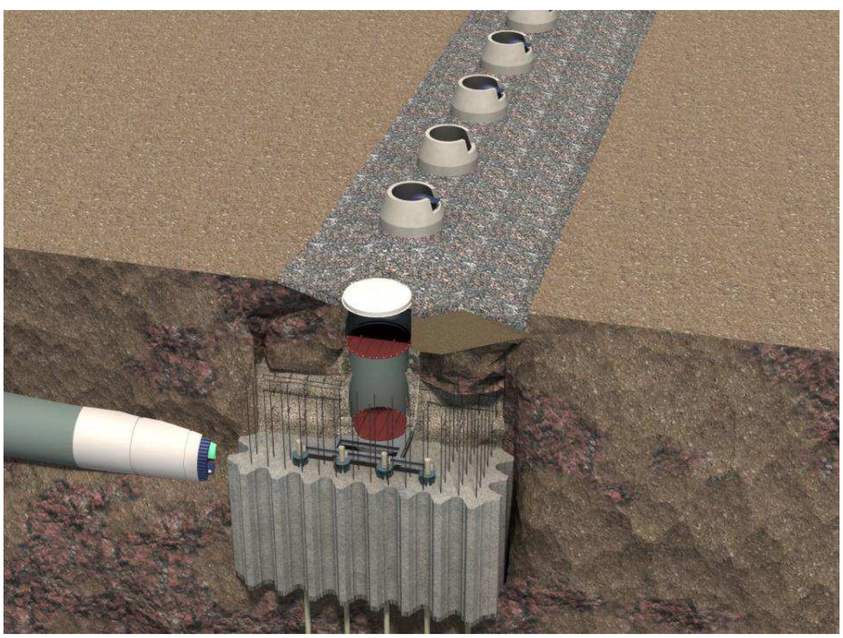
APPENDIX B
GEOTECHNICAL REPORTS

B.3: 1D Ground Response Analysis

Annacis Island WWTP New Outfall System

Vancouver Fraser Port Authority
Project and Environmental Review Application



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TECHNICAL MEMORANDUM

DATE 22 December 2017 **PROJECT No.** 1525010-031-TM-RevC

TO John Newby, PE
CDM Smith Canada ULC

CC

FROM Yannick Wittwer; Yen Bui, Viji Fernando, Trevor Fitzell **EMAIL** vfernando@golder.com

RESULTS OF THE ONE DIMENSIONAL GROUND RESPONSE ANALYSES - ANNACIS ISLAND WASTEWATER TREATMENT PLANT TRANSIENT MITIGATION AND OUTFALL, DELTA, BC

This Technical Memorandum summarizes the results of the one-dimensional (1D) ground response analyses carried out to assess the potential liquefaction of site soils along the final outfall alignment referred to as the Option 6 alignment. The analyses were carried for the design ground motions corresponding to a return period of 2,475 years consistent with both the 2010 National Building Code of Canada (NBCC) and 2015 NBCC.

This Technical Memorandum supersedes the previous draft technical memorandum, issued on May 30, 2016 summarizing the results of the preliminary 1D ground response analyses focusing on the initial western alignment. The ground response analyses were carried out based on the subsurface information collected along the Option 6 Outfall Alignment during the Phase III and IV geotechnical investigations as presented in the Draft Geotechnical Data Report (1525010-108-RevA-GDR) dated 20 September 2017. The characterizations of the site soils are as presented in the Draft Geotechnical Interpretive Report (1525010-028-RevB-GIR) dated 31 May 2017.

2D ground deformation analyses were also carried out to assess the potential liquefaction of the site soils, and the resulting lateral spreading and vertical settlements under the design ground motions consistent with both the 2010 NBCC and 2015 NBCC. The results of the 2D ground deformation analyses are summarized under separate cover. The ground motion parameters, design acceleration spectra, and the time histories related to the 2010 NBCC and 2015 NBCC ground motions can be found in the Technical Memorandum "Seismic Design Criteria and Performance Expectation – AIWWTP Transient Mitigation and Outfall System" dated 08 July 2016. This Technical memorandum should be read in conjunction with the above noted documents.

This Technical Memorandum presents the following:

- Design firm-ground spectra and acceleration-time histories corresponding to the 2010 NBCC and 2015 NBCC
- Subsurface conditions and engineering parameters along the Option 6 Outfall alignment
- Site response analyses methodology and the results of the analyses
- Estimated extent of liquefaction along the final outfall alignment corridor

1.0 DESIGN FIRM-GROUND SPECTRA AND INPUT GROUND MOTIONS

The 2,475-yr return period Uniform Hazard Response Spectra (UHRS) and the subduction earthquake spectra, provided by NRCan for the 4th and 5th generation seismic hazard models, are summarized in Table 1-1 and they are also shown in Figure 1-1.

Table: 1-1: Site-Specific Probabilistic Firm-Ground Motion Parameters (Site Class C)

Return Period (2,475 Years)	PHGA	Sa (0.2s)	Sa (0.5s)	Sa (1.0s)	Sa (2.0s)
2010 NBCC [4th generation model]	0.51 g	1.03 g	0.68 g	0.34 g	0.17 g
Subduction Earthquake [4th generation model]	0.16 g	0.37 g	0.31 g	0.17 g	0.09 g
2015 NBCC [5th generation model]	0.36 g	0.84 g	0.75 g	0.42 g	0.25 g
Subduction Earthquake [5th generation model]	0.14 g	0. 29 g	0.34 g	0.27 g	0.19 g

Note: PHGA refers to peak horizontal ground acceleration; Sa refers to spectral acceleration for a given period.

Consistent with the seismic ground motions that have been used for the Stage V expansion, three sets of ground motions were developed for the 2010 NBCC ground motions, with each set comprising two single-component time-histories to represent the crustal and inslab earthquakes, and one ground motion comprising two single-component time-histories to represent the subduction earthquakes. The time histories were matched to the design Site Class C spectra consistent with the 2010 NBCC ground motions; and they are shown on Figures 1-2a and 1-2b, for the crustal and inslab, and interface earthquakes, respectively.

Dr. Tuna Onur was retained to develop the applicable time histories based on the site-specific ground motion parameters consistent with the 2015 NBCC. A total of 11 single-component acceleration time-histories were developed to represent the crustal and inslab earthquakes. These were spectrally matched to the 2015 NBCC UHRS (Site Class C) over a period range extending from PHGA to about 2 seconds, as shown on Figure 1-3a and Figure 1-3b. A total of five single-component acceleration time-histories were developed to represent the interface earthquakes; they were spectrally matched to the interface spectrum as shown on Figure 1-3c.

2.0 SUBSURFACE CONDITIONS

The subsurface conditions at the subject site were established based on the results of the field investigations carried out along the western, central and the final Option 6 outfall alignment corridors, with a specific focus on the Option 6 alignment corridor. The results indicate that the site is underlain by fill (Unit 1) overlying overbank deposits (Unit 2) comprising clayey silt and organic silt. Unit 2 is followed by a Fraser River sand deposit (Unit 3). The Fraser River sand deposit, in turn, is underlain by an extensive marine sequence (Unit 4) comprising interlayered fine sand and clayey silt to silty clay, followed by a glacio-marine deposit (Unit 7).

The glacio-marine deposit was encountered at depths ranging from 60 to 80 m below ground surface on land, while the deposit was encountered at a depth of approximately 55 m below mudline in the offshore area. The glacio-marine deposit is inferred to be underlain by a glacial deposit comprising till-like soils. The till-like soils were encountered in the offshore area at a depth of 80 m below mudline near the Option 6 outfall alignment.

A stratigraphic profile along the Option 6 outfall alignment, including a proposed tunnel segment leading to a future shaft that will connect to the Stage V expansion, was developed and is shown on Figure 2-1. The stratigraphic profile was developed considering the test holes put down during the supplementary investigation completed along the Option 6 outfall alignment, as well as the test holes put down as part of the previous investigations along the conceptual alignments. In addition, a stratigraphic profile along the effluent tunnel leading to the effluent shaft from the outfall shaft was also developed, and is shown on Figure 2-1. All elevations shown on Figures 2-1 are with respect to the CVD28GVRD2005 datum, which is geodetic datum plus 100 metres.

The natural groundwater level at the site is expected to vary with the water level in the river, change in season, and amount of precipitation. Based on available information, the groundwater levels on land vary between Elevations 100 m and 101 m relative to the CVD28GVRD2005 datum.

3.0 LIQUEFACTION EVALUATION

Liquefaction potential of site soils was evaluated using the semi-empirical approach developed by Idriss and Boulanger (Idriss and Boulanger 2008[1]). Several approaches or frameworks have been proposed over the last 45 years for assessing the potential for liquefaction triggering. The most widely used approach has been the stress-based approach that compares the earthquake induced cyclic shear stresses normalized by the initial vertical effective stress (i.e., CSR) with the soil's cyclic shear resistance normalized by the initial vertical effective stress (i.e., CRR). Liquefaction is expected at depths where the induced cyclic shear stress exceeds the cyclic shear resistance of soil.

The procedure described above involves methods of estimating the earthquake-induced cyclic shear stress (i.e., CSR) and the in-situ CRR. The earthquake-induced CSR is often estimated via Seed's simplified method of analyses, which are recommended for depths up to 20 m. Liquefaction evaluations at greater depths require high quality site response analyses involving sufficient site characterization and taking into account the variability in the possible input ground motions.

The in-situ CRR of granular soils can be evaluated on the basis of laboratory testing of "undisturbed" field soil samples, but this would require the use of techniques such as frozen sampling if "disturbance" is to be minimized to obtain meaningful results. Consequently, semi-empirical relationships have been developed correlating the in-situ CRR of granular soils and results from in-situ tests such as SPT, CPT, and shear wave velocity (Vs), on the basis of compilations of case-histories, in which evidence of liquefaction has or has not been observed. The definition of liquefaction in this context refers to observations, in the form of ground fissures and sand boils on ground surface, which indicate that granular soils at depth must have developed excess pore water pressures and developed significant strains. The interpretation of the field observation is complicated by the fact that surface observations can be inconclusive in identifying the depths at which liquefaction probably occurred. The database associated with the case-histories is limited to depths of liquefaction up to about 15 m, and earthquake magnitudes (M) generally up to M7.5. Evidence of soil liquefaction and surface movement of soil strata related to large subduction earthquakes of the order of M8 to M9, on the West Coast of Canada, is based on paleo-seismological evidence.

Considering the limitation of the case history data, laboratory testing has been carried out to assess the key factors that influence the potential liquefaction of soils such as earthquake magnitude, overburden stress, level ground vs. sloping ground conditions, etc. The case history data supplemented with the laboratory testing is used to develop a single graph of CRR versus in-situ testing for reference conditions based on the key factors, which allow the case history data to be used for various conditions.

The details of the site response analyses and results of the liquefaction potential of soils are provided in the following sections.

[1] Idriss, I.M. and Boulanger, R.W. (2008). Soil Liquefaction During Earthquakes, EERI, Oakland, CA

3.1 Site Response Analyses

Site-specific one-dimensional (1D) ground response analyses involving propagation of ground motions from firm ground at depth, through the overburden soils to the ground surface, were carried out using the computer code SHAKE2000, developed by Geomotions LLC. In the SHAKE analyses, the non-linear and hysteretic stress-strain behaviour of the soil is modeled in the frequency domain using an equivalent linear approach with shear strain level-dependent moduli and viscous damping. Equivalence is achieved by an iterative procedure such that the moduli and damping values used are compatible with the computed strains in each layer.

SHAKE analyses were carried out to compute the variations in equivalent cyclic stress ratios (CSRs) with depth (i.e., 0.65 times the maximum cyclic shear stress ratio) for use in the assessment of the liquefaction potential corresponding to the 2,475 year ground motions consistent with the 2010 NBCC and 2015 NBCC.

1D soil columns were developed at five locations along the alignment corridor based on available subsurface information. The following sections describe the results of the site response analyses along with the input parameters used in the analyses.

3.1.1 Depth to Site Class C Ground Conditions

Vs measurements carried out within the glacio-marine deposit (Unit 7) encountered below Unit 4 indicate that Vs in this layer varied between 370 m/s and 460 m/s, which corresponds to Class C conditions.

In the absence of Vs measurements, the Class C ground conditions, especially in the effluent and the future shaft areas where Vs data at depths is not available, were established based on the mean curve suggested by Hunter et al. (1995[2]) for unconsolidated deposits within the upper 100 m of the Fraser Delta.

The site-specific acceleration time-histories corresponding to the 2010 NBCC and 2015 NBCC ground motions were applied at the Class C ground level in the site response analyses.

3.1.2 Shear Wave Velocity Profiles

The shear wave velocity profiles used in the site response analyses for the five locations are presented in Figures 3-1 through 3-5. They were generally established based on the site-specific shear wave velocity (Vs) measurements, as well as the empirical correlations, as summarized in Table 3-1.

[2] Hunter, J.A. (1995). “Shear-wave velocities of Holocene sediments, Fraser River Delta, BC, Current Research 1995A, Geological Survey of Canada, pp 29-32

Table 3-1: Summary of Shear Wave Data

SHAKE	Location	Vs Data
Column #1	Outfall Shaft	■ Downhole Vs measurements at 1 m intervals from SCPT16-05 and SCPT 16-06 to a depth of 62.5 m and 64 m below ground surface, respectively. ■ Downhole Vs measurements at 1 m intervals within SH16-05 to a depth of 90 m below ground surface. ■ Encountered Class C ground conditions with Vs measurements varying from 412 m/s to 533 m/s at a depth of 77 m below ground surface.
Column #2	Effluent Shaft	■ Inferred from empirical correlations based on CPT15-15 and Hunter et al. (1995). ■ Class C ground conditions was inferred from Hunter's curve and an average Vs of 450 m/s was used for analyses purposes in the absence of Vs measurements corresponding to the Class C conditions at a depth of 90 m below ground surface.
Column #3	Future Shaft	■ Downhole Vs measurements at 1 m intervals from SCPT16-03 and SCPT 16-04 to a depth of 63 m and 70 m below ground surface, respectively. ■ Downhole Vs measurements at 1 m intervals within SH16-07 to a depth of 88 m below ground surface. ■ Class C ground conditions was inferred from Hunter's curve and an average Vs of 450 m/s was used for analyses purposes in the absence of Vs measurements corresponding to the Class C conditions at a depth of 93 m below ground surface.
Column #4	Station 0+600, Nearshore	■ Downhole Vs measurements at 1 m intervals from SCPT16-09 to a depth of 74 m below ground surface. ■ Downhole Vs measurements at 1 m intervals within SH16-06 to a depth of 90 m below ground surface. ■ Encountered Class C ground conditions with Vs measurements varying from 364 m/s to 401 m/s at a depth of 78 m below ground surface.
Column #5	Riser Shaft	■ Downhole Vs measurements at 1 m intervals form SCPT16-10 to a depth of 36 m below mudline, where the SCPT encountered effective refusal. ■ Class C ground conditions was inferred from the nearshore location and an average Vs of 450 m/s was used for analyses purposes in the absence of Vs measurements corresponding to the Class C conditions at a depth of 61 m below ground surface.

The following correlation established by Seed (1986) was used in estimating the small strain shear modulus of the fill and sand units, where the field measurements were not available.

$$G_{max} = 21.7 \cdot Pa \cdot F \cdot [(N_1)_{60}]^{1/3} [\sigma'_m / P_a]^{1/2}$$

Where the F factors for the soil deposits are as follows:

- For the entire sand deposit at the effluent shaft location, a value of 15 was used
- For the fill layer at the onshore locations, a value of 20 was used

For Units 4 and 7 at the effluent shaft location, the Vs profile was established based on Hunter et al. (1995) as noted above. Similarly, the Vs profile for Unit 2 was established based on the Vs data available at other locations at the site.

3.1.3 Modulus Reduction and Damping Curves

The modulus reduction and damping curves considered for the ground response analyses are shown on Figure 3-6 and they are also shown on Figures 3-9 through 3-28 along with the soil profiles considered in the analyses.

The modulus reduction and damping curves published by Idriss (1970[3]) were used to model the shear and damping characteristics of the fill and Fraser River sand. The marine and the glacio marine deposits were modeled using the modulus reduction and damping curves developed by Vucetic and Dobry (1991[4]).

3.1.4 Results of Site Response Analyses

The results of site response analyses indicate that the CSR profiles computed for the crustal and inslab motions are generally higher than the CSR profiles for the subduction motions when considering the 2010 NBCC seismic hazard parameters as shown on Figure 3-7. Considering the significant difference in the CSR profiles and that the potential liquefaction of soils is expected to be governed by the crustal and inslab ground motions, the site response analyses were limited the crustal and inslab ground motions under the design ground motions consistent with the 2010 NBCC In contrast, the CSR profiles computed for the subduction motions, when considering the 2015 NBCC seismic hazard parameters, are lower in the upper 30 m and higher below 30 m depth, when compared with the corresponding crustal and inslab earthquake motions. This is primarily due to the higher earthquake magnitude and higher spectral accelerations at the resonance period of the soil column, which is approximately 1 second. A comparison of the CSR profiles associated with the 2015 NBCC ground motions for a typical location is shown on Figure 3-8.

The variation of the computed equivalent cyclic stress ratio (CSR), peak ground acceleration, and cyclic shear strain with depth for the design ground motions corresponding to the crustal and inslab earthquakes consistent with the 2010 NBCC are shown on Figures 3-9 through 3-13.

The variation of the CSR, peak ground acceleration, and cyclic shear strain with depth for the design ground motions associated with the 2015 crustal and inslab earthquakes are shown on Figures 3-14 through 3-23, while those for the subduction earthquakes are shown on Figures 3-24 through 3-28.

The predicted peak ground surface accelerations for the 2010 NBCC and 2015 NBCC motions are summarized in Table 3-2.

Table 3-2: Summary of Ground Surface Accelerations Computed Using SHAKE – 2,475 Year Demand

Location	Peak Ground Acceleration (g)					
	2010 Crustal and Inslab		2015 Crustal and Inslab		2015 Subduction	
	Class C	Surface	Class C	Surface	Class C	Surface
Outfall Shaft	0.51	0.24 – 0.32	0.36	0.25 – 0.38	0.14	0.15 - 0.18
Effluent Shaft	0.51	0.20 – 0.29	0.36	0.22 – 0.37	0.14	0.14 – 0.17
Future Shaft	0.51	0.20 – 0.29	0.36	0.25– 0.36	0.14	0.14 – 0.17
Nearshore	0.51	0.20 – 0.28	0.36	0.20 – 0.34	0.14	0.14 – 0.17
Riser Shaft	0.51	0.31 – 0.37	0.36	0.31 – 0.51	0.14	0.16 – 0.25

[3] Seed, H.B. and Idriss, I.M., (1970). Soil Moduli and Damping Factors for Dynamic Response Analysis, Report No. EERC70-10, University of California, Berkeley, December.

[4] Vucetic, M. and Dobry, R. (1991). Effect of Soil Plasticity on Cyclic Response, Journal of Geotechnical Engineering, ACSE, 17(1), pp 89-107.

3.2 Liquefaction Potential of Fraser River Sand

Liquefaction potential of the sand deposit was evaluated based on the following approaches.

- Approach 1: Based on Standard Penetration Test (SPT) blow count values using Boulanger and Idriss 2014[5]
- Approach 2: Based on Cone Penetration Test (CPT) tip resistance using Boulanger and Idriss 2015[6]
- Approach 3: Based on Vs measurements using Kayen et al. (2013[7])

In accordance with the recommendations made by the Task Force (2007[8]) (formed to provide geotechnical design guidelines for buildings on liquefiable sites) an earthquake of magnitude M7 is to be considered for the crustal and inslab earthquakes for the liquefaction evaluation corresponding to the 2010 NBCC ground motions. Based on the PGA-based de-aggregation of the site-specific seismic hazard for the 2015 NBCC motions, an earthquake magnitude of M7 was considered for the crustal and inslab earthquakes, and an earthquake magnitude of M9 was considered for the subduction earthquake.

The overall liquefaction evaluation along the outfall alignment corridor, presented herein, was carried out following Approach 1. Approaches 2 and 3 were followed at one location for comparison purposes. The details of the approaches followed along with the results are presented in the following sections.

3.2.1 SPT-Based Liquefaction Assessment

The SPT based liquefaction triggering correlations provided in the Monograph (Idriss and Boulanger 2008) were further updated by Boulanger and Idriss in 2014 with revised correlation for the magnitude scaling factor (MSF) extending to earthquake magnitudes up to M9. The database has also been updated with an additional 24 case histories; however, there is no change to the liquefaction triggering chart from its earlier version.

The liquefaction assessment based on SPTs consisted of the following steps:

- Step 1: Compute standard penetration test values normalized to an effective stress level of 100 kPa corrected for fines content SPT $(N_1)_{60cs}$ from the measured CPT and SPT data. The fines contents computed using the Robertson and Wride (1998[9]) method was utilized to establish a continuous profile of corrected SPT $(N_1)_{60cs}$ from the CPT data. The Robertson and Wride method correlates the fines content values inferred from CPT data with the measured values (cf. sieve analyses) well. The SPT $(N_1)_{60cs}$ values were also computed from the measured SPT blow count values and fines contents from the sieve analyses. Further details on the interpreted SPT$(N_1)_{60cs}$ profiles along the outfall alignment corridor were provided in a draft geotechnical interpretive report dated May 31, 2017;
- Step 2: Compute Cyclic Resistance Ratio (CRR) profiles for the reference conditions corresponding to M7.5 and an effective stress of 100 kPa for the SPT$(N_1)_{60cs}$ profiles based on the liquefaction triggering chart developed by Idriss and Boulanger (2014);

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5 Boulanger, R. W., and Idriss, I. M. (2014). CPT and SPT Based Liquefaction Triggering Procedures, Rep. No. UCD/CGM-14/01, Univ. of California, Davis, CA.
6 Boulanger, R.W., and Idriss, I.M. (2015). CPT Based Liquefaction Triggering Procedure, JGGE, ASCE, 04015065, 10.1061/(ASCE)GT.1943-5606.0001388
7 Kayen, R., Moss, R.E.S., Thompson, E.M., Seed, R.B., Cetin, K.O., Der Kiureghian, A., Tanaka, Y., and Tokimatsu, K. (2013), Shear Wave Velocity Based Probabilistic and Deterministic Assessment of Cyclic Soil Liquefaction Potential, JGGE, ASCE, 139(3), pp 407-419.
8 Task Force Report (2007), Geotechnical Guidelines for Buildings on Liquefiable Sites in Accordance with NBCC 2005 in Greater Vancouver Region.
9 Robertson, P.K. and Wride, C.E., (1998). Evaluating Cyclic Liquefaction Potential using the CPT, Canadian Geotechnical Journal, Vol. 35, No. 3.

