.01 – 7.61	3/3/6/6	90.4	2.5	94.5
28 - 30	8.53 – 9.13	3/3/4/4	92.1	3.0	95.8
33 - 35	10.05 – 10.65	4/6/5/6	91.1	2.4	95.5
38 – 40	11.58 – 12.18	3/5/6/6	92.7	2.4	96.1
43 - 45	13.11 – 13.72	4/5/7/10	87.6	2.3	92.7
48 - 50	14.63 – 15.24	5/7/6/5	91.3	1.9	95.3
53 - 55	16.15 – 16.76	9/10/10/9	91.8	2.1	95.2
58 - 60	17.67 – 18.29	9/8/10/9	90.7	2.5	95.2
63 - 65	19.20 – 19.80	8/11/11/11	92.1	2.2	95.6
68 - 70	20.72 – 21.32	5/7/9/12	94.1	1.0	95.7
73 - 75	22.25 – 22.85	7/8/8/13	91.3	3.5	95.7
78 - 80	23.77 – 24.37	8/8/10/12	90.6	3.5	96.6

Depth Range	Depth Range	Blow Counts	Energy Transfer Ratio (ETR) (%)		
83 - 85	25.29 – 25.89	10/13/12/12	93.5	3.4	96.9
88 - 90	26.82 – 27.43	2/1/7/5	90.8	3.2	96.7
91 - 93	27.74 - 28.34	16/20/19/17	90.7	3.2	96.9
98 - 100	29.87 – 30.47	12/13/13/17	91.6	3.9	96.9
103 - 105	31.39 – 31.99	13/17/19/20	91.4	2.2	96.8
108 - 110	32.92 – 33.53	7/9/11/15	89.7	2.8	96.5
113 - 115	34.44 – 35.04	6/9/10/12	92.2	3.6	97.5
118 - 120	35.96 – 36.57	3/2/4/8	93.1	2.1	95.4

Table 2: Standard Penetration Testing (SPT) – Results at Borehole BH15-14

Depth Range	Depth Range	Blow Counts	Energy Transfer Ratio (ETR) (%)		
(ft.)	(m)	(for 6 inches)	Average	Std. Dev.	Maximum
8 -10	2.43 – 3.03	6/7/3/2	91.4	2.1	94.6
13 -15	3.96 – 4.56	2/1/1/2	92.6	2.4	95.2
18 - 20	5.49 – 6.09	4/6/7/6	93.0	1.2	95
23 - 25	7.01 – 7.61	5/7/7/8	91.3	2.7	94.9
28 - 30	8.53 – 9.13	5/4/4/4	92.2	2.3	95.1
33 - 35	10.05 – 10.65	3/5/2/3	90.8	2.2	94.5
38 – 40	11.58 – 12.18	3/6/6/6	93.5	2.8	96.2
43 - 45	13.11 – 13.72	3/3/6/5	92.7	2.7	95.6
48 - 50	14.63 – 15.24	4/5/5/5	93.0	2.8	96.8
53 - 55	16.15 – 16.76	7/8/8/8	92.9	1.7	96.4
58 - 60	17.67 – 18.29	6/9/9/9	92.3	2.5	96.1
63 - 65	19.20 – 19.80	6/9/10/14	90.5	2.1	94.9
68 - 70	20.72 – 21.32	8/9/12/13	90.9	2.4	95.2
73 - 75	22.25 – 22.85	8/14/18/23	92.8	1.9	95.8
78 - 80	23.77 – 24.37	15/25/29/28	92.4	2.9	96.9
83 - 85	25.29 – 25.89	7/9/13/15	92.2	2.6	96.7
88 - 90	26.82 – 27.43	10/9/10/12	93.0	3.1	96.9
93 - 95	28.35 - 28.95	8/12/15/19	94.0	1.9	97.3
98 - 100	29.87 – 30.47	9/11/14/19	90.9	3.4	96.9
103 - 105	31.39 – 31.99	10/10/15/16	92.6	3.0	96.8
108 - 110	32.92 – 33.53	9/10/13/17	94.5	1.4	96.3
113 - 115	34.44 – 35.04	8/13/18/25	90.8	4.0	96.2
118 - 120	35.96 – 36.57	11/16/16/16	92.9	1.7	96.0
123 - 125	37.49 – 38.09	14/10/14/27	89.3	2.4	95.7
128 -130	39.01 – 39.62	5/14/19/28	90.5	3.8	95.9
133 - 135	40.54 – 41.15	6/10/10/8	92.1	3.3	95.7



Photograph 3 shows a typical force and velocity plot with time for a blow at borehole BH 15-04.

5.0 CLOSURE

We trust that this memorandum provides adequate information for your immediate purposes. Should you have any questions or comments, please contact us.

GOLDER ASSOCIATES LTD.

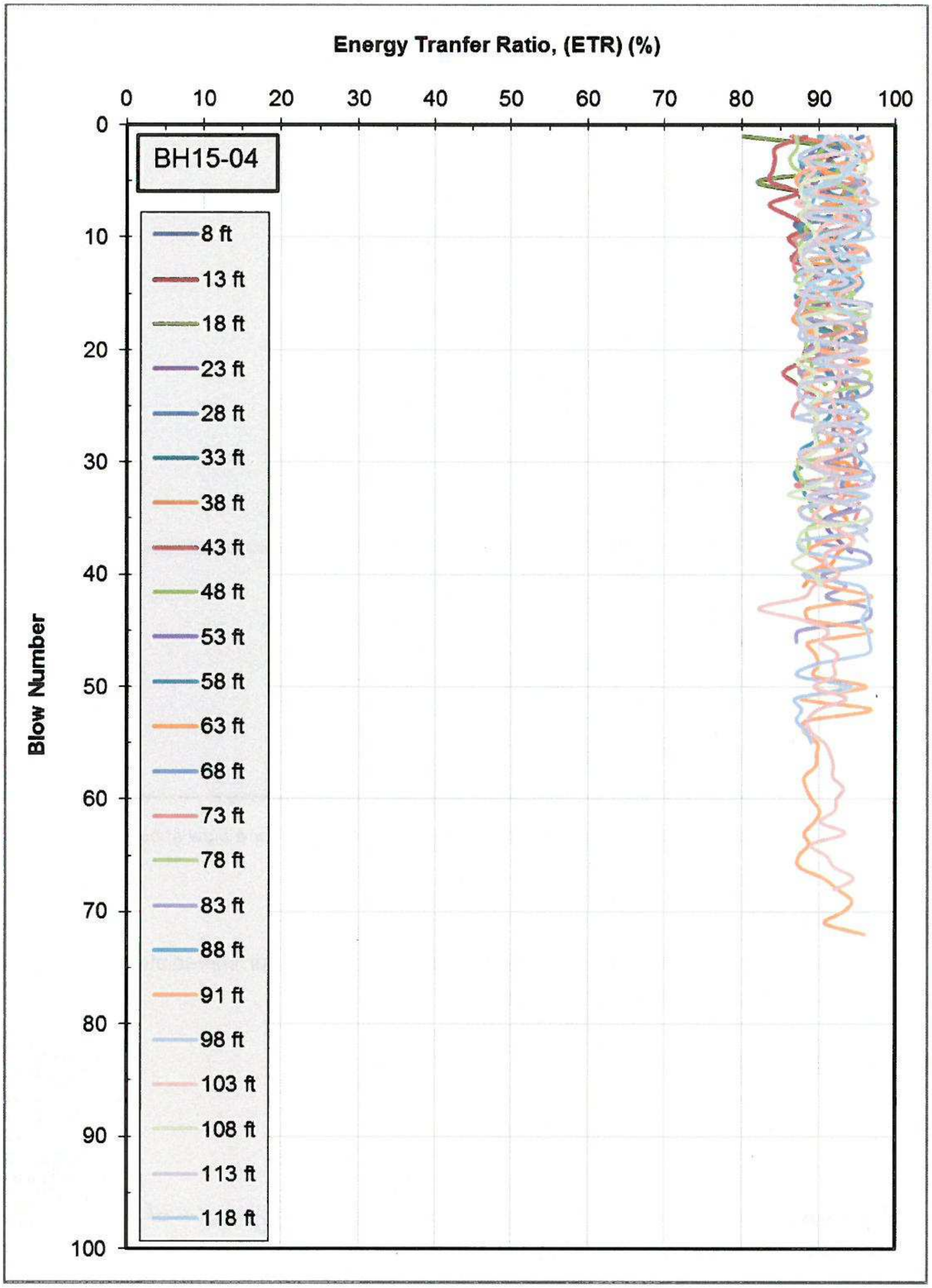
V. (Mathan) Manmatharajan, M.A.Sc, E.I.T.
Geotechnical Engineer

M. (Yogi) Yogendrakumar, Ph.D., P.Eng.
Principal and Senior Geotechnical Engineer

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA
Dr. M. YOGENDRAKUMAR
20540
Sept 3/2015

VM/MY/kn

Attachments: Figure 1 & 2.



PROJECT **BLACK & VEATCH CANADA CORPORATION**
TRANSIENT MITIGATION AND OUTFALL SYSTEM
ANNACIS ISLAND, BC.