- Step 3: Obtain equivalent cyclic stress ratio (CSR) profiles for the design earthquakes consistent with the 2010 NBCC and 2015 NBCC seismic hazard parameters from the site response analyses as noted above. The average CSR profiles from earthquake records was used for each scenario;
- Step 4: Apply appropriate magnitude scaling factor (MSF) to the CSR profiles to obtain the scaled CSR profiles corresponding to M7.5. It is noted that the MSF varied between 1.0 and 1.1 for the crustal an inslab earthquakes associated with both the 2010 NBCC and 2015 NBCC. The MSF for the subduction earthquakes consistent with the 2015 NBCC varied between 0.7 and 0.9. A scaling factor is also applied to account for variations in the effective overburden stress. ; and,
- Step 5: Compare scaled CSR with CRR for each design earthquake and liquefaction is expected to occur when the scaled CSR is higher than the CRR.

Figures 3-29 through 3-33 illustrate the extent of liquefaction at the five locations along the outfall alignment corridor, where the site response analyses were carried out. The extent of liquefaction was established based on a Factor of Safety (FoS) against liquefaction of 1.0 (i.e., a ratio between CSR and CRR) as shown on the figures. It is noted that although a FoS of 1 was used for the purpose of the liquefaction evaluation, a higher FoS about 1.3 is often used to limit the excess pore pressure ratio within the liquefiable deposit to be less than 40%. An excess pore pressure ratio higher than 40% may lead to some strength and stiffness reductions along with ground displacements, even though the soils are not liquefied. A similar FoS was considered in the liquefaction evaluation carried out for the Stage V expansion.

The equivalent SPT $(N_1)_{60}cs$ profiles estimated from the field data along with the required SPT $(N_1)_{60}cs$ profiles based on the triggering correlation for the design ground motions consistent with the 2010 NBCC and 2015 NBCC were also shown on the Figures 3-29 through 3-33 for comparison purposes. Figure 3-34 illustrates the extent of liquefaction both vertically and laterally based on the design ground motions consistent with the 2010 NBCC and 2015 NBCC.

The results of the assessment indicate that the upper 22 m to 36 m of the sand deposit at the on-land locations are considered potentially liquefiable under the 2010 NBCC crustal and inslab ground motions. The potential liquefaction depth increases from the upper 40 m to the full depth sand deposit for the crustal and inslab motions at the on-land locations associated with the 2015 NBCC. The entire sand deposit at the riser shaft is considered potentially liquefiable under the 2010 NBCC and 2015 NBCC interface ground motions. It is noted that there are localised zones with a slightly larger FoS against liquefaction and they are generally considered as potentially liquefiable for the purpose of liquefaction evaluation.

3.2.2 Extent of Liquefaction Comparison – Other Approaches

The liquefaction evaluation was also carried out using Approaches 2 and 3 for comparison purposes as part of the preliminary analyses completed previously focusing on the western alignment and it is presented herein for completeness. This comparison was carried out for a typical location (i.e., SCPT16-05) for illustration purposes considering the 2015 subduction motions.

It is noted that the CPT-based liquefaction assessment (Approach 2) provided in the Monograph (Idriss and Boulanger 2008) was further updated by Boulanger and Idriss in 2015. This includes changes in the magnitude scaling factor (MSF), liquefaction triggering curve, and fine content corrections for CPT. This is a very recent update and the use of this approach in the current practice, in our opinion, is very limited at this time.

The Vs based liquefaction assessment (Approach 3) is generally considered as a screening level tool primarily due to its lack of sensitivity to relative density (D_r) of cohesionless soils (Idriss & Boulanger, 2008). Note that a relative density varying from 30% to 80%, which can control the potential from generally liquefiable to non-liquefiable soils, may have an increment factor of 1.4 in terms of the shear wave velocity. The Vs-based liquefaction evaluation developed by Kayen et al. (2013), which is an update of the approach developed by Chen et al. (2008) was used. The Vs approach is limited to a maximum overburden stress of 200 kPa, which is equivalent to a depth of about 20 m at the subject site. However, for comparison purposes, the liquefaction evaluation was extended to the depth of the potentially liquefiable soils at the site.

Figure 3-35 shows the potential liquefaction of the sand deposit based on the liquefaction evaluation approaches noted above including the SPT based approach. The results of the assessment generally indicate a deeper liquefaction estimate by the other two approaches compared to the SPT-based approach.

4.0 CLOSURE

We trust that the information presented in this Technical Memorandum is sufficient for your immediate requirements. Please do not hesitate to contact us if you have questions or require clarification of contents.

Yours truly,

GOLDER ASSOCIATES LTD.

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Reviewed by:

Trevor Fitzell, PEng
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YEW/VF/TPF/le

Attachments:

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Figure 3-12: Results of Site Response Analyses 2010 NBCC Crustal & Inslab - Nearshore
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Figure 3-14: Results of Site Response Analyses 2015 NBCC Crustal – Outfall Shaft
Figure 3-15: Results of Site Response Analyses 2015 NBCC Crustal – Effluent Shaft
Figure 3-16: Results of Site Response Analyses 2015 NBCC Crustal – Future Shaft
Figure 3-17: Results of Site Response Analyses 2015 NBCC Crustal - Nearshore
Figure 3-18: Results of Site Response Analyses 2015 NBCC Crustal – Riser Shaft
Figure 3-19: Results of Site Response Analyses 2015 NBCC Inslab – Outfall Shaft
Figure 3-20: Results of Site Response Analyses 2015 NBCC Inslab – Effluent Shaft
Figure 3-21: Results of Site Response Analyses 2015 NBCC Inslab – Future Shaft
Figure 3-22: Results of Site Response Analyses 2015 NBCC Inslab - Nearshore
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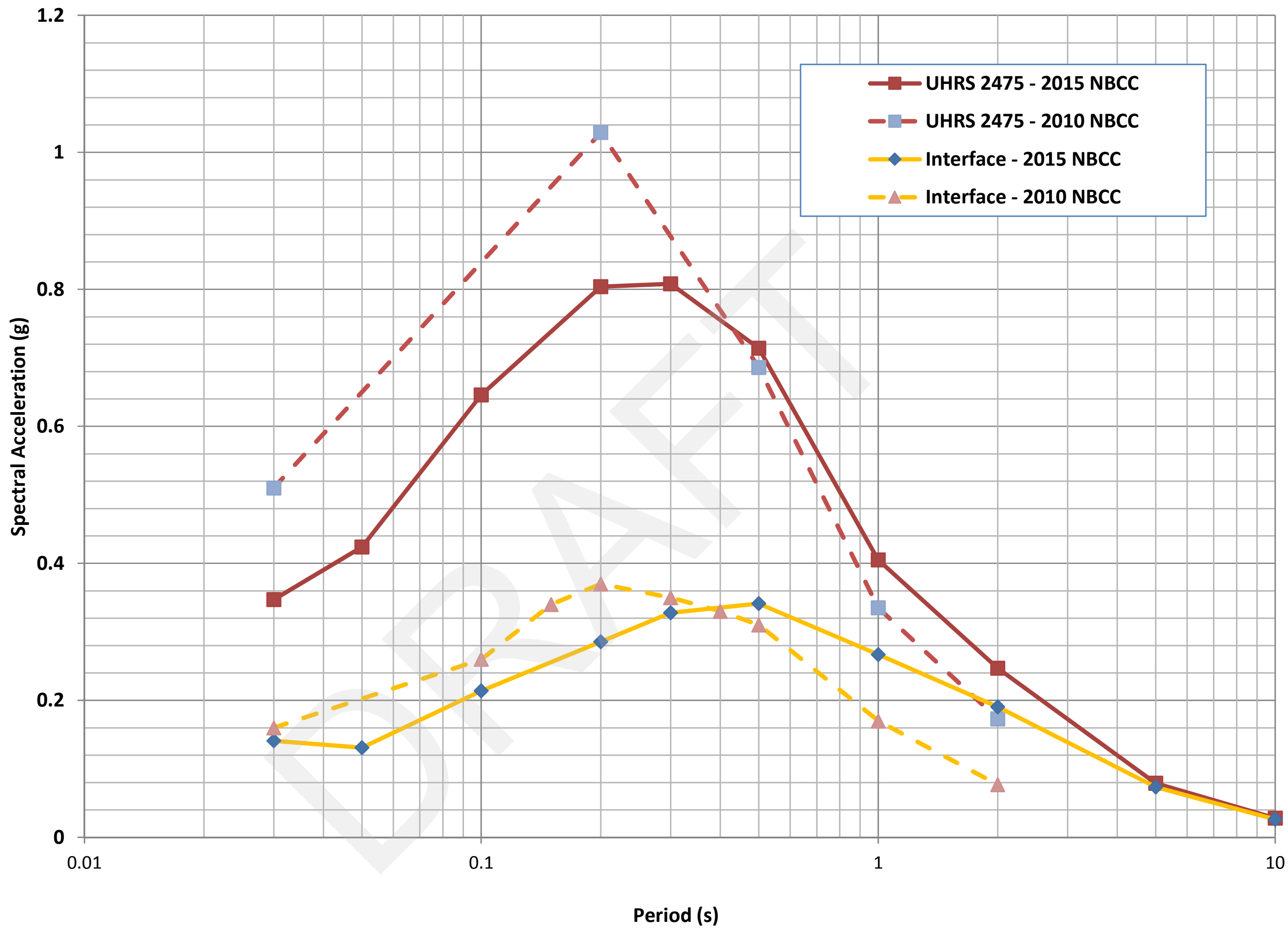

DRAFT

Note:
Acceleration response spectra for 5% damping

CLIENT	CDM SMITH CANADA ULC	PROJECT	AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC
CONSULTANT	Golder Associates	TITLE	Acceleration Response Spectra 2010 NBCC and 2015 NBCC
YYYY-MM-DD	19 DEC 2017	PROJECT No.	1525010
PREPARED	YEW	PHASE	2100
DESIGN	YEW	Rev	C
REVIEW	----	FIGURE	1-1
APPROVED	----		

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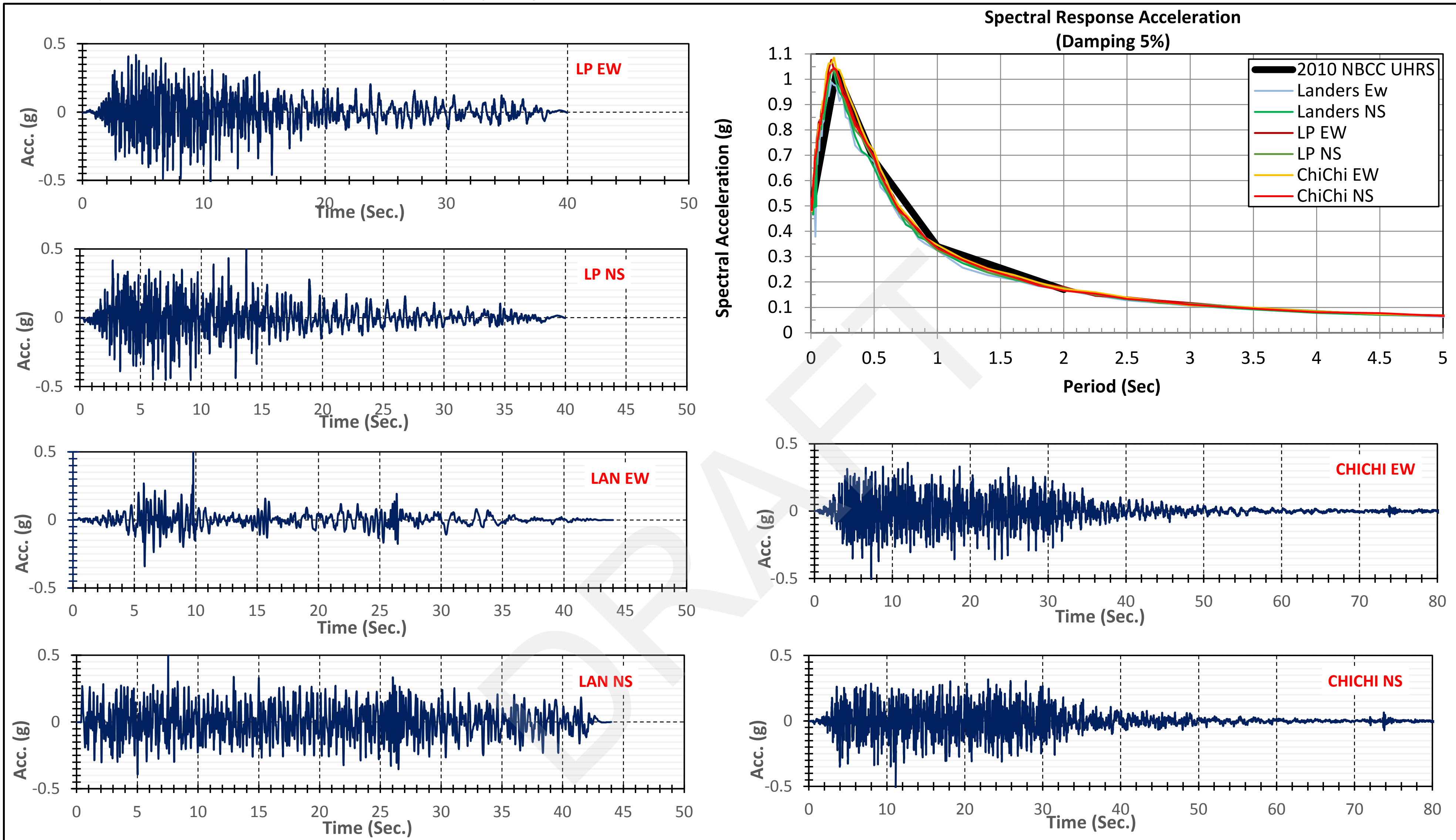


CLIENT

CDM SMITH CANADA ULC

PROJECT

AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT

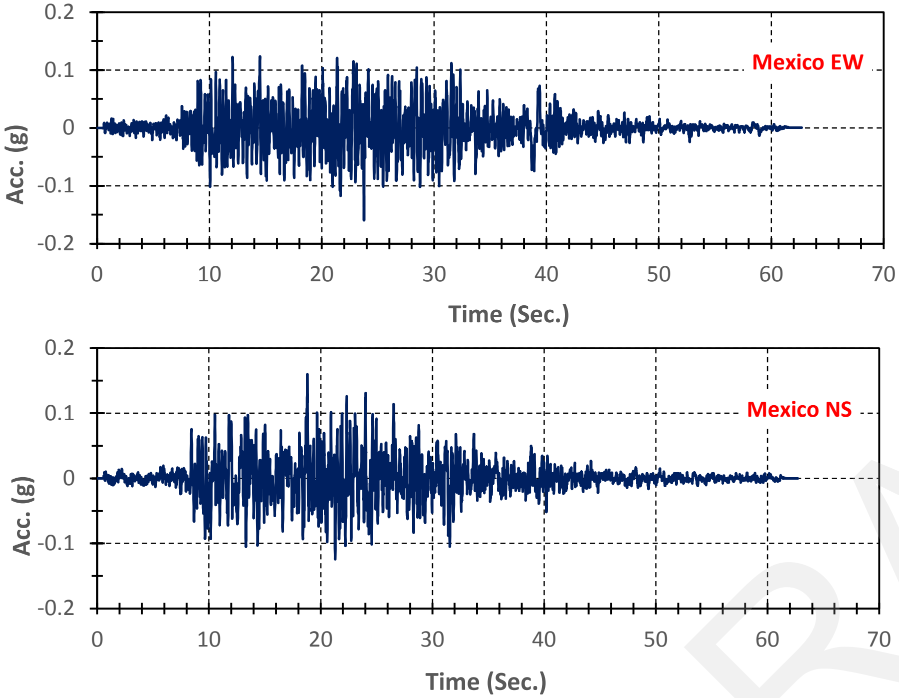
Golder Associates

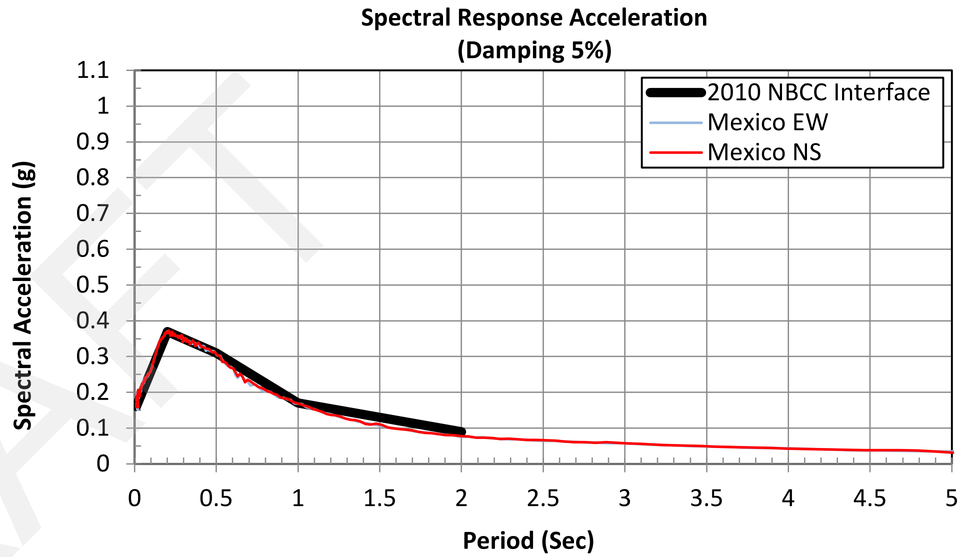
YYYY-MM-DD	20 DEC 2017
PREPARED	MSK
DESIGN	MSK
REVIEW	----
APPROVED	---