TITLE

ENERGY TRANSFER RATIO, (ETR)
BOREHOLE BH15-04

Golder Associates

PROJECT No. 1532895			PHASE No.	
DESIGN	VM	13 JULY 15	SCALE NTS	REV.
CADD	----	13 JULY 15	**FIGURE 1**	
CHECK	MY	13 JULY 15		
REVIEW	MY	13 JULY 15		

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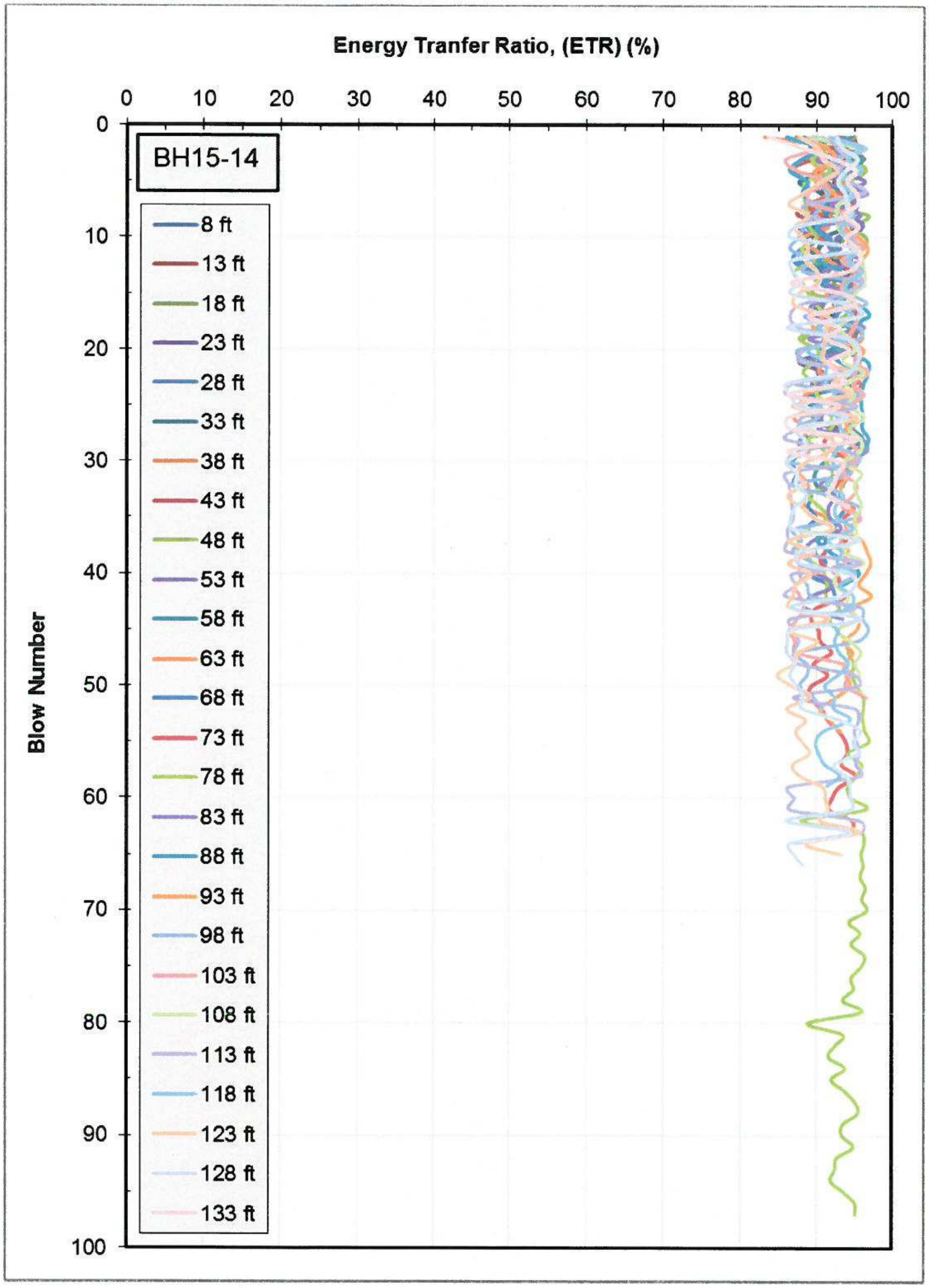

PROJECT **BLACK & VEATCH CANADA CORPORATION**
TRANSIENT MITIGATION AND OUTFALL SYSTEM
ANNACIS ISLAND, BC.

TITLE

ENERGY TRANSFER RATIO, (ETR)
BOREHOLE BH15-14

Golder Associates

PROJECT No.	1532895		PHASE No.	
DESIGN	VM	13 JULY 15	SCALE NTS	REV.
CADD	----	13 JULY 15	**FIGURE 2**	
CHECK	MY	13 JULY 15		
REVIEW	MY	13 JULY 15		

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TECHNICAL MEMORANDUM

DATE December 1, 2015 **REFERENCE No.** 1525010-109-TM-Rev0

TO Aran Thurairajah
Golder Associates Ltd.

FROM M. (Yogi) Yogendrakumar **EMAIL** myogendrakumar @golder.com

ENERGY MEASUREMENTS ON SPT AND LPT HAMMERS
GEOTECHNICAL INVESTIGATION – TRANSIENT MITIGATION AND OUTFALL SYSTEM
ANNACIS ISLAND, BC

This technical memorandum presents the results of series of energy measurements carried out by Golder Associates Ltd. (Golder) during Standard Penetration Testing (SPT) and Large Penetration Testing (LPT) as part of the geotechnical investigation for the Annacis Outfall project in Annacis Island, BC.

The energy measurements were carried out in accordance with ASTM Standard Designation D4633-10. The Force Velocity method (EFV) specified in the standard was used to compute the energy that was delivered to the sampling rods during testing.

1.0 INTRODUCTION

Golder carried out the energy measurements during both offshore and onshore drilling investigations. For the offshore investigation, the energy measurements were carried out during both Standard Penetration Testing (SPT) and Large Penetration Testing (LPT) at one borehole BH15-01. This work was carried out during the period between September 21, 2015 and September 22, 2015.

For the onshore investigation, the energy measurement was carried out during the LPT at one onshore borehole BH15-03. This work was carried out on October 5, 2015. Golder was able to record the energy measurement readings at two depths only due to time constraints on that day.

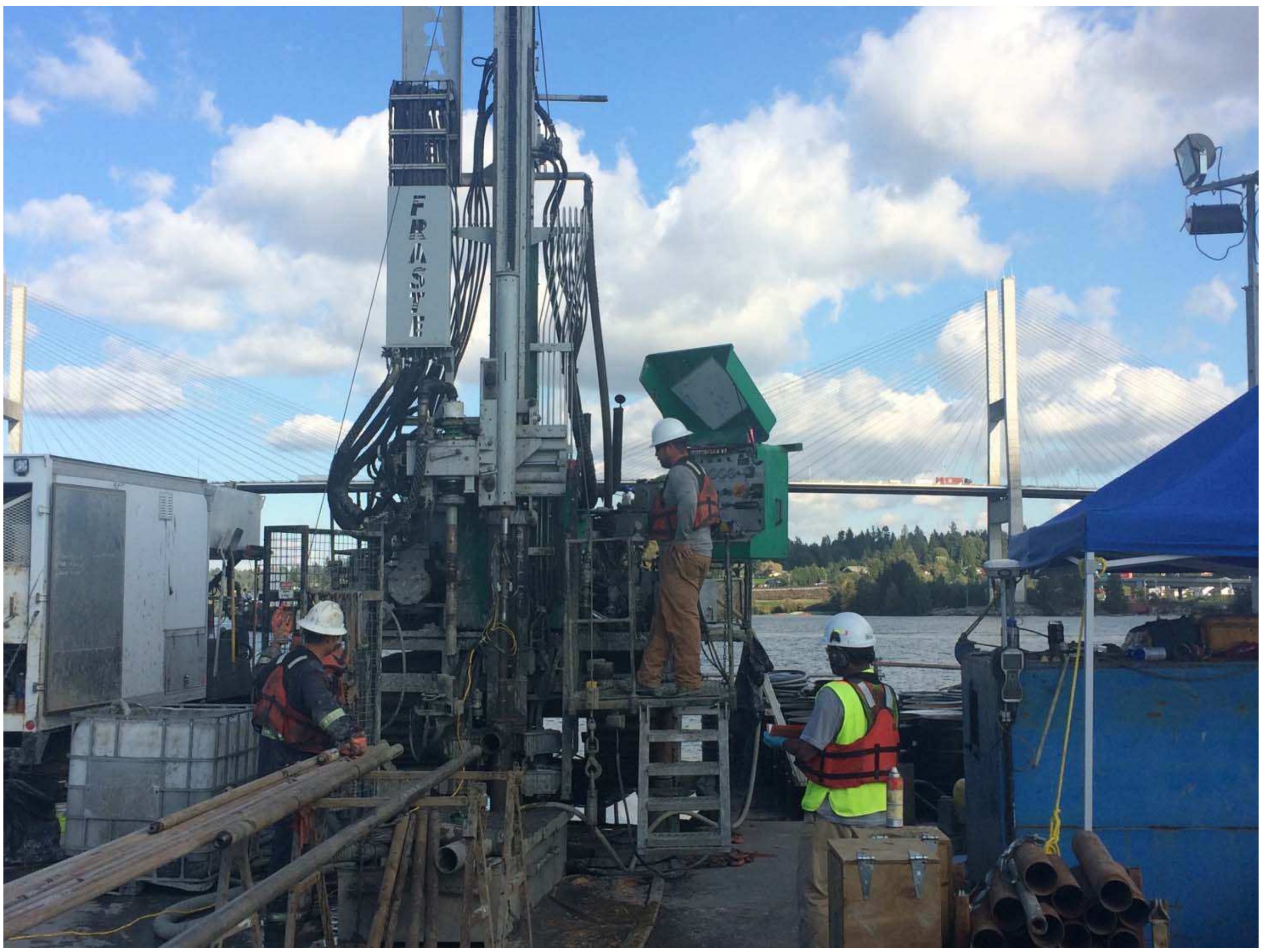
Automatic trip hammers mounted on Fraste XL-1 and XL-2 track mounted drill rigs were used for offshore and onshore investigation, respectively. The drill rigs were supplied and operated by Mud Bay Drilling Co. Ltd. The energy measurements were carried out at 5 ft. depth intervals.