TITLE

ACCELERATION TIME HISTORIES
2010 NBCC – CRUSTAL/INSLAB

PROJECT No.	Phase	Rev	FIGURE
1525010	2100	C	1-2a





CLIENT
CDM SMITH CANADA ULC

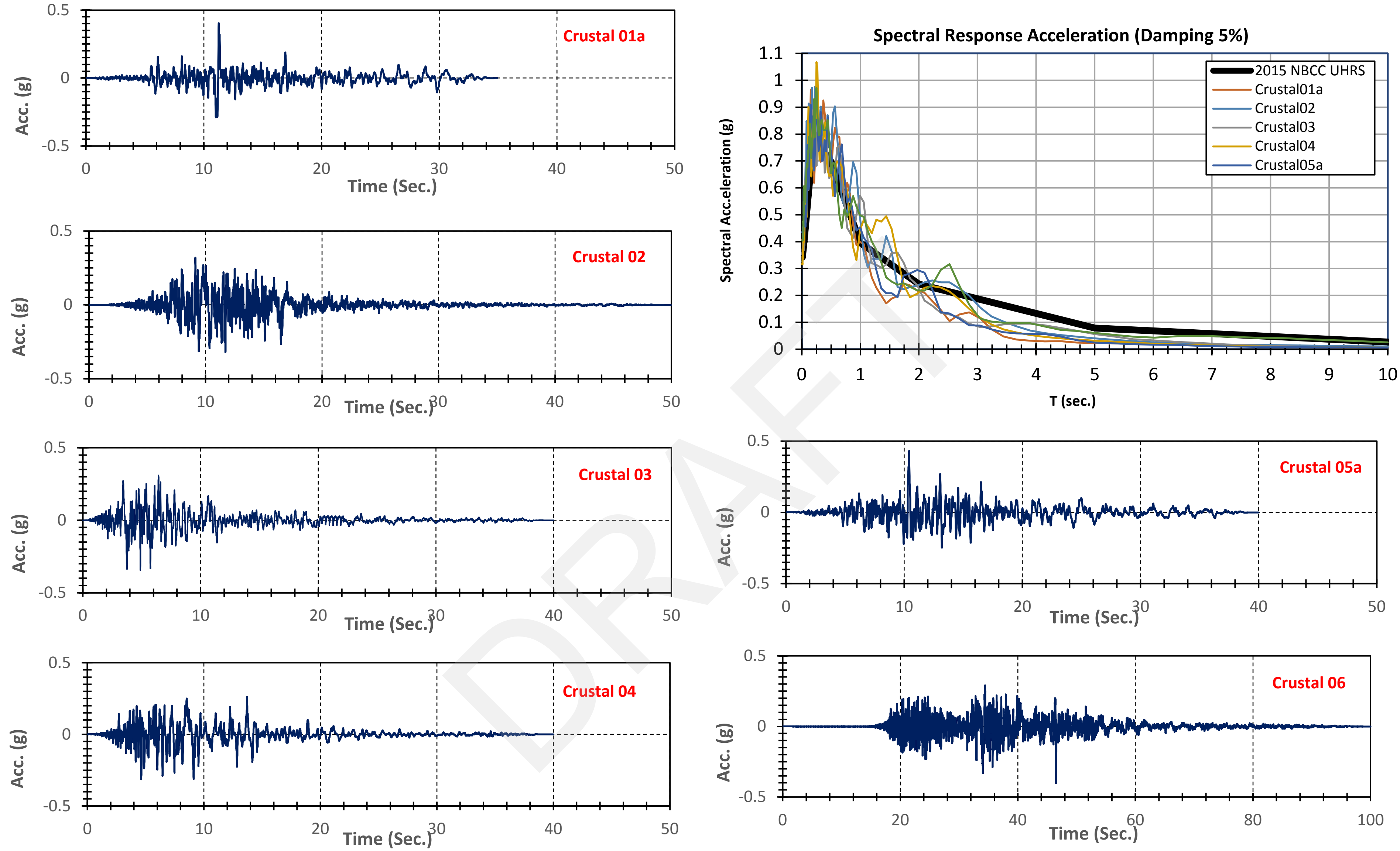
CONSULTANT
Golder Associates

YYYY-MM-DD	20 DEC 2017
PREPARED	MSK
DESIGN	MSK
REVIEW	----
APPROVED	---

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

TITLE
ACCELERATION TIME HISTORIES
2010 NBCC - INTERFACE

PROJECT No.	Phase	Rev	FIGURE
1525010	2100	C	1-2b



CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT

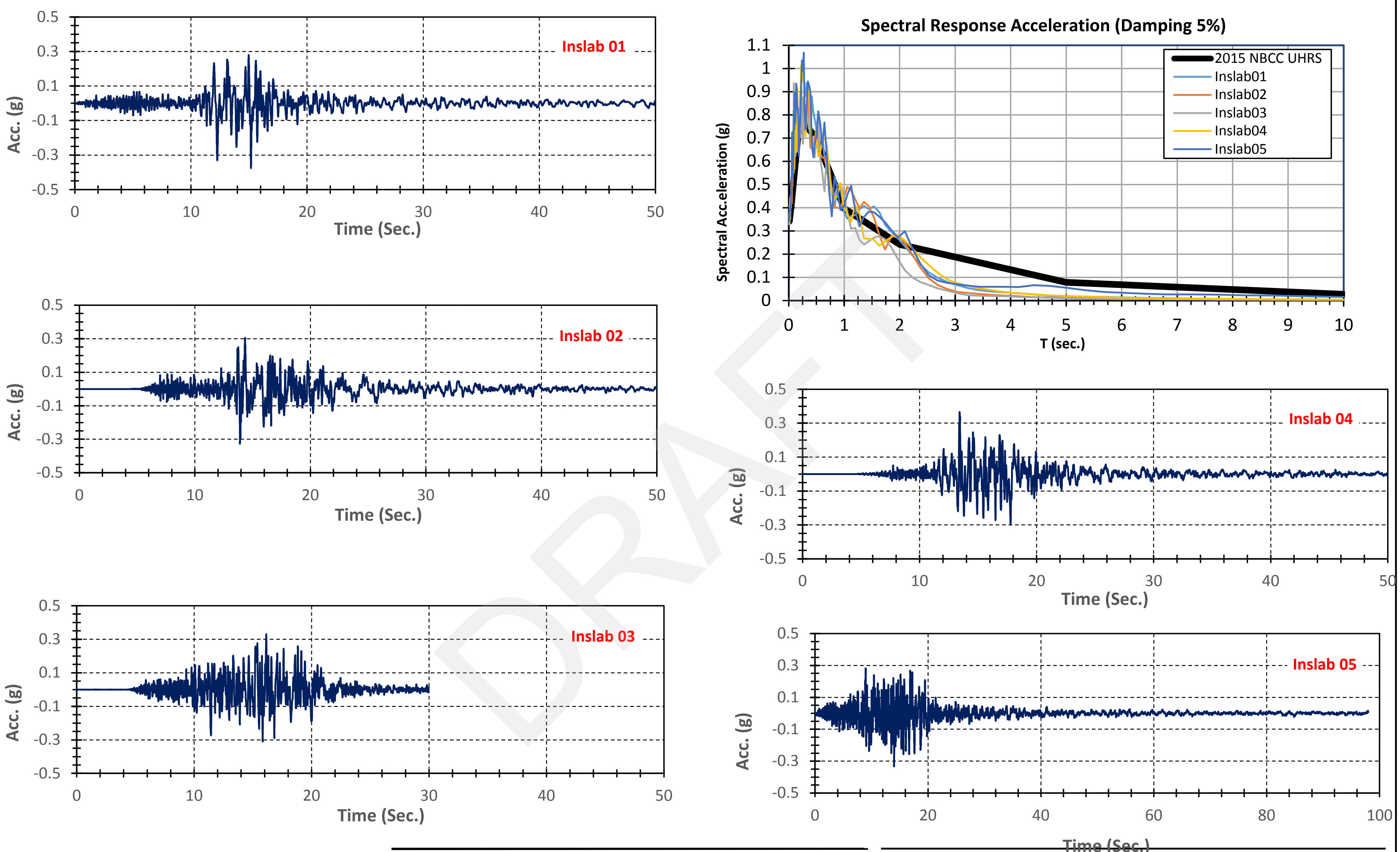
Golder Associates

YYYY-MM-DD	20 DEC 2017
PREPARED	MSK
DESIGN	MSK
REVIEW	----
APPROVED	---

TITLE
ACCELERATION TIME HISTORIES
2015 NBCC – CRUSTAL

PROJECT No.	Phase	Rev	FIGURE
1525010	2100	C	1-3a

Path: O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev C\Figures



CLIENT

CDM SMITH CANADA ULC

CONSULTANT

Golder Associates

YYYY-MM-DD	20 DEC 2017
PREPARED	MSK
DESIGN	MSK
REVIEW	----
APPROVED	---

PROJECT

AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

TITLE

ACCELERATION TIME HISTORIES
2015 NBCC - INSLAB

PROJECT No.	Phase	Rev	FIGURE
1525010	2100	C	1-3b

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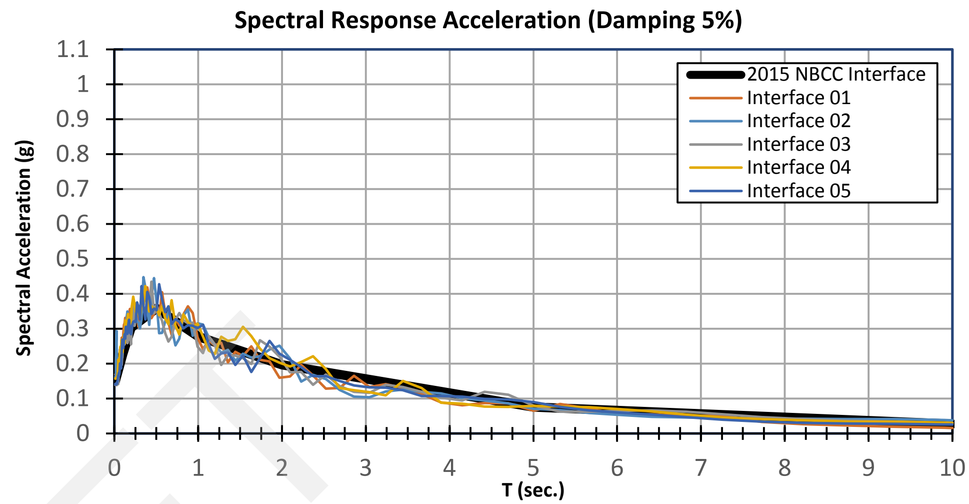

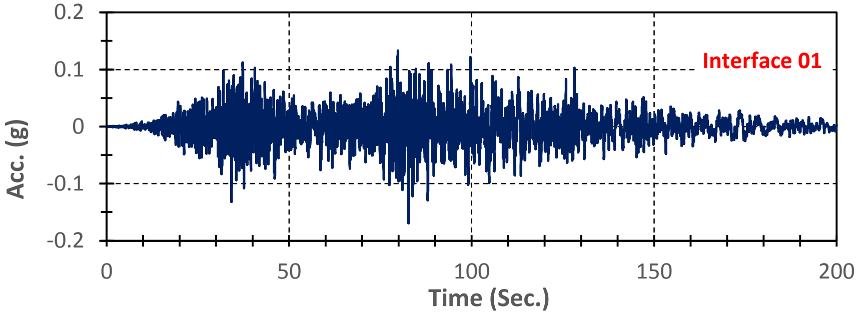

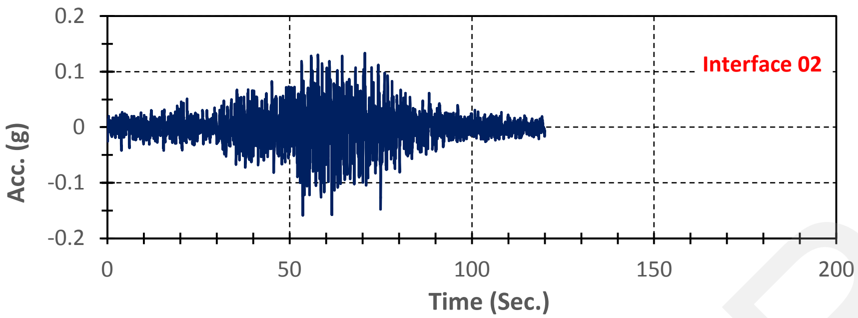

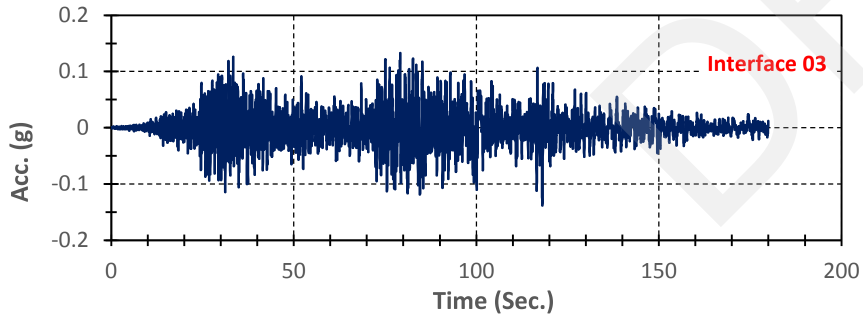

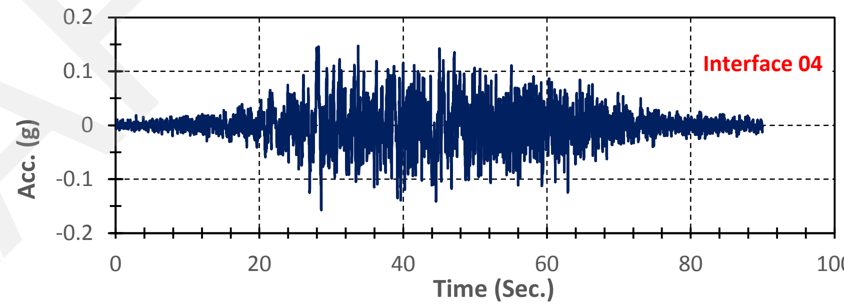

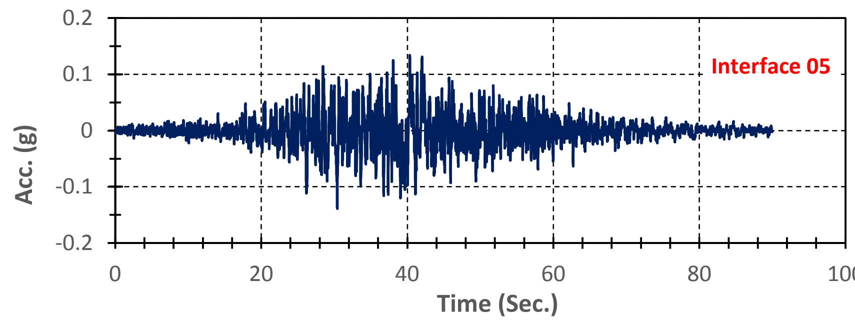

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CDM SMITH CANADA ULC

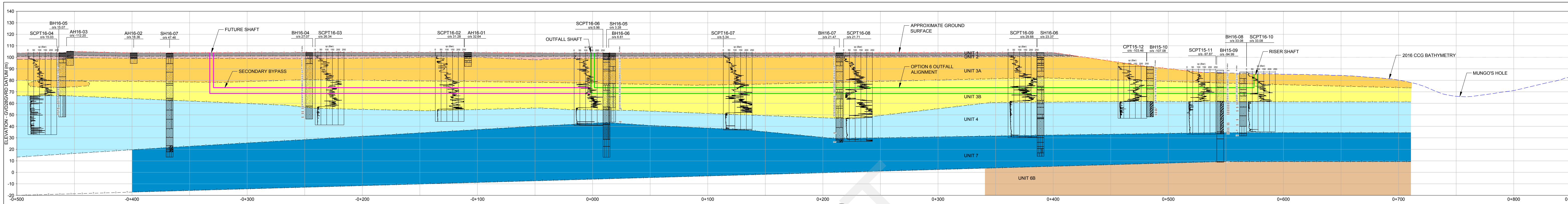
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT
Golder Associates

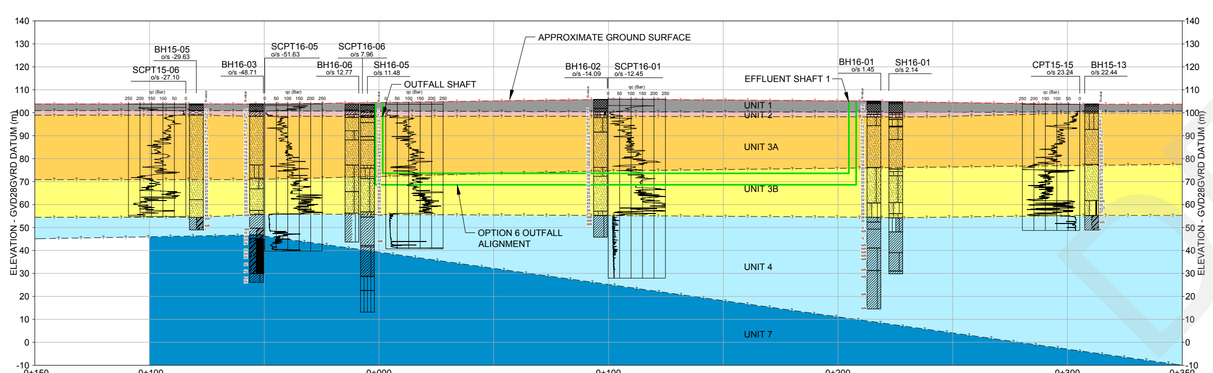
YYYY-MM-DD	20 DEC 2017
PREPARED	MSK
DESIGN	MSK
REVIEW	----
APPROVED	---

TITLE
ACCELERATION TIME HISTORIES
2015 NBCC - INTERFACE

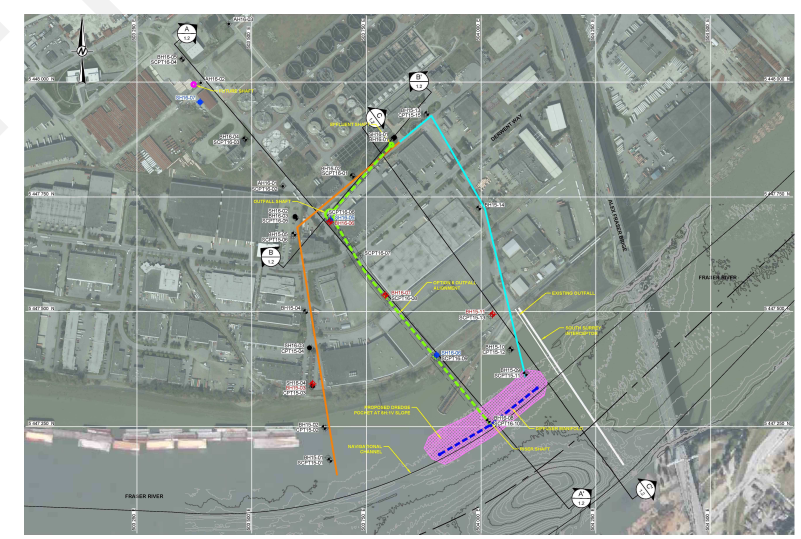
PROJECT No.	Phase	Rev	FIGURE
1525010	2100	C	1-3c



SCALE 1:1,000 m A-A' 1.1 STRATIGRAPHIC PROFILE



SCALE 1:1,000 m B-B' 1.1 STRATIGRAPHIC PROFILE



PLAN
APPROXIMATE SCALE: 1:5,000m

DATA CONCERNING THE VARIOUS STRATA HAVE BEEN OBTAINED AT TEST HOLE LOCATIONS ONLY. THE SOIL STRATIGRAPHY BETWEEN TEST HOLES HAS BEEN INFERRED FROM GEOLOGICAL EVIDENCE AND MAY VARY FROM THAT SHOWN.

LEGEND

TEST HOLE RECORD SHOWING SOIL CONDITIONS
(FOR DETAILED GEOTECHNICAL INFORMATION REFER TO RECORD OF BOREHOLE)

BH15-03 – DENOTES TEST HOLE TYPE, INVESTIGATION YEAR AND ID NUMBER
o/s 21.14 – DENOTES PERPENDICULAR DISTANCE FROM TEST HOLE TO SECTION LINE IN METRES
SPT N-value
SPT - DENOTES STANDARD PENETRATION TEST BLOW COUNT (BLOWS/0.3m)

- SONIC HOLE LOCATION
- BOREHOLE LOCATION
- AUGERHOLE LOCATION
- (SEISMIC) CONE PENETRATION TEST LOCATION

SOIL LITHOLOGY

- PEAT (PT)
- ORGANIC SILT (OL)
- ORGANIC SILT (OH)
- SILTY CLAY (CL)
- SILTY CLAY (CI)
- CLAY (CH)
- CLAYEY SILT (MH)
- CLAYEY SILT OR SILT (ML)
- CLAYEY SAND (SC)
- SAND - WELL GRADED (SW)
- SILTY SAND (SM)
- SAND - POORLY GRADED (SP)
- CLAYEY GRAVEL (GC)
- SILTY GRAVEL (GM)
- GRAVEL - POORLY GRADED (GP)
- GRAVEL - WELL GRADED (GW)

qc (Bar) 0 50 100 150 200 250 – DENOTES CONE PENETRATION TEST TIP RESISTANCE (Bar)

STRATIGRAPHY LEGEND

- UNIT 1 - FILL
- UNIT 2 - OVERBANK DEPOSITS
- UNIT 3A - FRASER RIVER SAND (LOOSE TO COMPACT)
- UNIT 3B - FRASER RIVER SAND (COMPACT TO DENSE)
- UNIT 4 - MARINE DEPOSIT
- UNIT 6B - GLACIAL DEPOSITS
- UNIT 7 - GLACIOMARINE DEPOSIT

NOTES

1. COORDINATES ARE IN UTM NAD83 ZONE 10 AND CONVERTED TO GROUND LEVEL USING A COMBINED SCALE FACTOR OF 10397558.
2. ELEVATIONS ARE IN METRES AND REFER TO CVD28GVRD - 100 METRES PLUS GEODETIC DATUM.
3. STRATIGRAPHIC PROFILE ALONG THE OPTION 6 OUTFALL ALIGNMENT WAS DEVELOPED BASED ON ENGINEERING JUDGEMENT CONSIDERING THE AVAILABLE DATA ALONG THE WESTERN AND CENTRAL ALIGNMENTS
4. SECTION C-C' IS SIMILAR TO SECTION A-A' WITH A DIFFERENCE IN TOPOGRAPHY, SPECIFICALLY IN THE OFFSHORE AREA.

REFERENCES

1. NAVIGATIONAL CHANNEL, ORTHOPHOTO AND GROUND SURVEY DATA PROVIDED BY BLACK & VEATCH.
FILE: ANNACISNAD27Z10GRND.TIF, ANNACIS-RIVER.TIF, C000A_XXXXX-1.DWG
2. 2016 CCG BATHYMETRY SURVEY AND OPTION 6 ALIGNMENT PROVIDED BY CDM SMITH CANADA ULC ON MAY 19, 2016. FILE: C201072016.DWG.
3. 60% DETAIL DESIGN DRAWING OBTAINED FROM CDM SMITH.

DRAFT

0 50 100
1:1,000 METRES

CLIENT
CDM SMITH

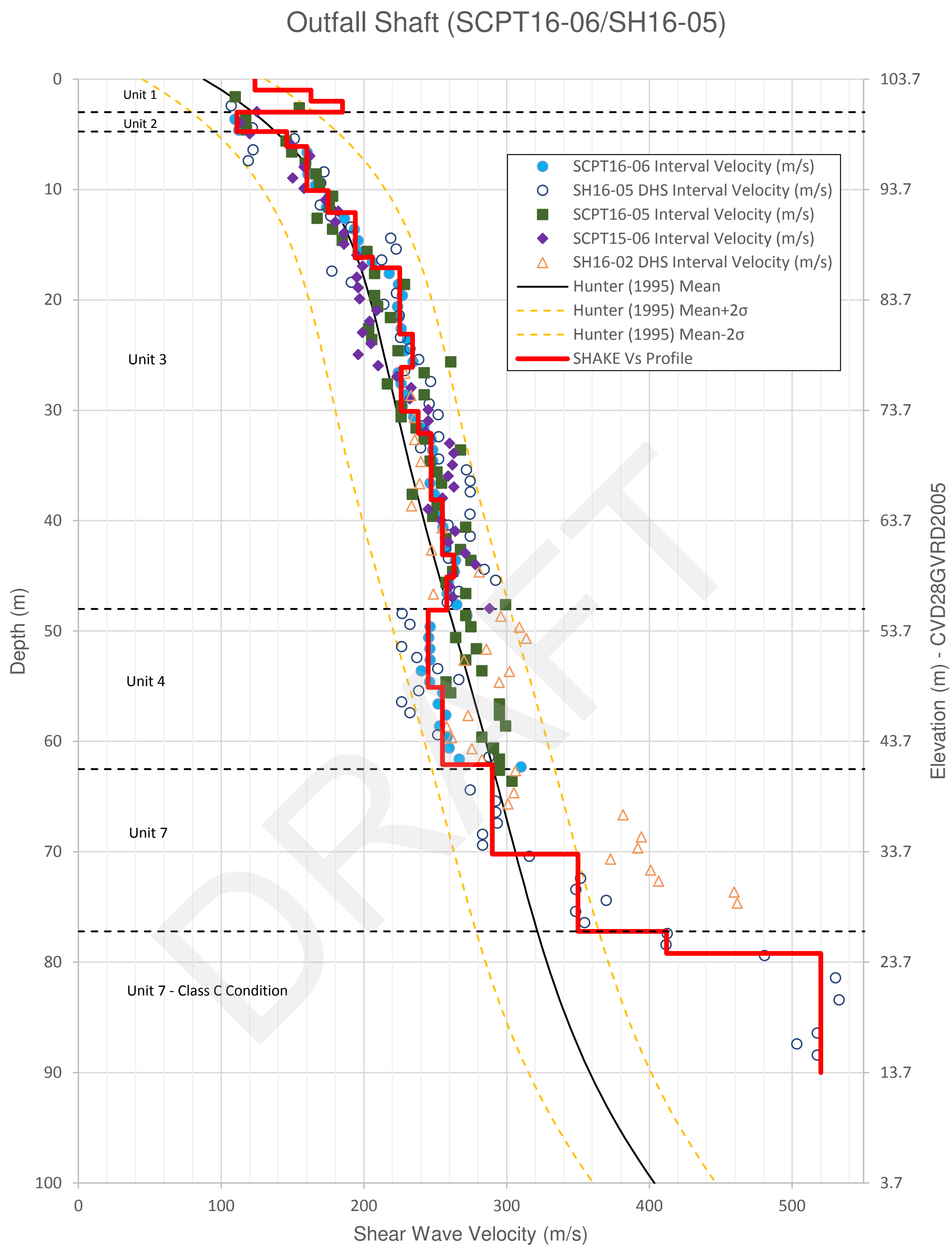
CONSULTANT
Golder Associates

YYYY-MM-DD	2017-12-22
DESIGNED	Y. WITTWER
PREPARED	S. REDDY
REVIEWED	V. FERNANDO
APPROVED	V. FERNANDO

PROJECT
ANNACIS ISLAND WWTP TRANSIENT MITIGATION AND OUTFALL
DELTA, B.C.