2.0 INSTRUMENTED ROD AND HAMMER

Instrumented 0.6 m (2 ft.) subassembly of NW rod was used in the energy measurements. The subassembly was instrumented with two strain gauges and two accelerometers. The accelerometers that were used in the energy measurements are capable of measuring the acceleration of high impact steel (Piezo-Resistive Type).

A Pile Driving Analyzer (PDA-8G version 2015-10) unit was used to record strains and accelerations for every blow.

Photographs 1 and 2 below show the automatic trip hammer on top of sampling rod and instrumented NW rod at borehole BH15-01 and BH15-03, respectively.



Photograph 1: SPT Hammer on top of NW subassembly at Borehole BH15-01 (Offshore Investigation)

Photograph 2: SPT Hammer on top of NW subassembly at Borehole BH15-03 (Onshore Investigation)

3.0 ENERGY MEASUREMENTS & ETR CALCULATIONS

The energy transfer ratio (ETR) (i.e., efficiency) was computed based on the maximum energy transferred to the sampling rod (EFV) and theoretical maximum potential energy (PE). The following equation is used to calculate the ETR:

$$ETR = EFV / PE$$

The energy transferred to the sampling rod (EFV) was calculated using the time-varying functions of measured force F (t) and Velocity v (t) as shown in the equation below:

$$EFV = max\ [\int F(t)\ v(t)\ dt]$$

For the SPT, the maximum potential energy (PE) is taken as 0.47 kNm, which is equivalent to a 0.62 kN (140 lbs) of hammer weight falling a distance of 0.76 m (30 inches).

For the LPT, the maximum potential energy (PE) is taken as 1.02 kNm, which is equivalent to a 1.34 kN (300 lbs) of hammer weight falling a distance of 0.76 m (30 inches).

4.0 SUMMARY OF THE RESULTS

Tables 1 and 2 summarize the results of energy measurements including blow counts, statistical average and standard deviation of ETR and the maximum of ETR computed during the penetration testing at different depth intervals. Photograph 3 shows a typical force and velocity plot with time for a blow at 80 ft. Figures 1 and 2 show the variation of energy transfer ratio (ETR) with blow numbers at each depth of SPT and LPT hammer, respectively for BH15-01 while Figure 3 shows the ETR variation at each depth of the LPT hammer for BH15-03.

Table 1: Results at Borehole BH15-01

Depth Range	Depth Range	Hammer Type	Blow Counts	Energy Transfer Ratio (ETR) (%)		
(ft.)	(m)		(for 6 inches)	Average	Std. Dev.	Maximum
50 - 52	15.2 – 15.8	SPT	14/19/22/22	89.4	1.0	92.2
55 - 57	16.7 – 17.3	SPT	19/20/20/22	90.1	1.3	93.2
60 - 62	18.4 – 19.0	SPT	11/13/14/21	90.3	1.7	93.0
65 - 67	19.8 – 20.4	SPT	10/14/17/22	91.0	1.5	92.8
70 - 72	21.3 – 21.9	SPT	10/16/23/31	90.2	1.6	93.0
75 - 77	22.9 – 23.5	SPT	21/27/30/22	89.9	1.7	92.6
80 - 82	24.4 – 25.0	LPT	6/22/32/36	88.1	2.0	92.6
85 - 87	25. 9 – 26.5	LPT	11/20/19/22	89.2	2.1	93.8
90 - 92	27.4 – 28.0	LPT	5/17/20/15	88.9	2.3	93.3
95 - 97	28.9 – 29.5	LPT	3/2/2/1	88.8	2.2	91.6

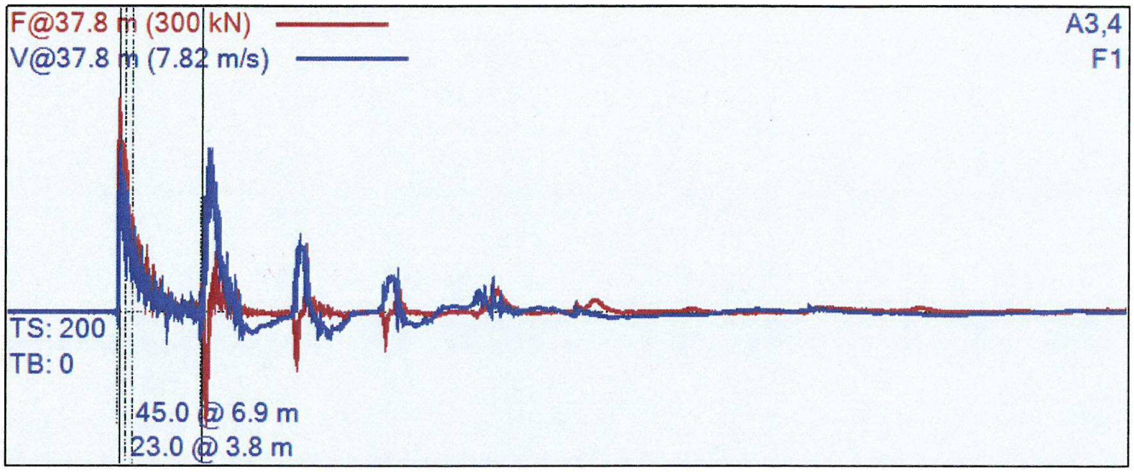
Table 2: Results at Borehole BH15-03

Depth Range	Depth Range	Hammer Type	Blow Counts	Energy Transfer Ratio (ETR) (%)		
(ft.)	(m)		(for 6 inches)	Average	Std. Dev.	Maximum
99-101	30.2 – 30.8	LPT	8/16/13/7	91.6	1.2	93.9
104-106	31.7 – 32.3	LPT	13/14/18/17	92.2	1.3	94.6

Pile Dynamics, Inc.

Pile Driving Analyzer ® (PDA)

1525010 CDM SMITH-ANNACIS OUTFALL BH15-01-80ft



Photograph 3: A typical force and velocity plot with time for a blow at borehole BH15-01.

5.0 CLOSURE

We trust that this memorandum provides adequate information for your immediate purposes. Should you have any questions or comments, please contact us.

GOLDER ASSOCIATES LTD.

M. (Yogi) Yogendrakumar, PhD, PEng
Principal, Senior Geotechnical Engineer

MY/asd

Attachments: Figure 1, 2 and 3

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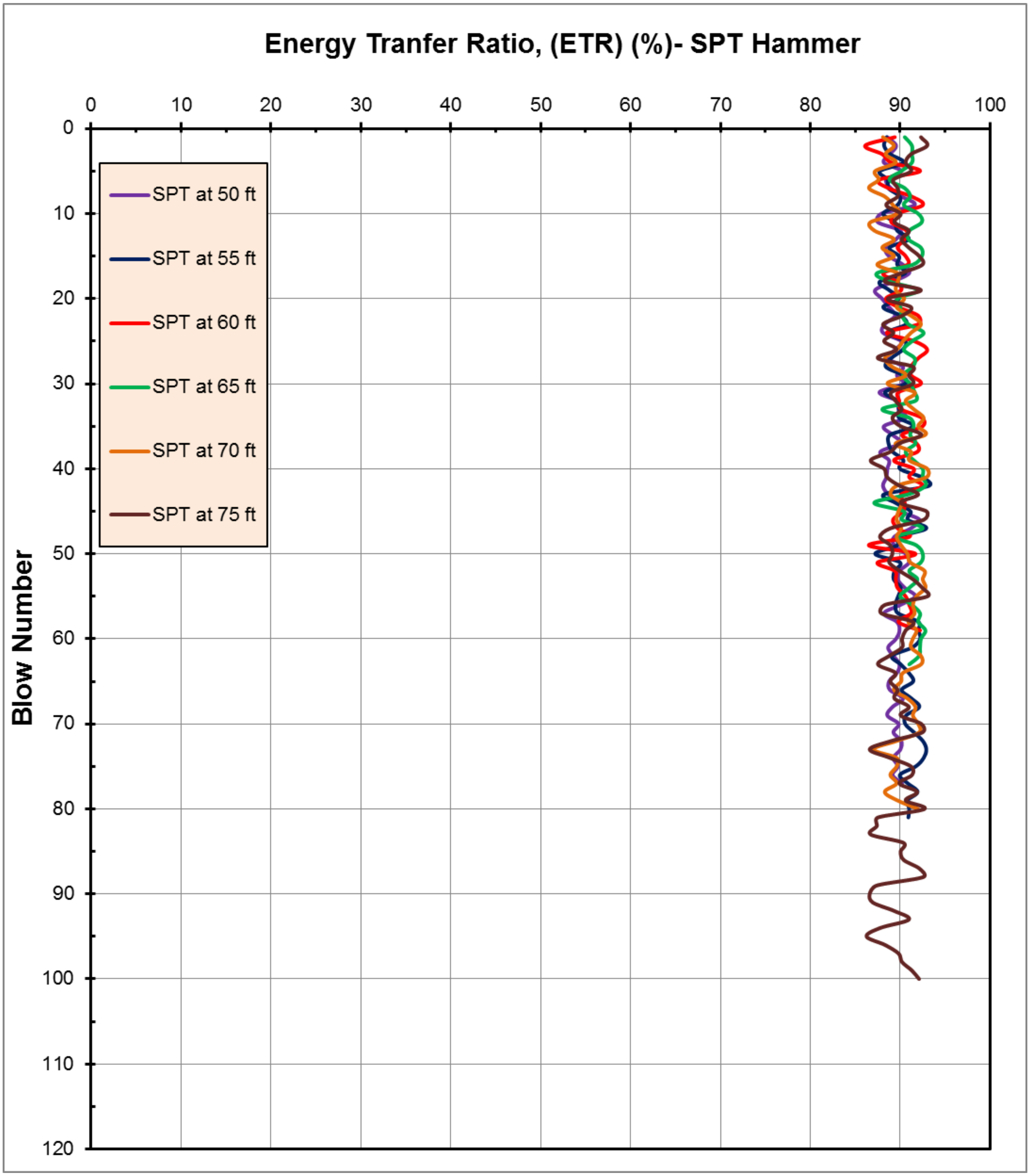