TITLE
STRATIGRAPHIC PROFILES - OPTION 6 OUTFALL ALIGNMENT

PROJECT NO.	PHASE/TASK	REV.	FIGURE
1525010	2200	A	2-1



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CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

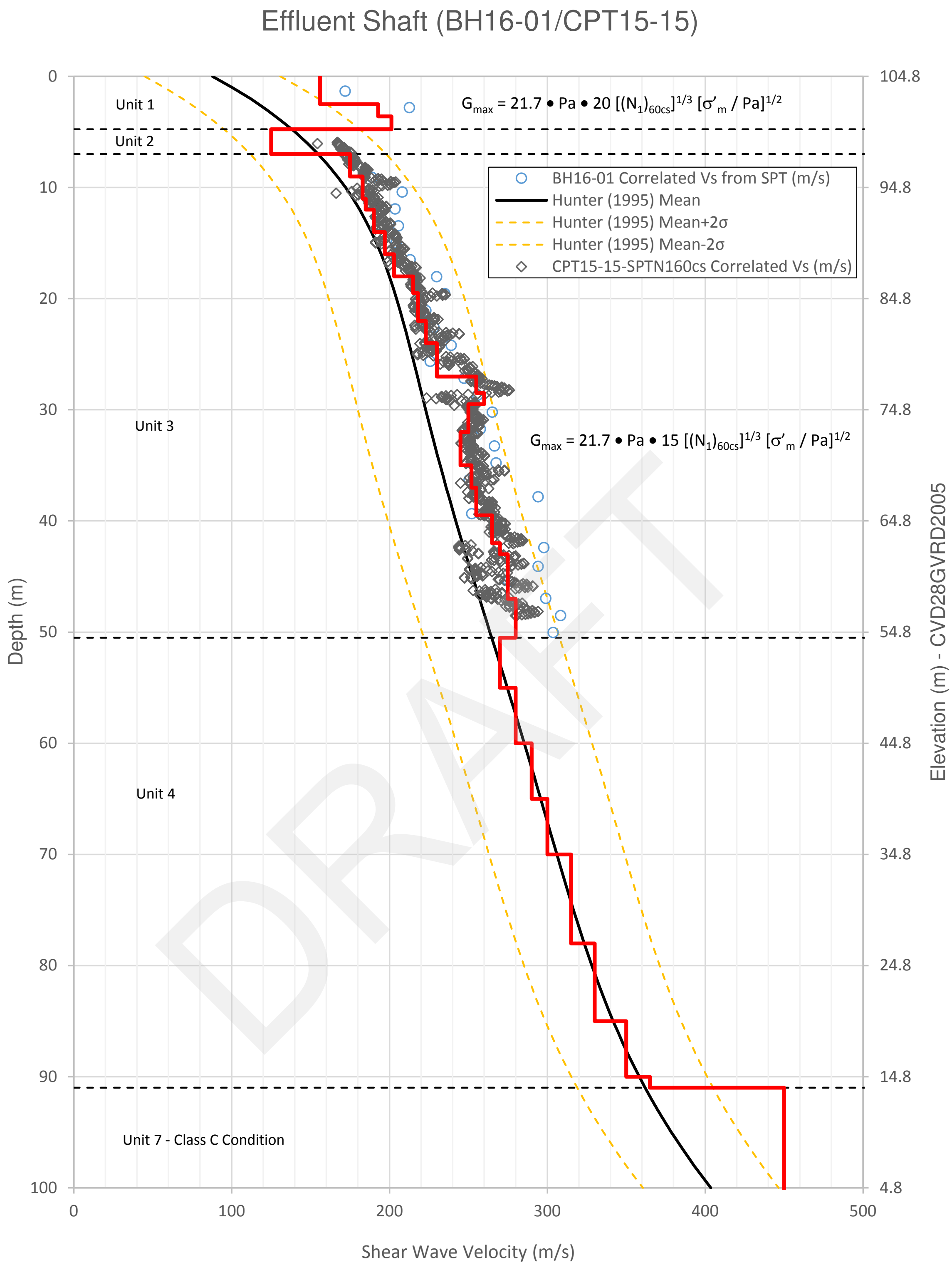
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YEW
REVIEW	---
APPROVED	---

TITLE
SHEAR WAVE VELOCITY PROFILE – OUTFALL SHAFT

PROJECT No	PHASE	REV	FIGURE
1525010	2000	C	3-1

Path: O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



DRAFT

CLIENT	PROJECT
CDM SMITH CANADA ULC	AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

CONSULTANT: Golder Associates

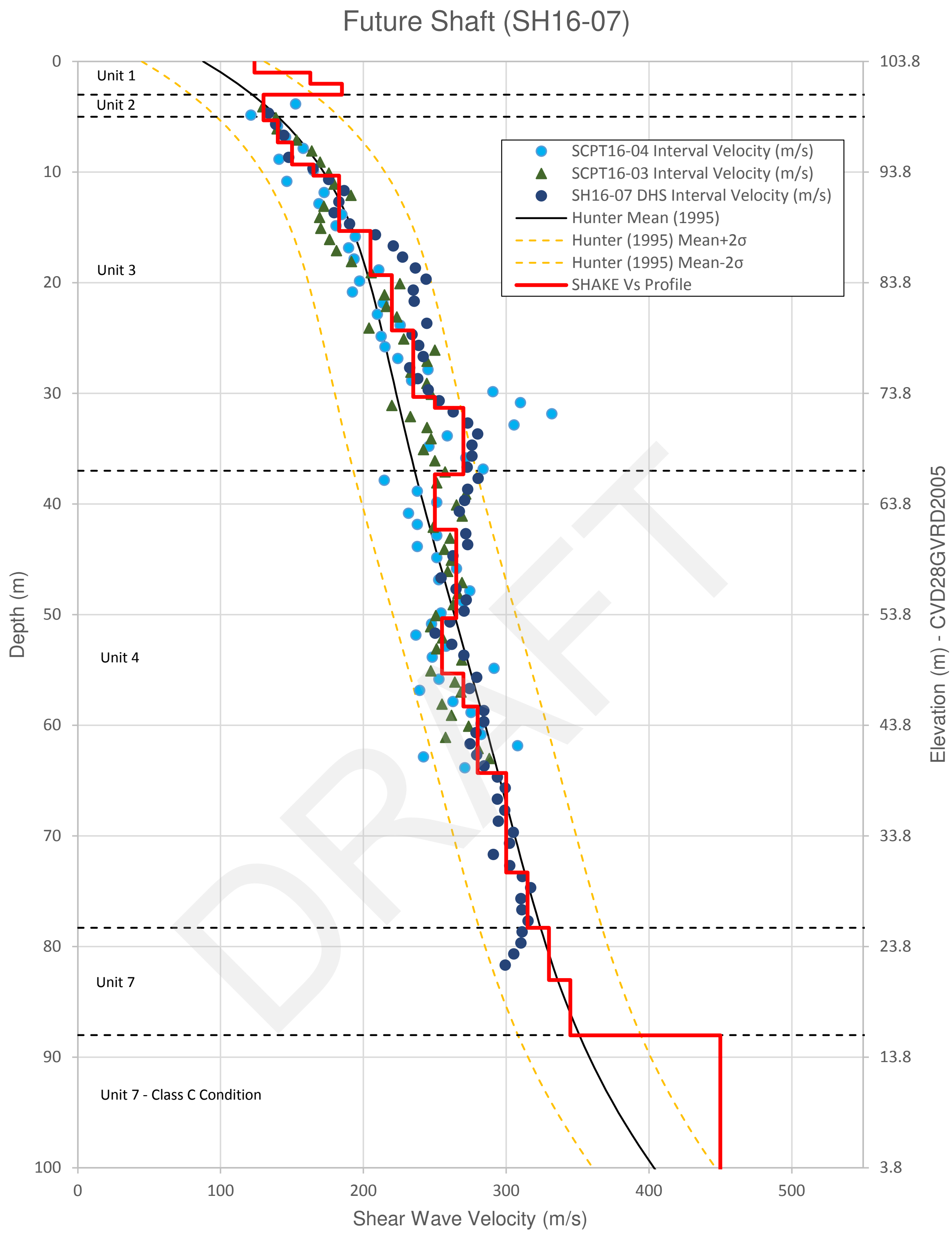
YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YEW
REVIEW	---
APPROVED	---

TITLE

SHEAR WAVE VELOCITY PROFILE – EFFLUENT SHAFT

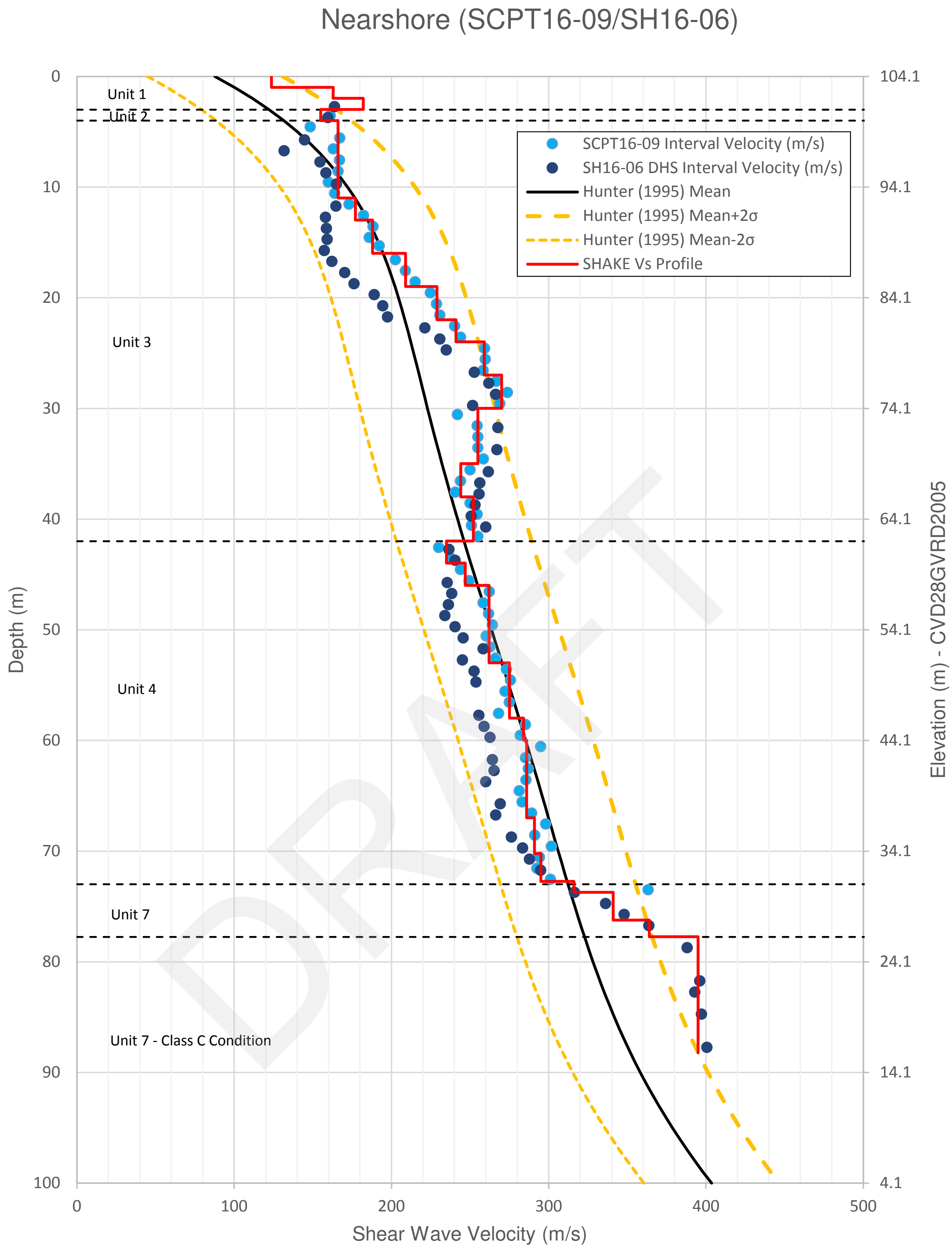
PROJECT No	PHASE	REV	FIGURE
1525010	2000	C	3-2

Path: O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



DRAFT

CLIENT CDM SMITH CANADA ULC		PROJECT AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC	
CONSULTANT Golder Associates	YYYY-MM-DD: 19 DEC 2017 PREPARED: YEW DESIGN: YEW REVIEW: --- APPROVED: ---	TITLE **SHEAR WAVE VELOCITY PROFILE – FUTURE SHAFT**	
		PROJECT No 1525010	PHASE 2000 / REV C / FIGURE 3-3



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CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT

Golder Associates

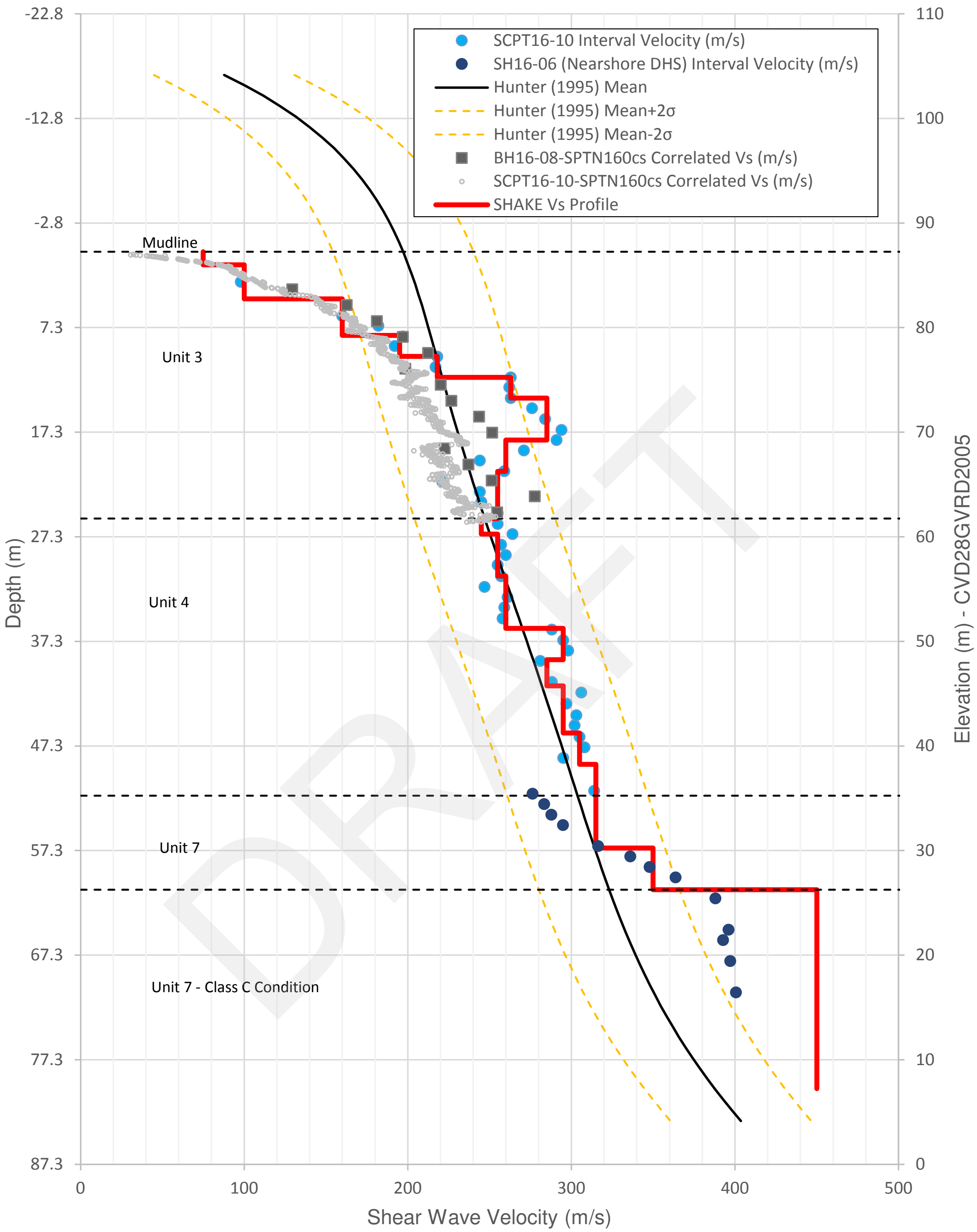
YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YEW
REVIEW	---
APPROVED	---

TITLE
SHEAR WAVE VELOCITY PROFILE – NEARSHORE

PROJECT No	PHASE	REV	FIGURE
1525010	2000	C	3-4

Path: O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures

Riser Shaft (SCPT16-10)



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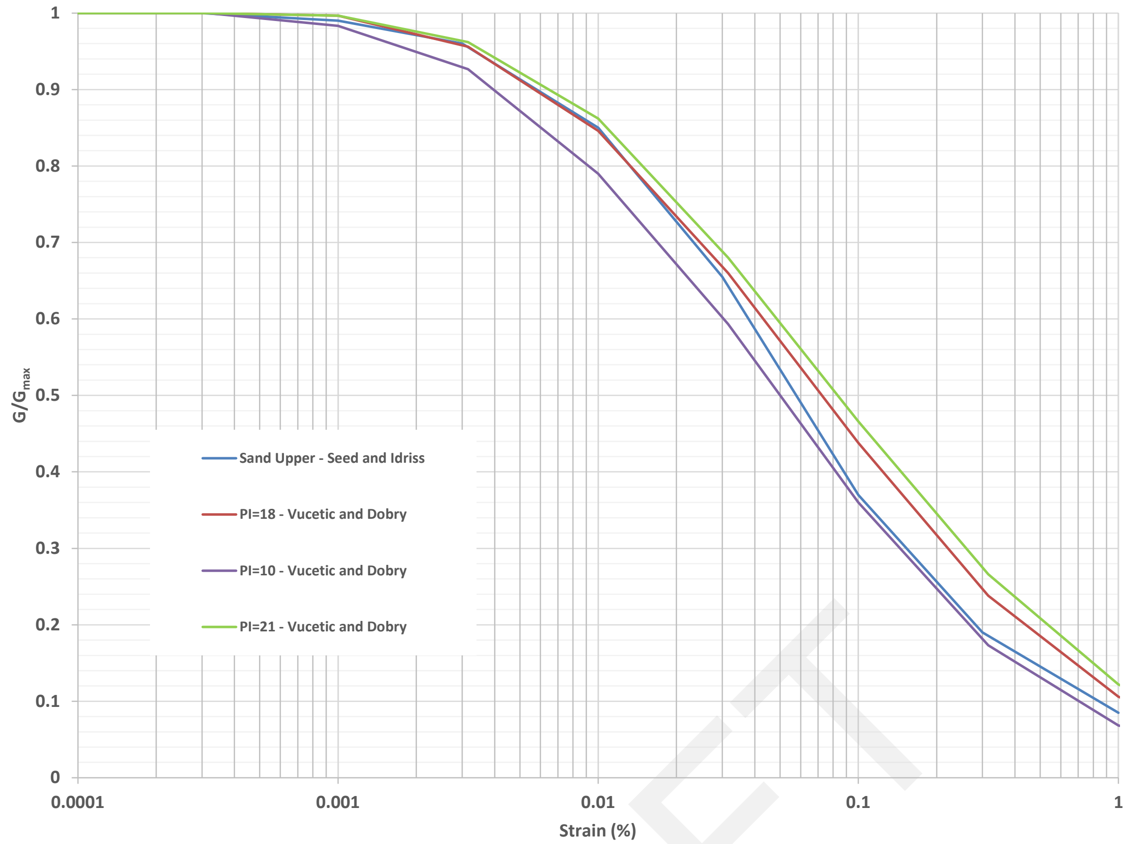
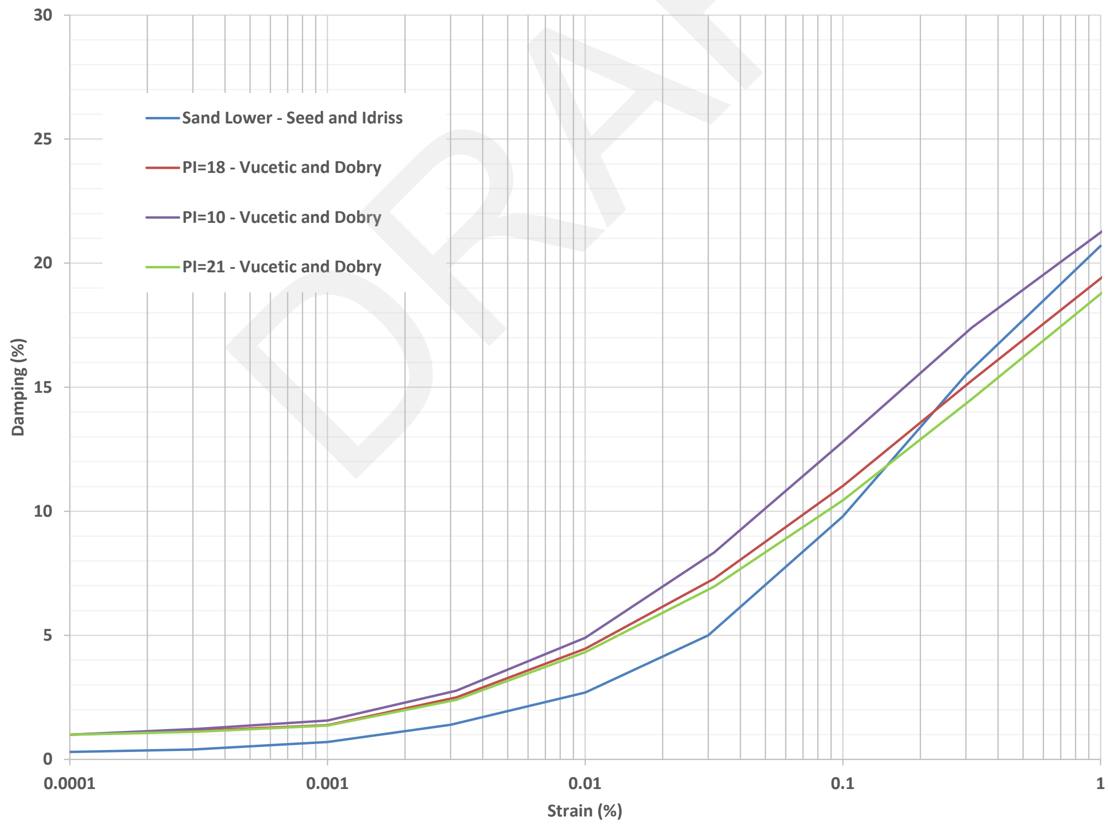
CLIENT CDM SMITH CANADA ULC		PROJECT AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC	
CONSULTANT Golder Associates	YYYY-MM-DD	19 DEC 2017	TITLE **SHEAR WAVE VELOCITY PROFILE – RISER SHAFT**
	PREPARED	YEW	
	DESIGN	YEW	
	REVIEW	---	PROJECT No 1525010 · PHASE 2000 · REV C · FIGURE 3-5
	APPROVED	---	





CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT

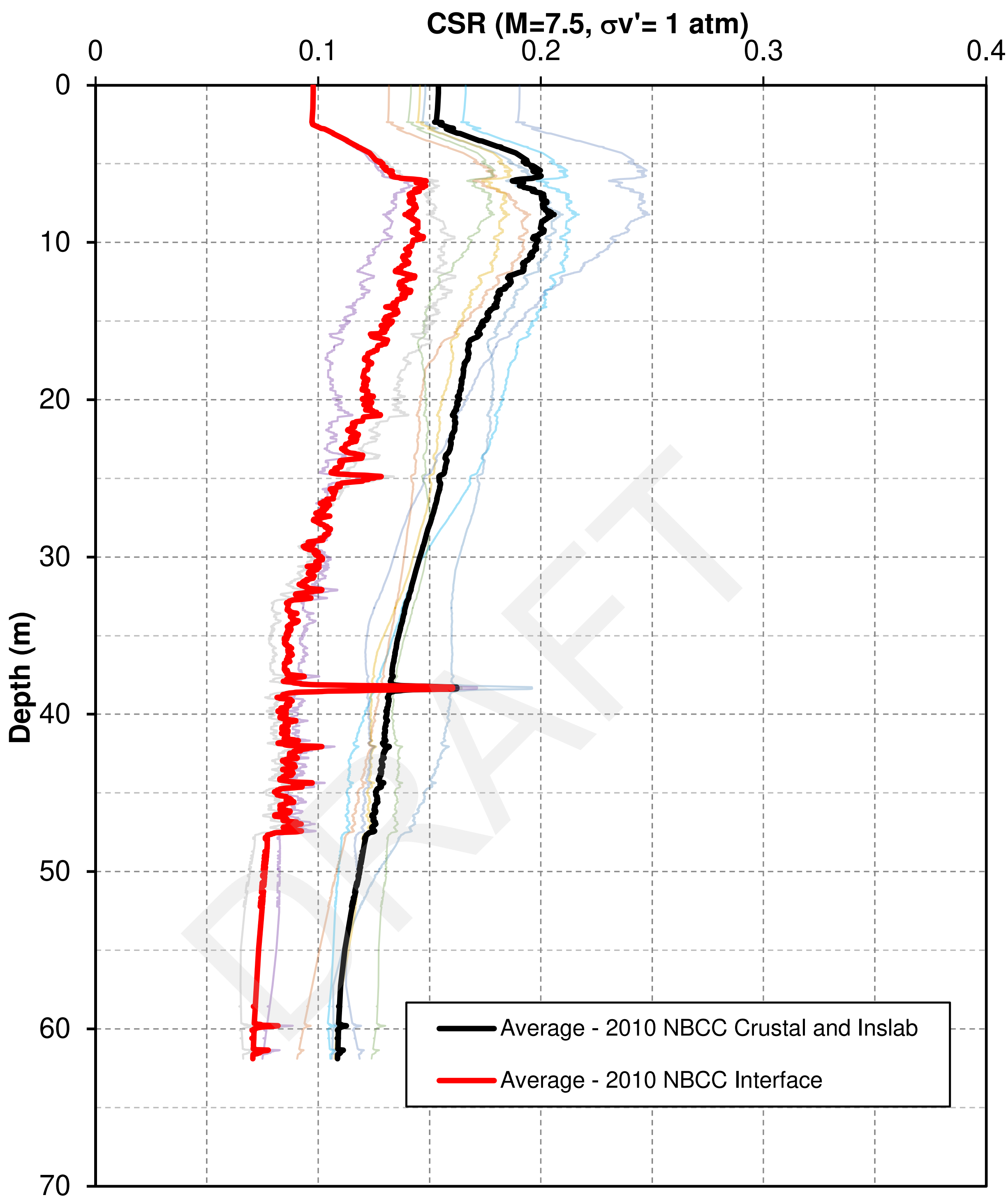
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YEW
REVIEW	---
APPROVED	---

TITLE

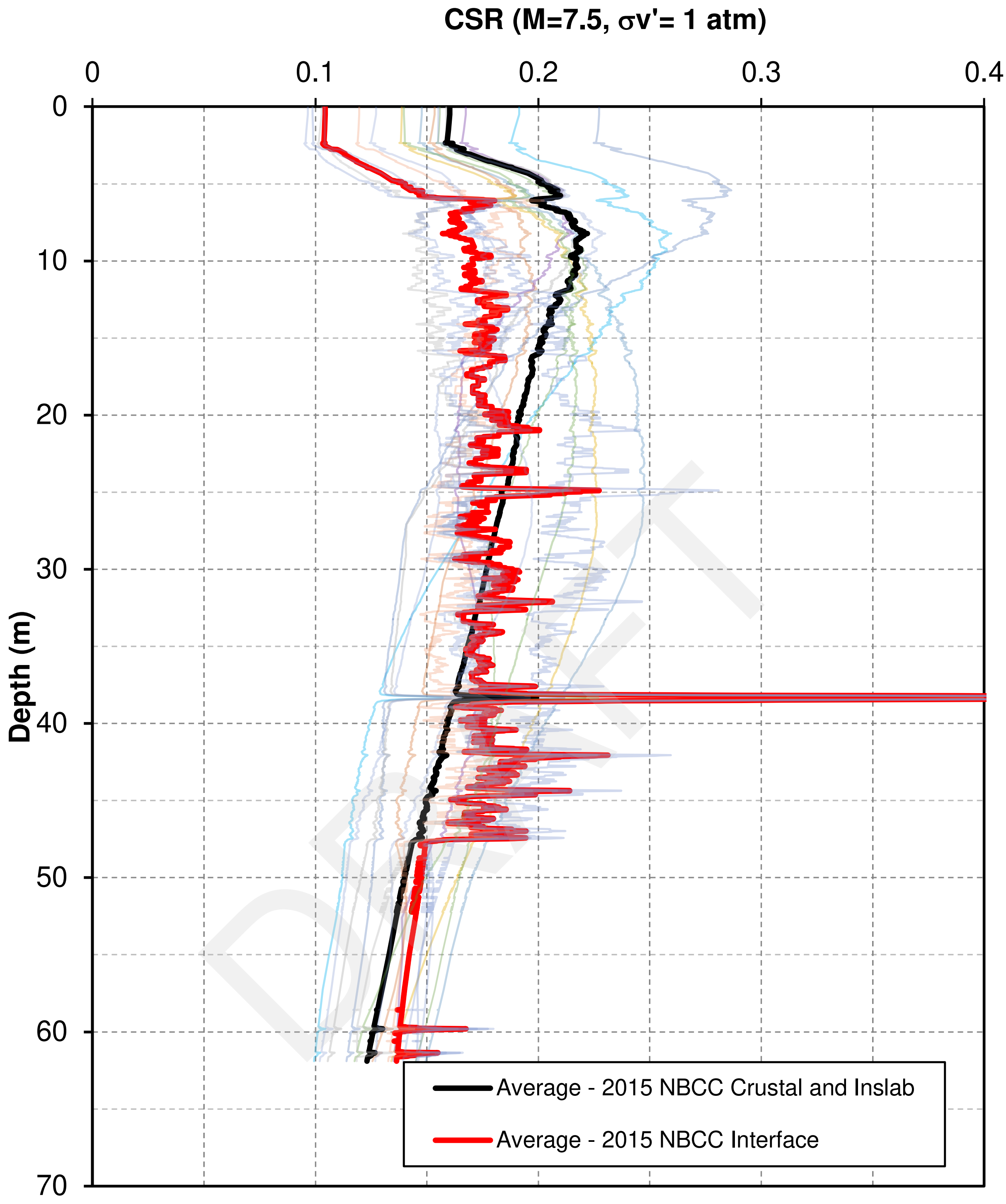
MODULUS REDUCTION AND DAMPING CURVES

PROJECT No	PHASE	REV	FIGURE
1525010	2000	C	3-6



DRAFT

CLIENT	CDM SMITH CANADA ULC	PROJECT	AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC
CONSULTANT	Golder Associates	TITLE	**COMPARISON OF CSR – TYPICAL LOCATION 2010 NBCC**
YYYY-MM-DD	19 DEC 2017	PROJECT No	1525010
PREPARED	YEW	PHASE	2100
DESIGN	YEW	REV	C
REVIEW	---	FIGURE	3-7
APPROVED	---		



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CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

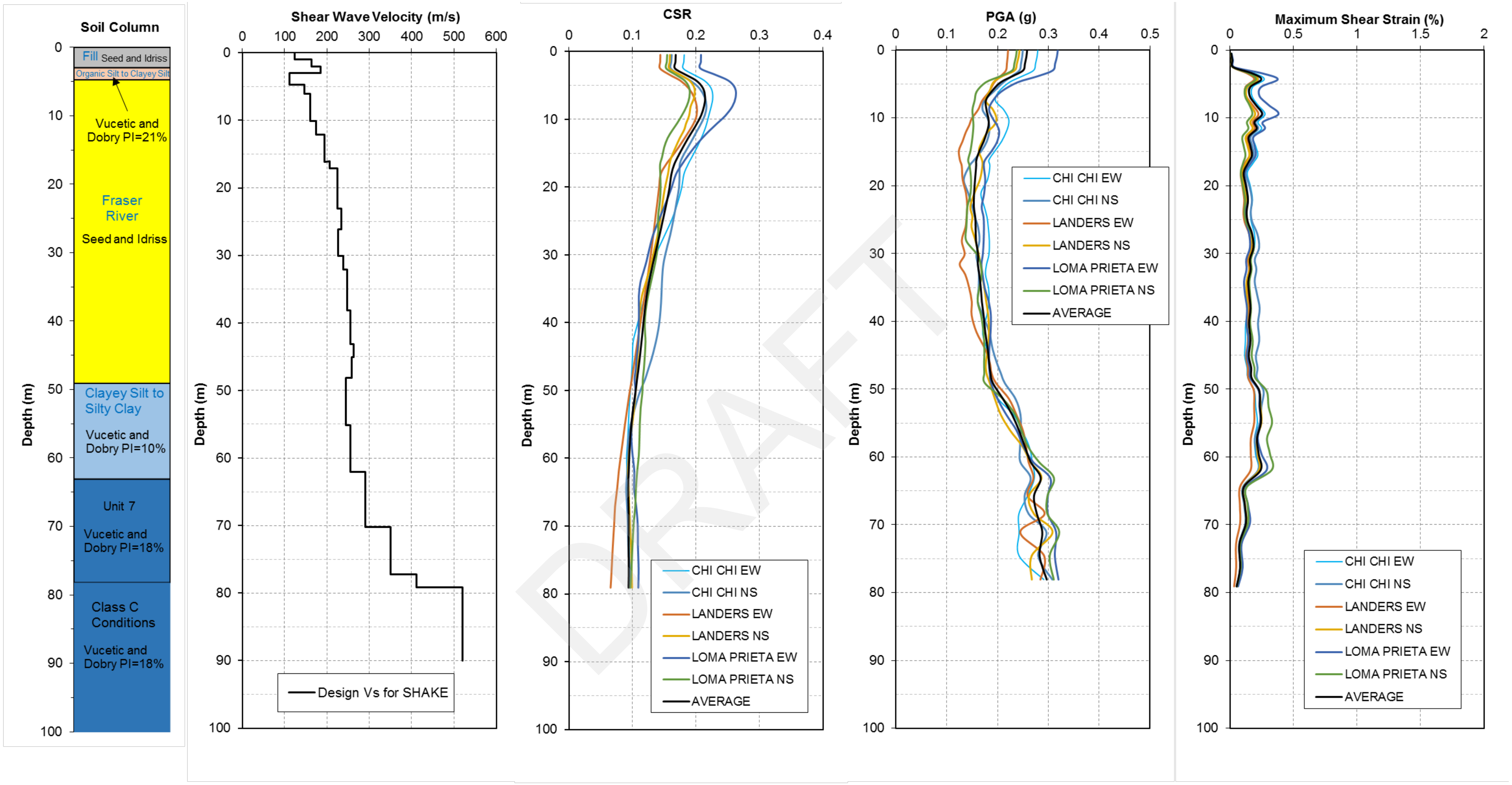
CONSULTANT

Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YEW
REVIEW	---
APPROVED	---

TITLE
COMPARISON OF CSR – TYPICAL LOCATION
2015 NBCC

PROJECT No	PHASE	REV	FIGURE
1525010	2100	C	3-8



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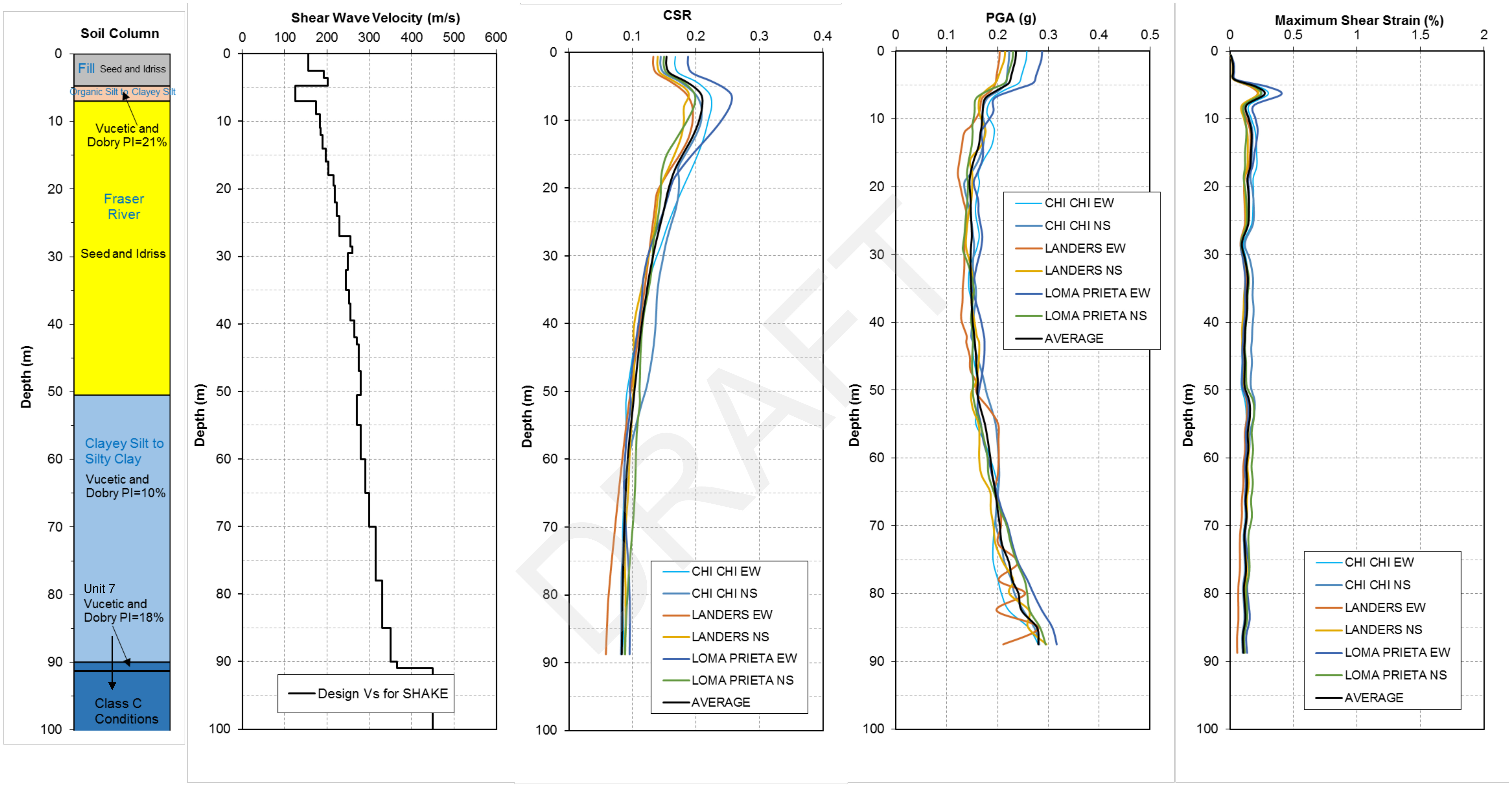
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2010 NBCC CRUSTAL & INSLAB - OUTFALL SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-9



CLIENT
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PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

CONSULTANT

Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2010 NBCC CRUSTAL & INSLAB - EFFLUENT SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-10

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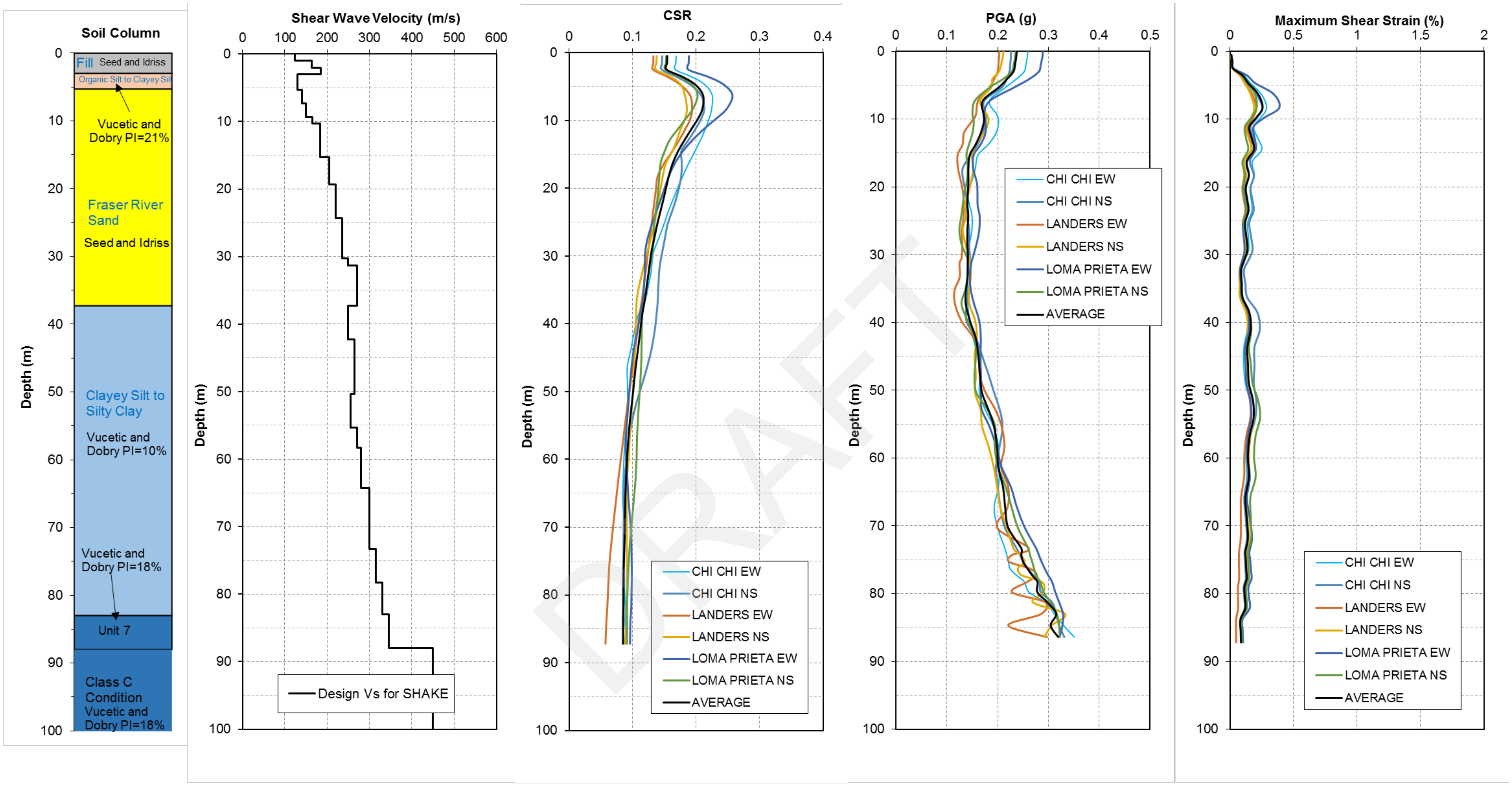

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PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