PROJECT	CDM SMITH TRANSIENT MITIGATION OUTFALL SYSTEM ANNACIS ISLAND, BC.				
TITLE	ENERGY TRANSFER RATIO, (ETR) – SPT HAMMER BOREHOLE BH15-01				
Golder Associates	PROJECT No. 1525010			PHASE No.	
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	CADD	----		FIGURE 1	
	CHECK	MY	29 SEP 15		
	REVIEW	MY	29 SEP 15		

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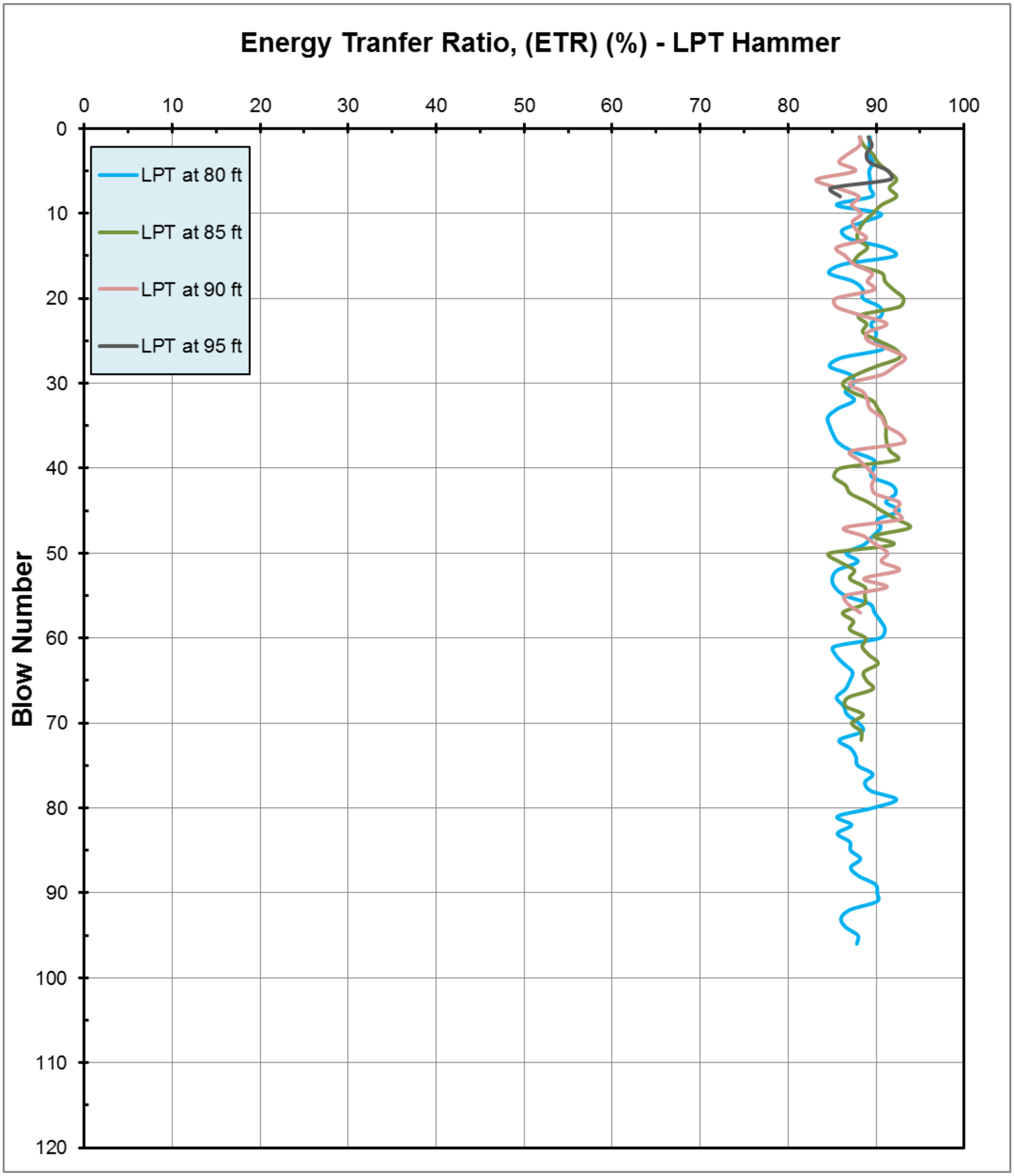

PROJECT

CDM SMITH
TRANSIENT MITIGATION OUTFALL SYSTEM
ANNACIS ISLAND, BC.

TITLE

ENERGY TRANSFER RATIO, (ETR) – LPT HAMMER
BOREHOLE BH15-01

Golder Associates

PROJECT No.	1525010		PHASE No.	
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CADD	----			
CHECK	MY	29 SEP 15	**FIGURE 2**	
REVIEW	MY	29 SEP 15		

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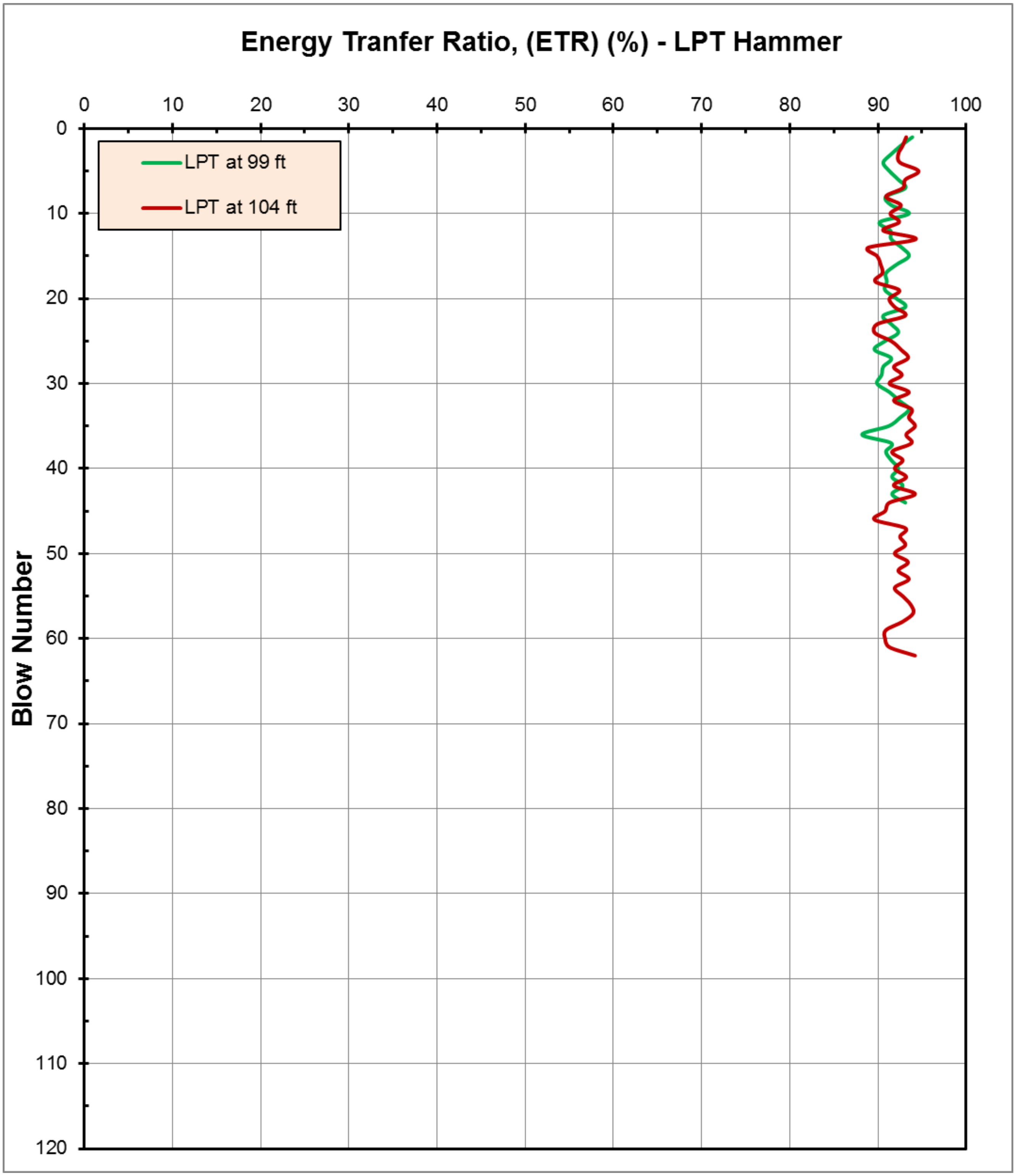

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PROJECT
CDM SMITH
TRANSIENT MITIGATION OUTFALL SYSTEM
ANNACIS ISLAND, BC.

TITLE
ENERGY TRANSFER RATIO, (ETR) – LPT HAMMER
BOREHOLE BH15-03

Golder Associates

PROJECT No. 1525010		
DESIGN	VM	23 NOV15
CADD	----	
CHECK	MY	23 NOV 15
REVIEW	MY	23 NOV15

PHASE No.
SCALE NTS
REV.0

FIGURE 3

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CDM Smith

cdmsmith.com