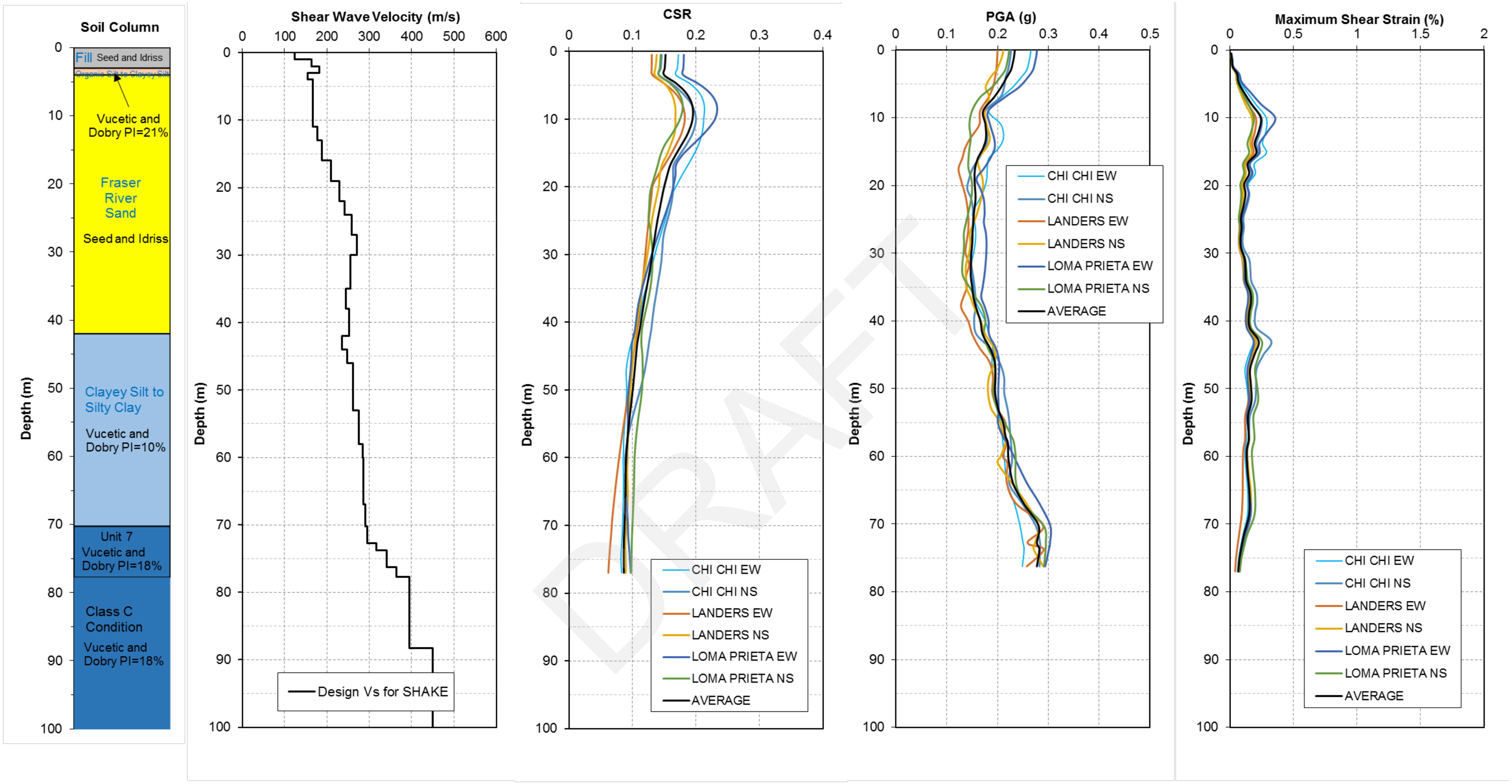
CONSULTANT

Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2010 NBCC CRUSTAL & INSLAB - FUTURE SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-11



CLIENT
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PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2010 NBCC CRUSTAL & INSLAB - NEARSHORE

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-12

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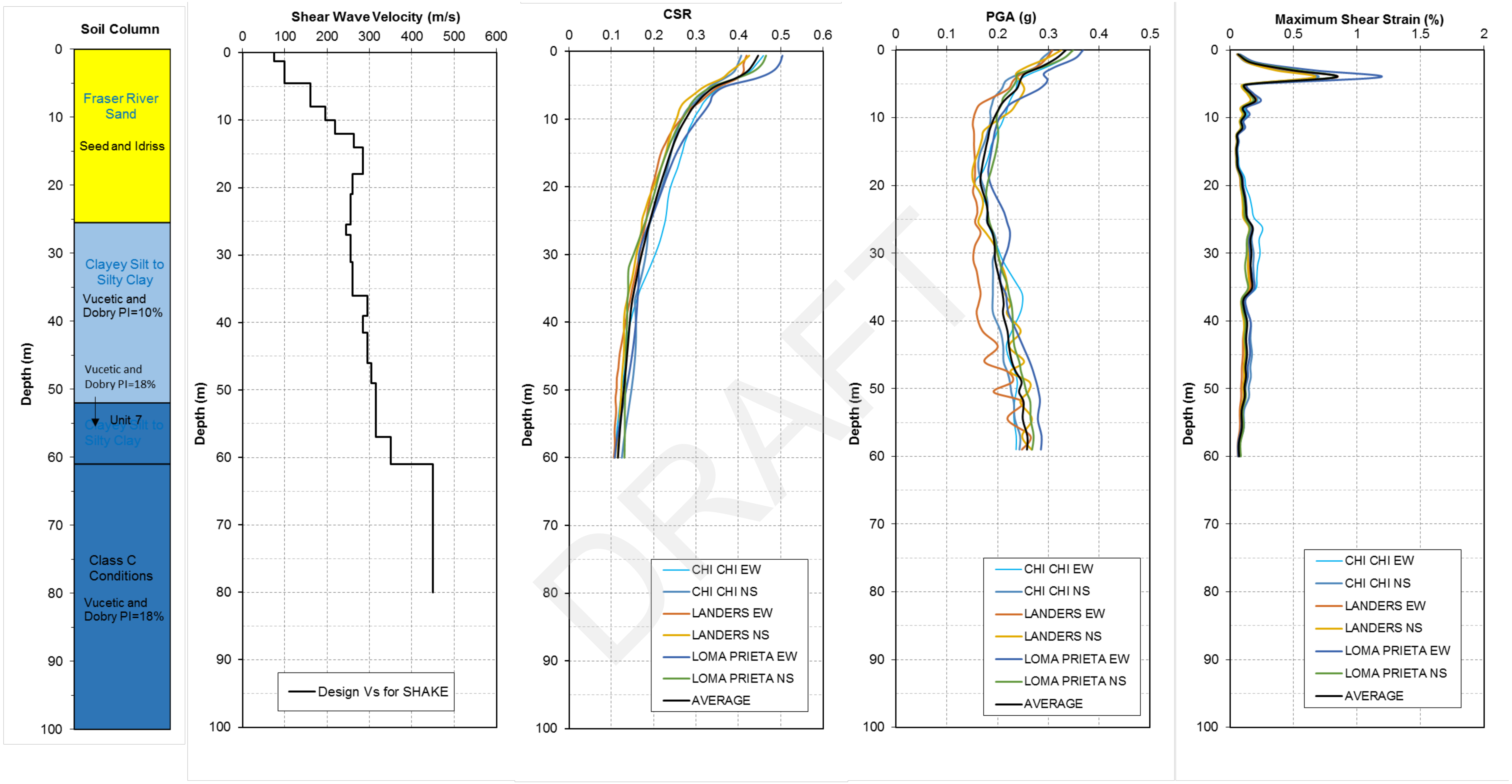

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CLIENT
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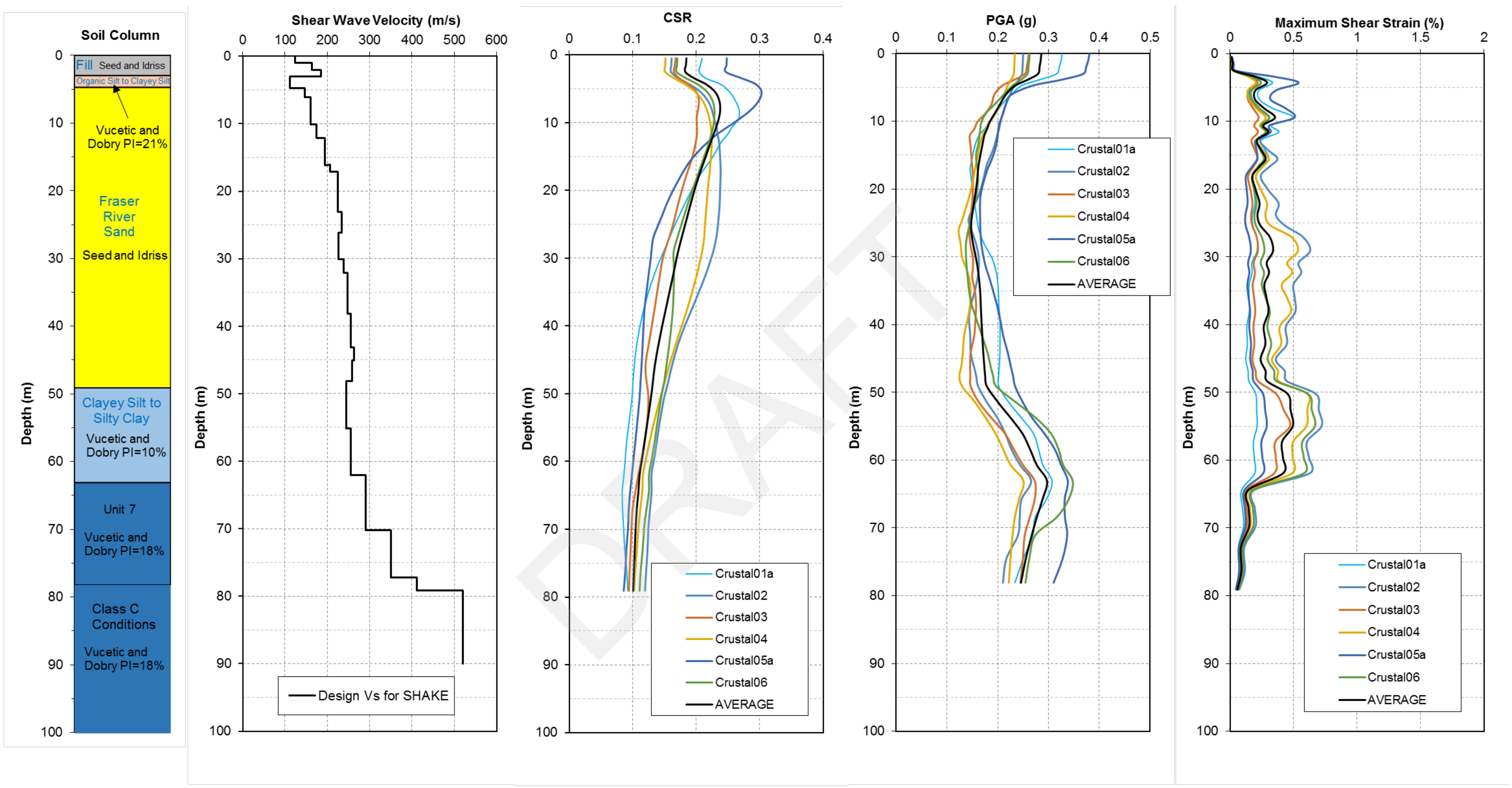
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES 2010 NBCC CRUSTAL & INSLAB - RISER SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-13



CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

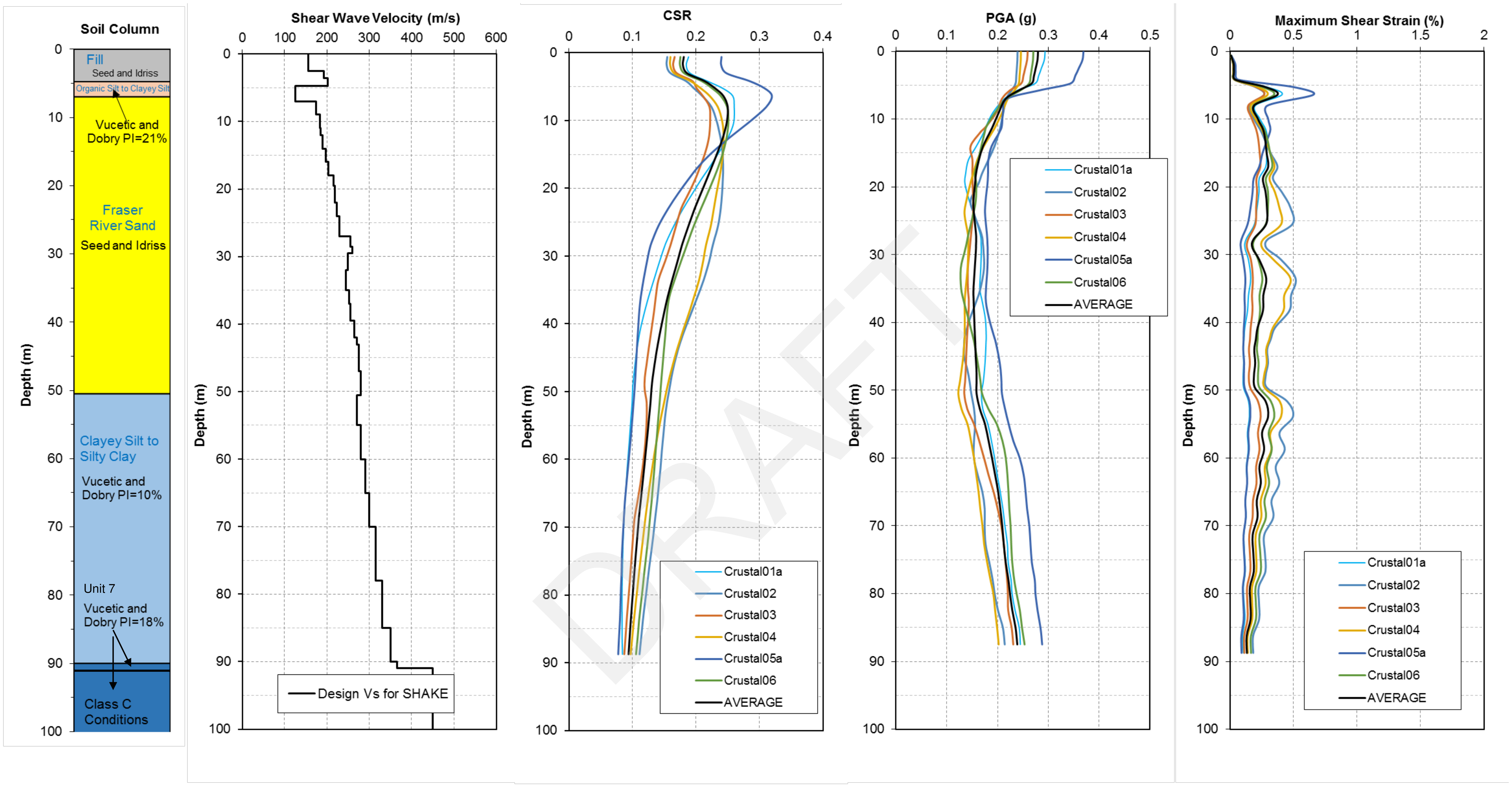
CONSULTANT

Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2015 NBCC CRUSTAL - OUTFALL SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-14



CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

CONSULTANT

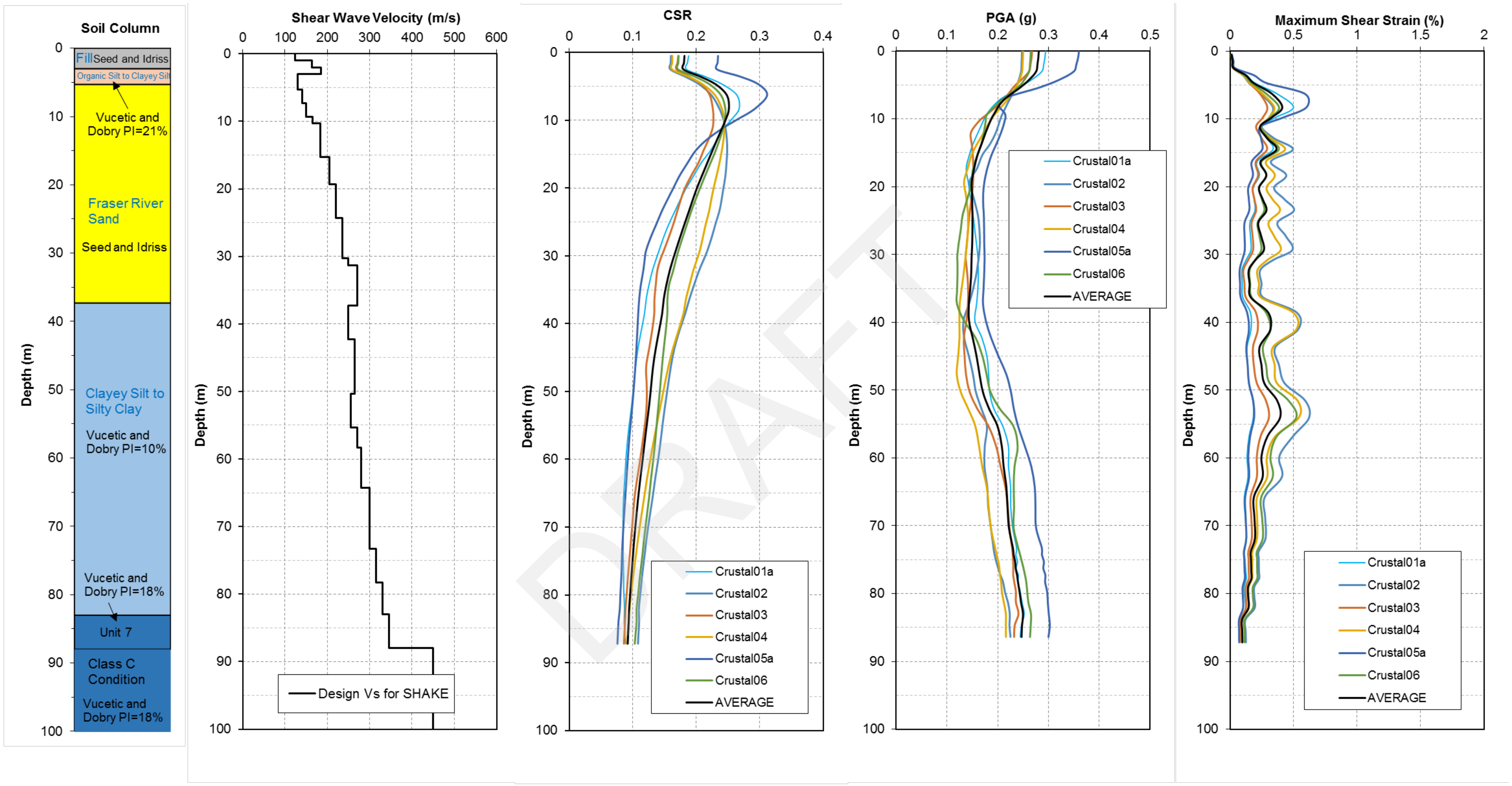
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC CRUSTAL - EFFLUENT SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-15

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



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CLIENT
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PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

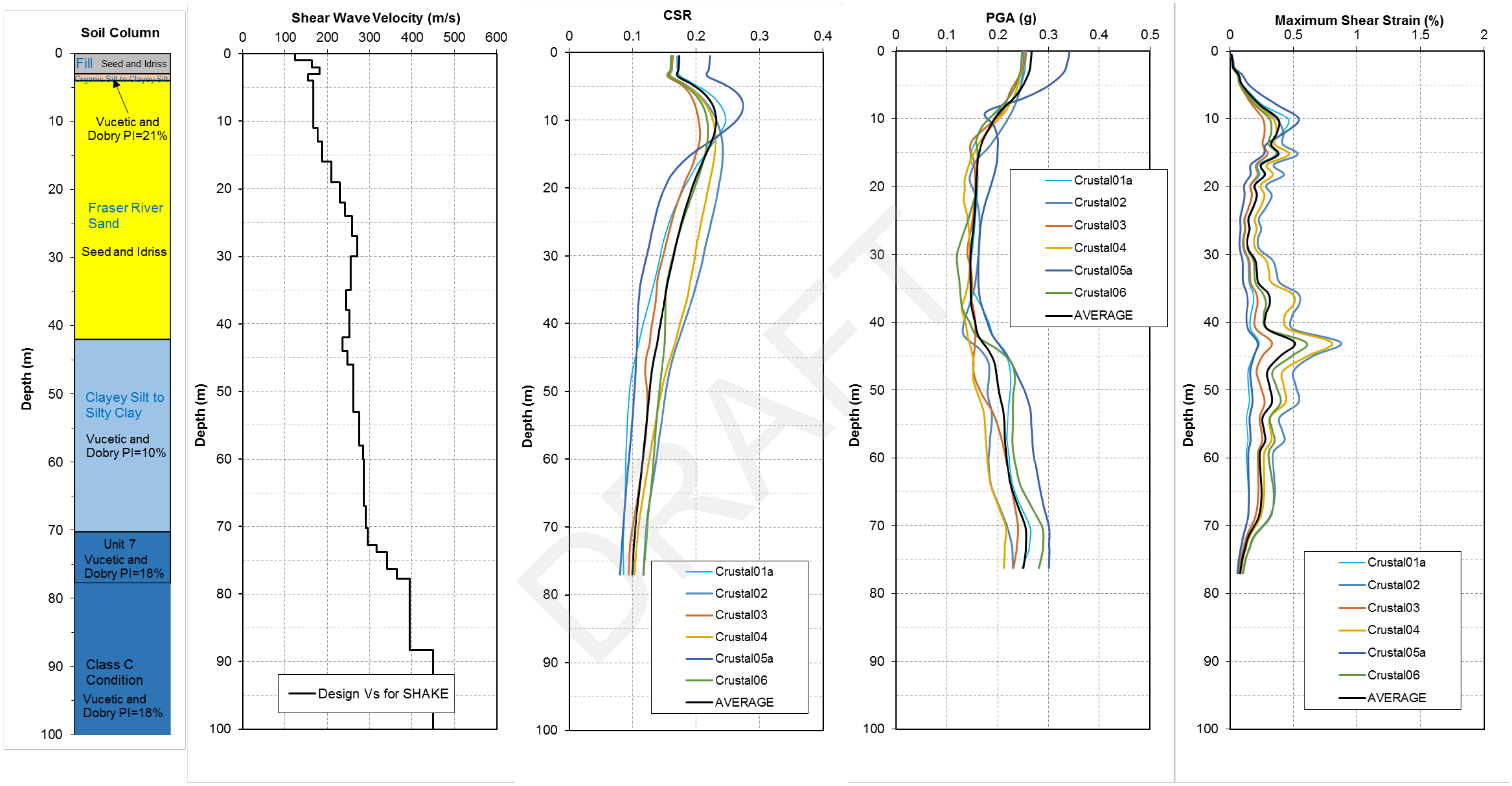
CONSULTANT

Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

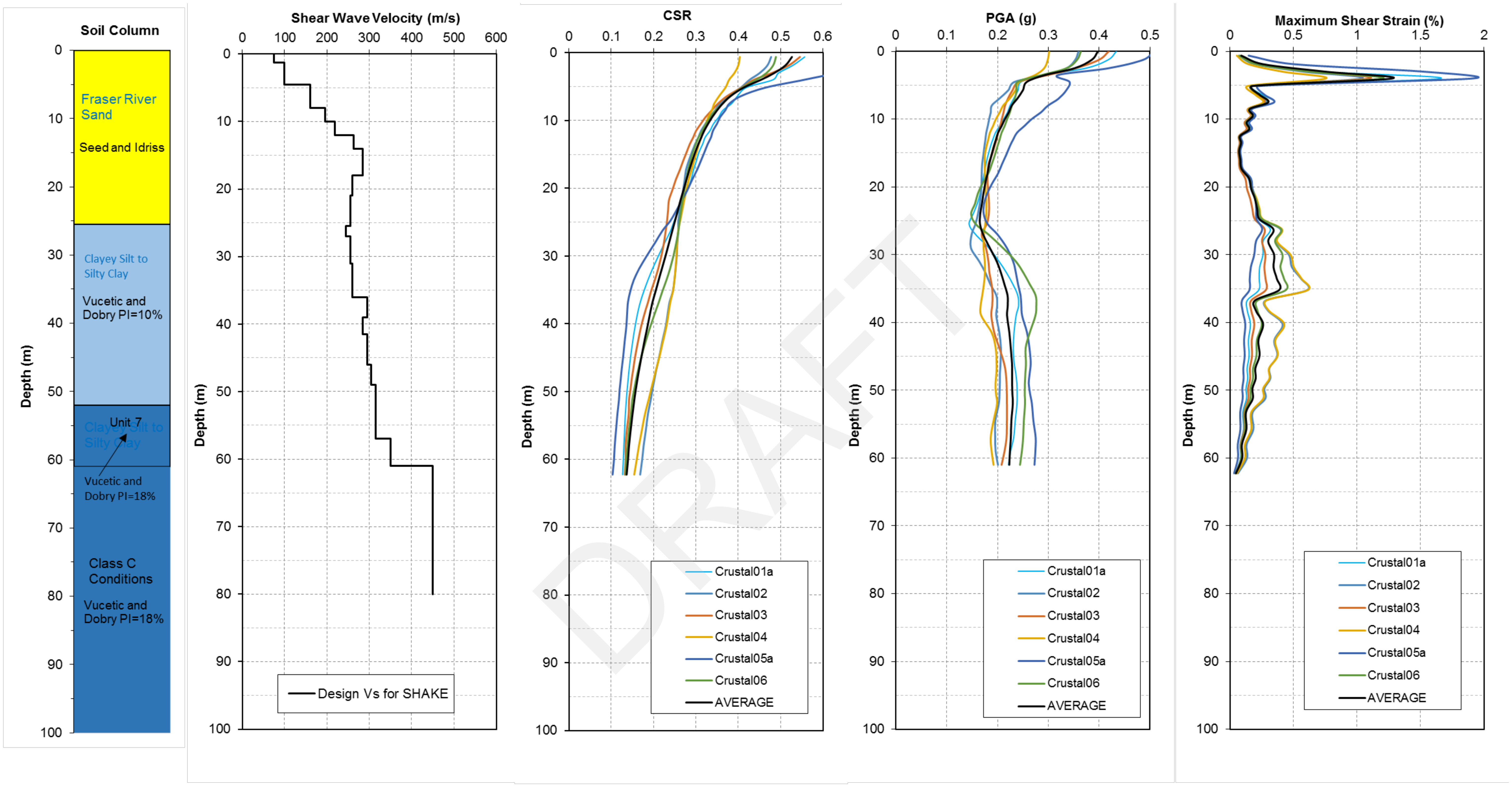
TITLE
RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC CRUSTAL - FUTURE SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-16



O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures

CLIENT CDM SMITH CANADA ULC	PROJECT AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC
CONSULTANT Golder Associates YYYY-MM-DD: 19 DEC 2017 PREPARED: YEW DESIGN: YB REVIEW: --- APPROVED: ---	TITLE RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC CRUSTAL – NEARSHORE
PROJECT No. 1525010	PHASE 2100 · Rev C · FIGURE 3-17



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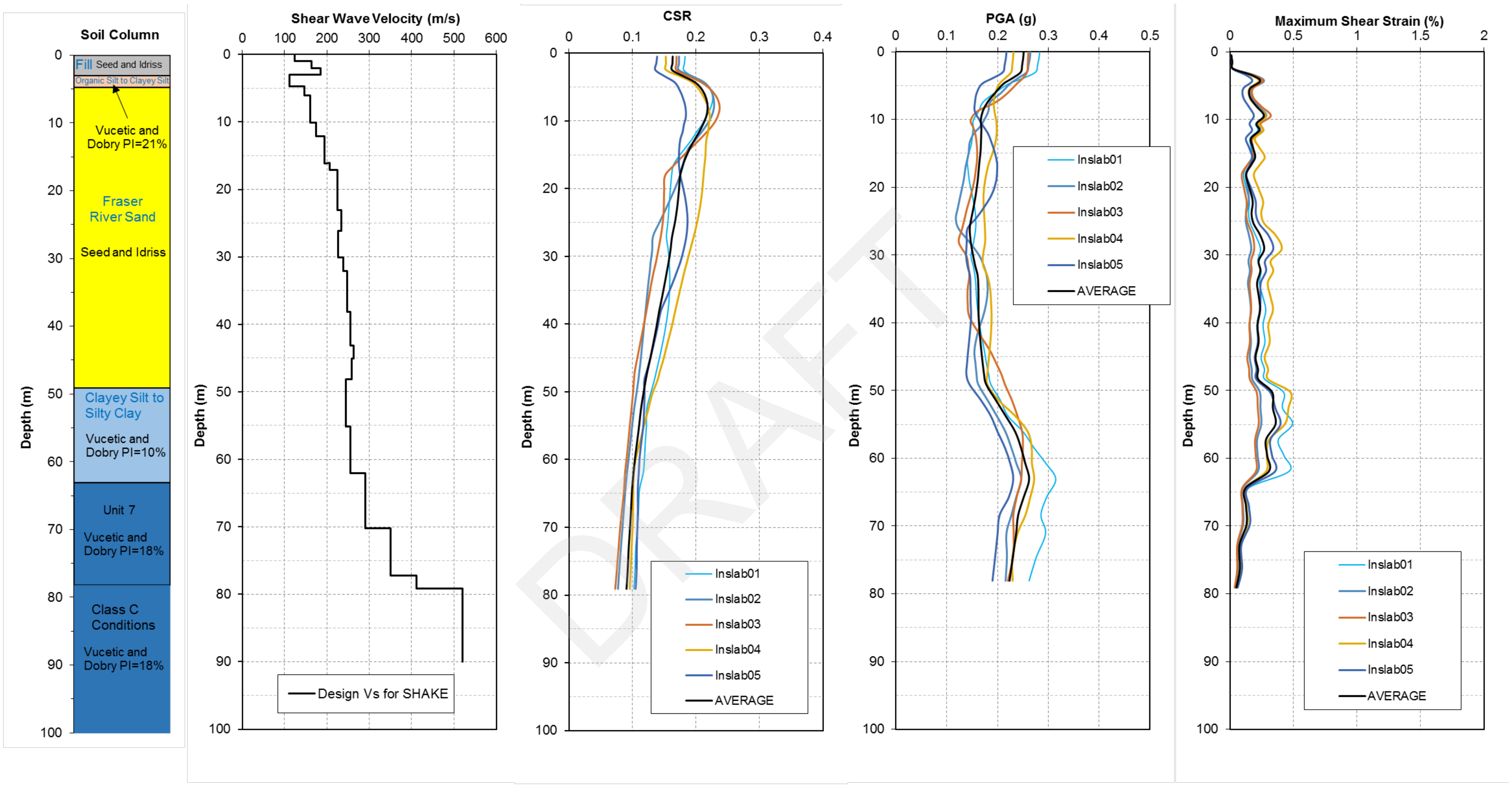
CLIENT **CDM SMITH CANADA ULC**	PROJECT **AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC**
CONSULTANT Golder Associates YYYY-MM-DD: 19 DEC 2017 PREPARED: YEW DESIGN: YB REVIEW: --- APPROVED: ---	TITLE **RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC CRUSTAL - RISER SHAFT**
	PROJECT No.: 1525010 · PHASE: 2100 · Rev: C · FIGURE: 3-18



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CLIENT
CDM SMITH CANADA ULC

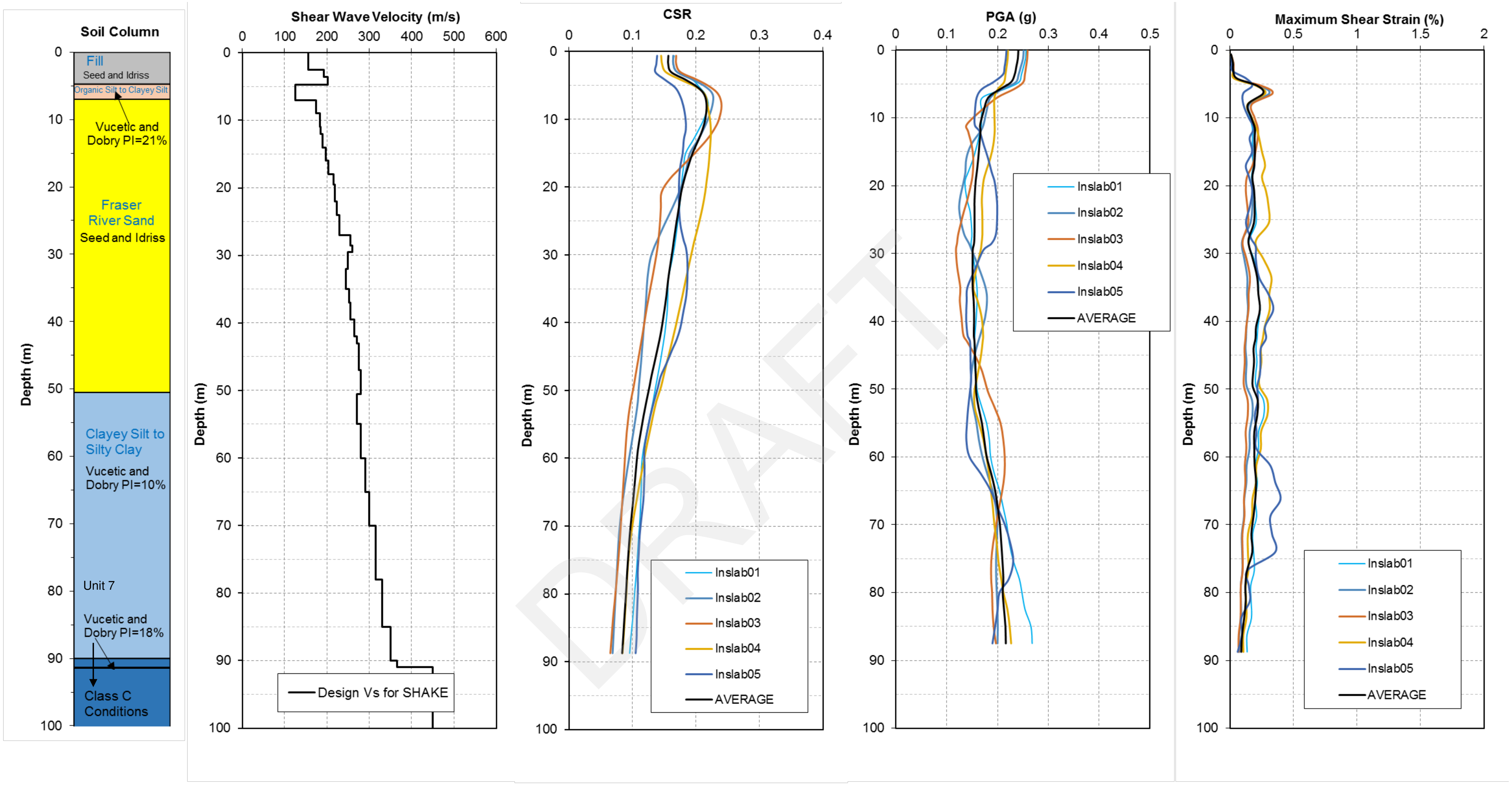
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC INSLAB - OUTFALL SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-19



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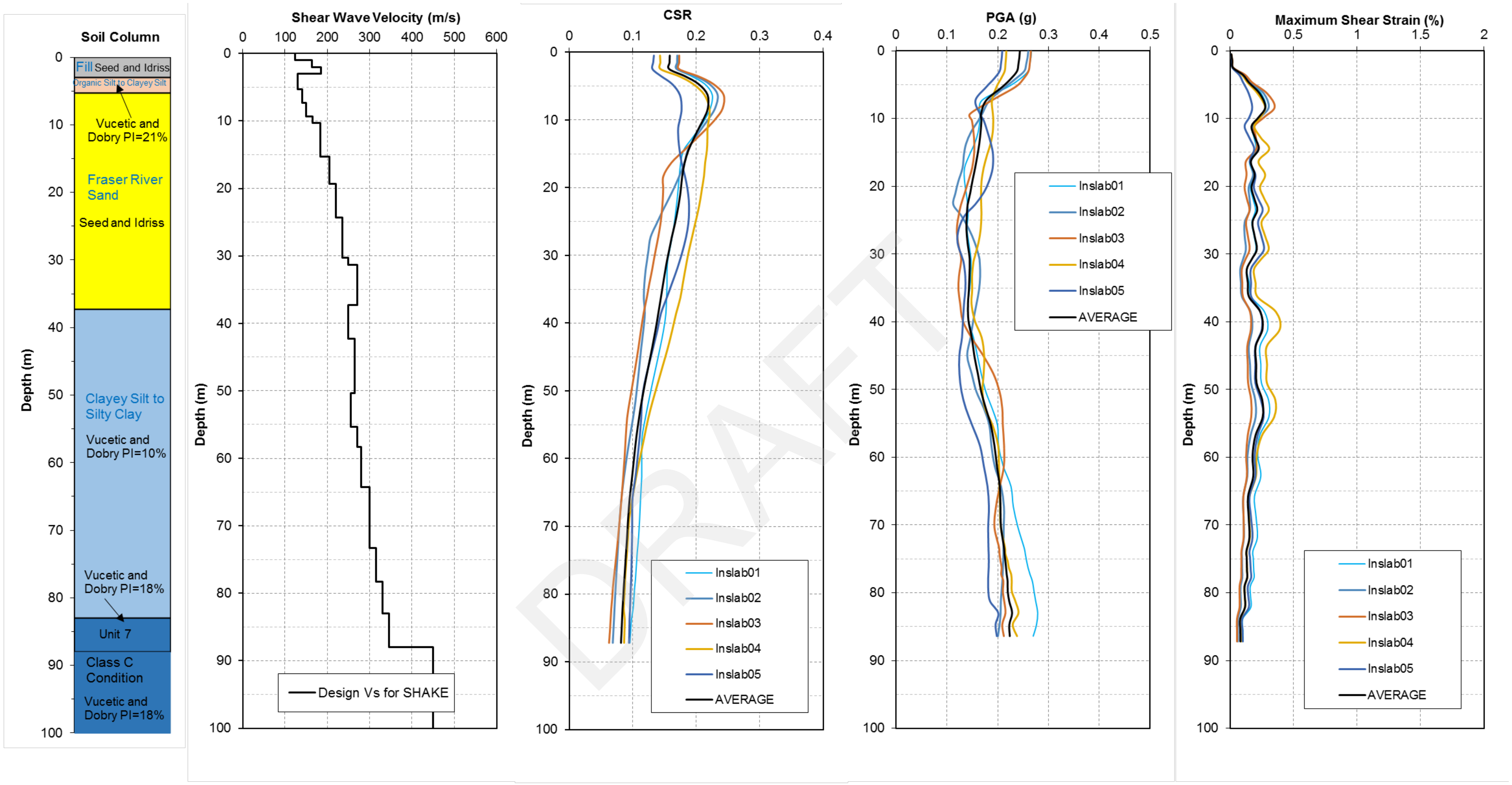
CLIENT CDM SMITH CANADA ULC		PROJECT AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC	
CONSULTANT Golder Associates	YYYY-MM-DD: 19 DEC 2017 PREPARED: YEW DESIGN: YB REVIEW: --- APPROVED: ---	TITLE RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC INSLAB - EFFLUENT SHAFT	
		PROJECT No. 1525010 · PHASE 2100 · Rev C	FIGURE 3-20



CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

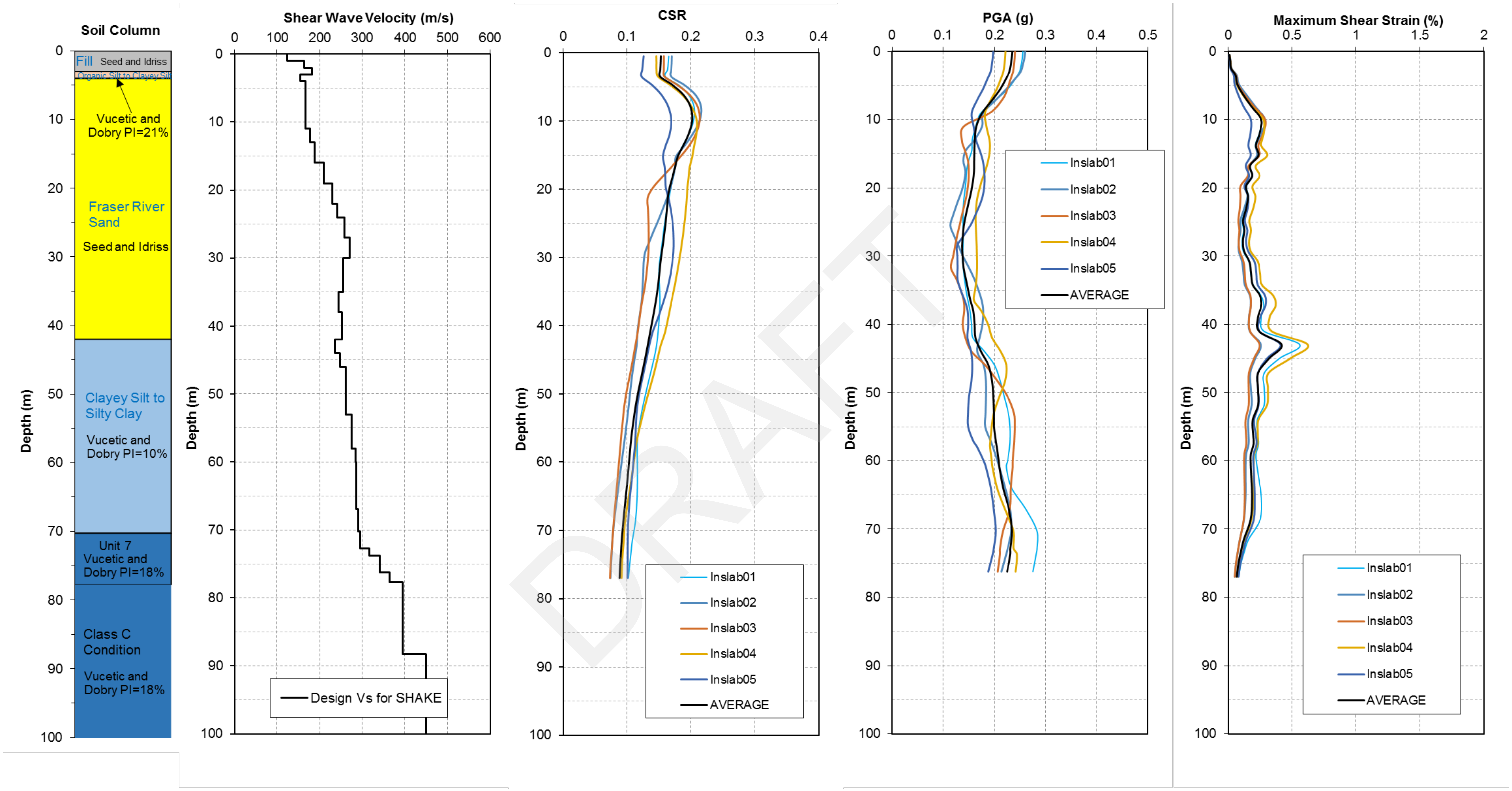
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2015 NBCC INSLAB - FUTURE SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-21

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



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CLIENT
CDM SMITH CANADA ULC

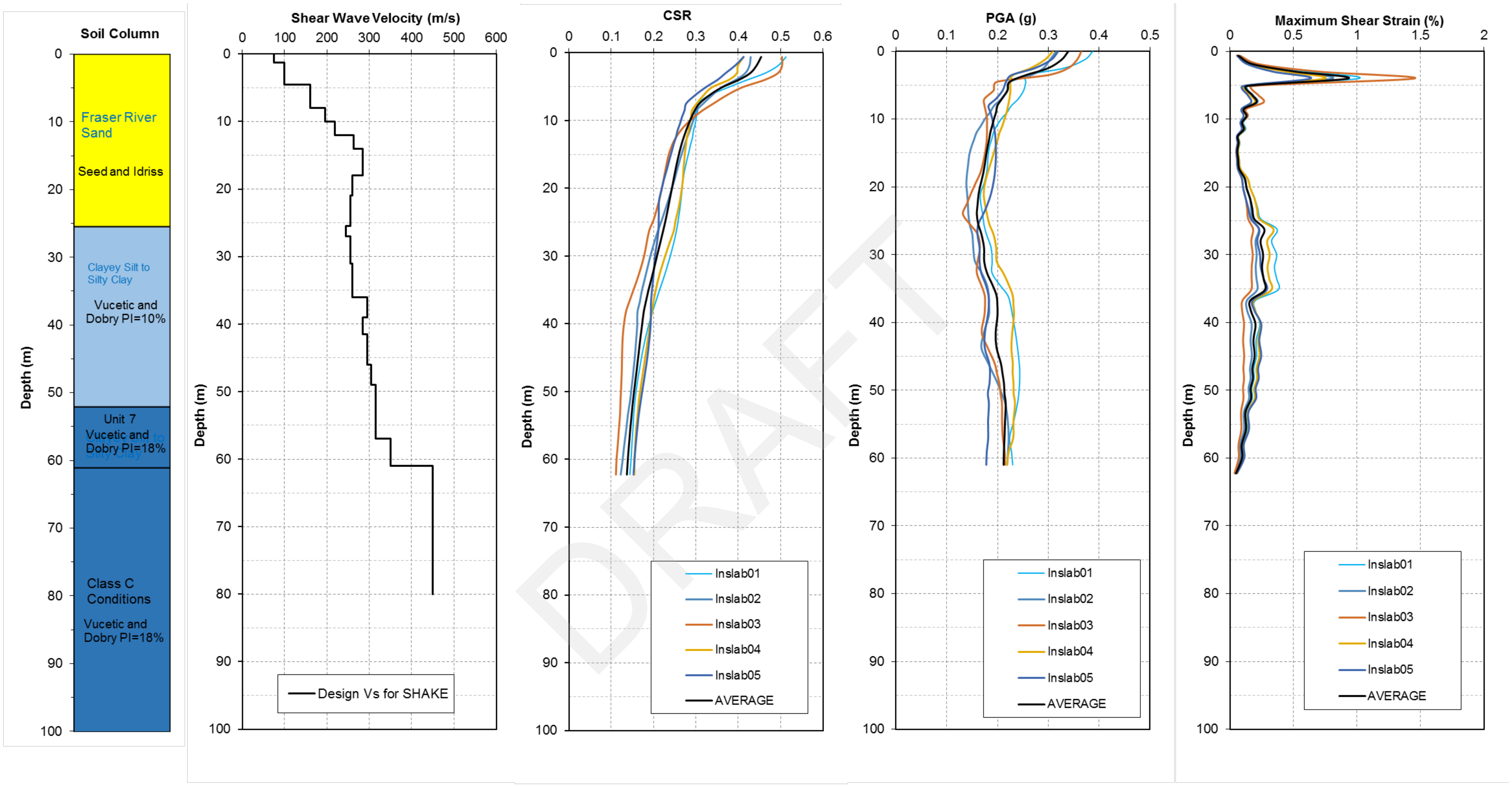
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC INSLAB – NEARSHORE

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-22



CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

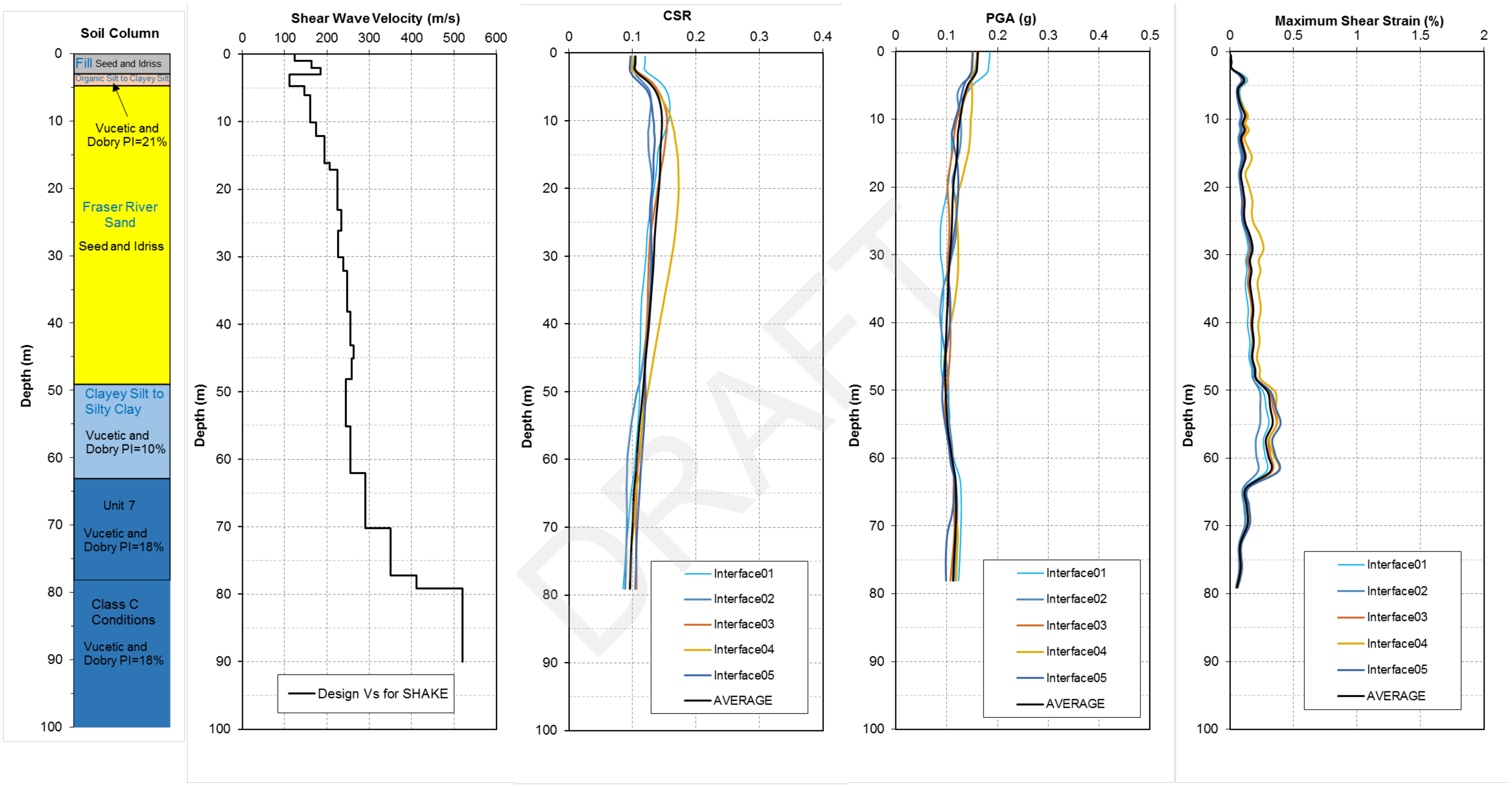
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2015 NBCC INSLAB - RISER SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-23

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



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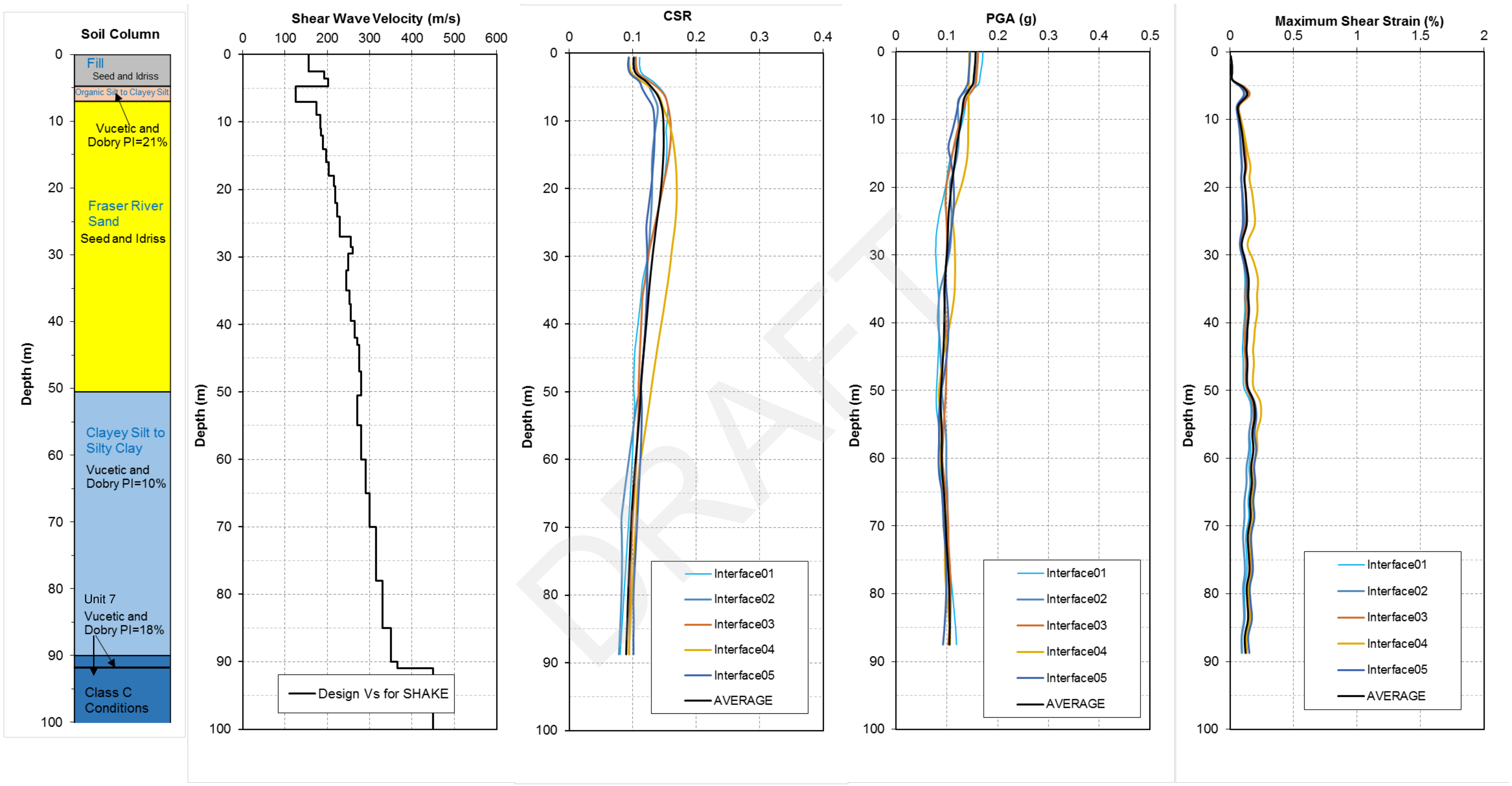
CLIENT **CDM SMITH CANADA ULC**	PROJECT **AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC**
CONSULTANT Golder Associates YYYY-MM-DD 19 DEC 2017 PREPARED YEW DESIGN YB REVIEW --- APPROVED ---	TITLE **RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC INTERFACE - OUTFALL SHAFT**
	PROJECT No. 1525010 · PHASE 2100 · Rev C · FIGURE 3-24



CLIENT
CDM SMITH CANADA ULC

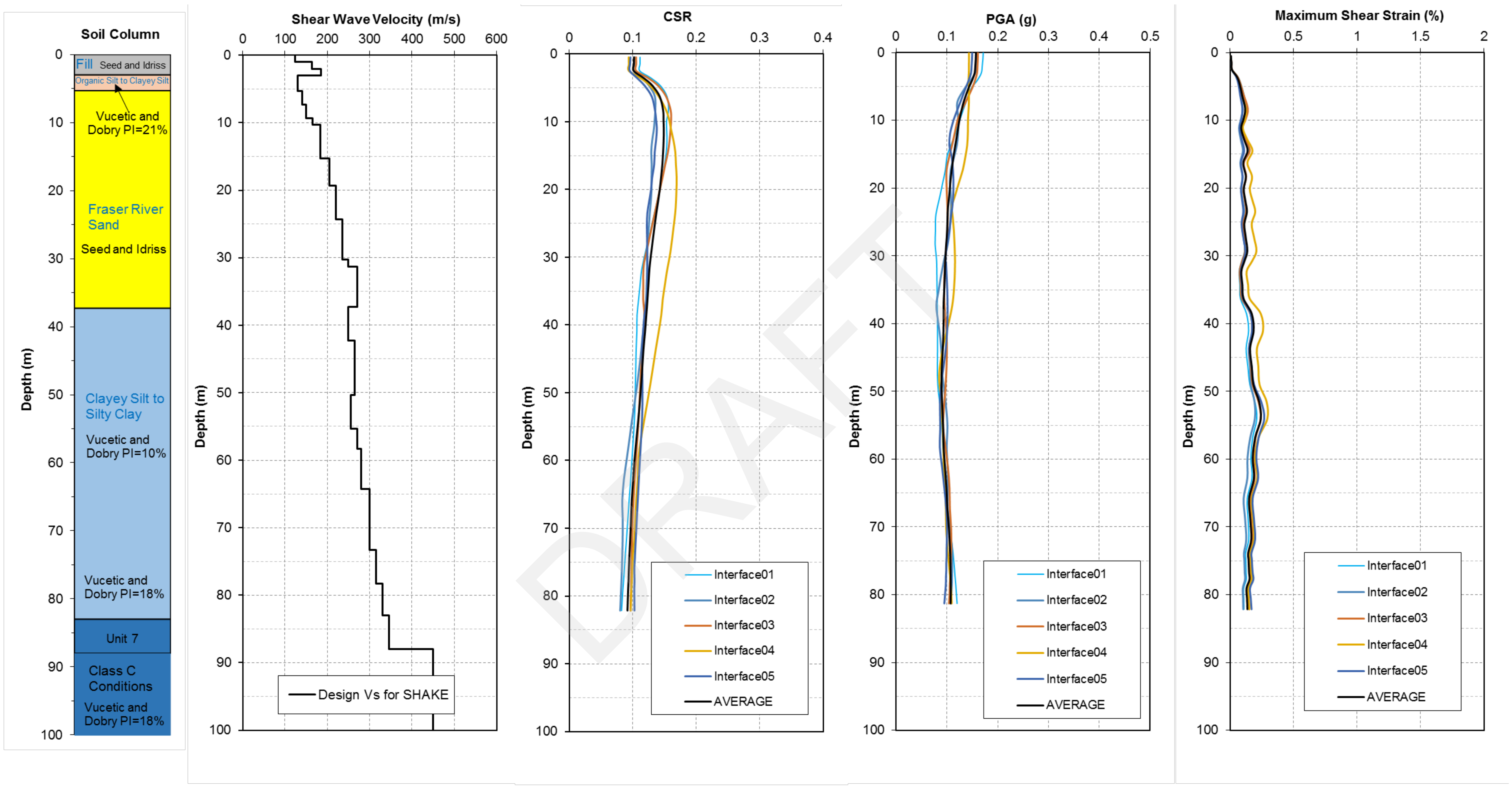
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
RESULTS OF SITE RESPONSE ANALYSES
2015 NBCC INTERFACE - EFFLUENT SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-25



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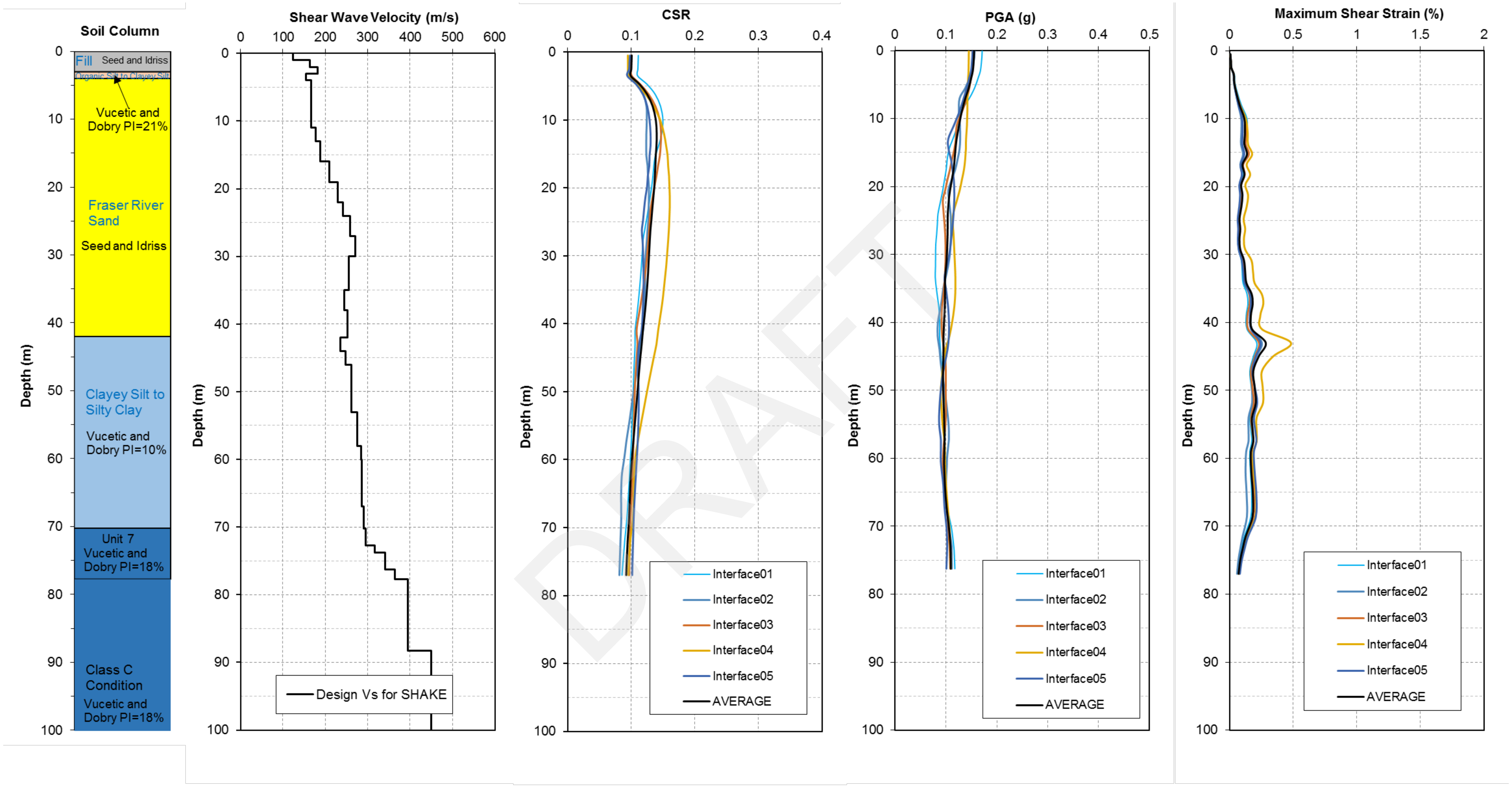
CLIENT **CDM SMITH CANADA ULC**	PROJECT **AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC**
CONSULTANT Golder Associates YYYY-MM-DD: 19 DEC 2017 PREPARED: YEW DESIGN: YB REVIEW: --- APPROVED: ---	TITLE **RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC INTERFACE - FUTURE SHAFT**
	PROJECT No. 1525010 · PHASE 2100 · Rev C · FIGURE 3-26



CLIENT

CDM SMITH CANADA ULC

PROJECT

AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT

Golder Associates

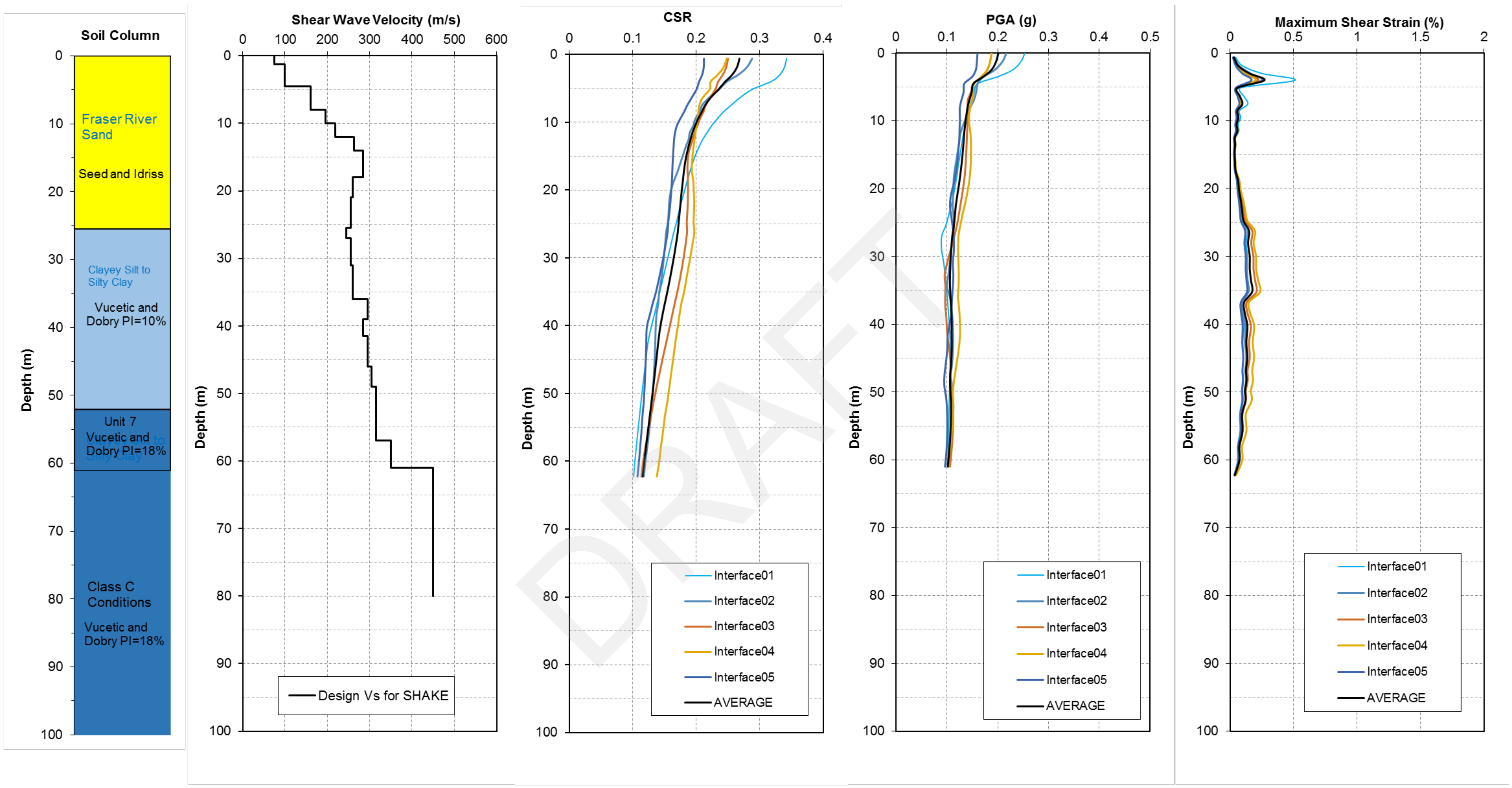
YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE

RESULTS OF SITE RESPONSE ANALYSES
2015 NBCC INTERFACE – NEARSHORE

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-27

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



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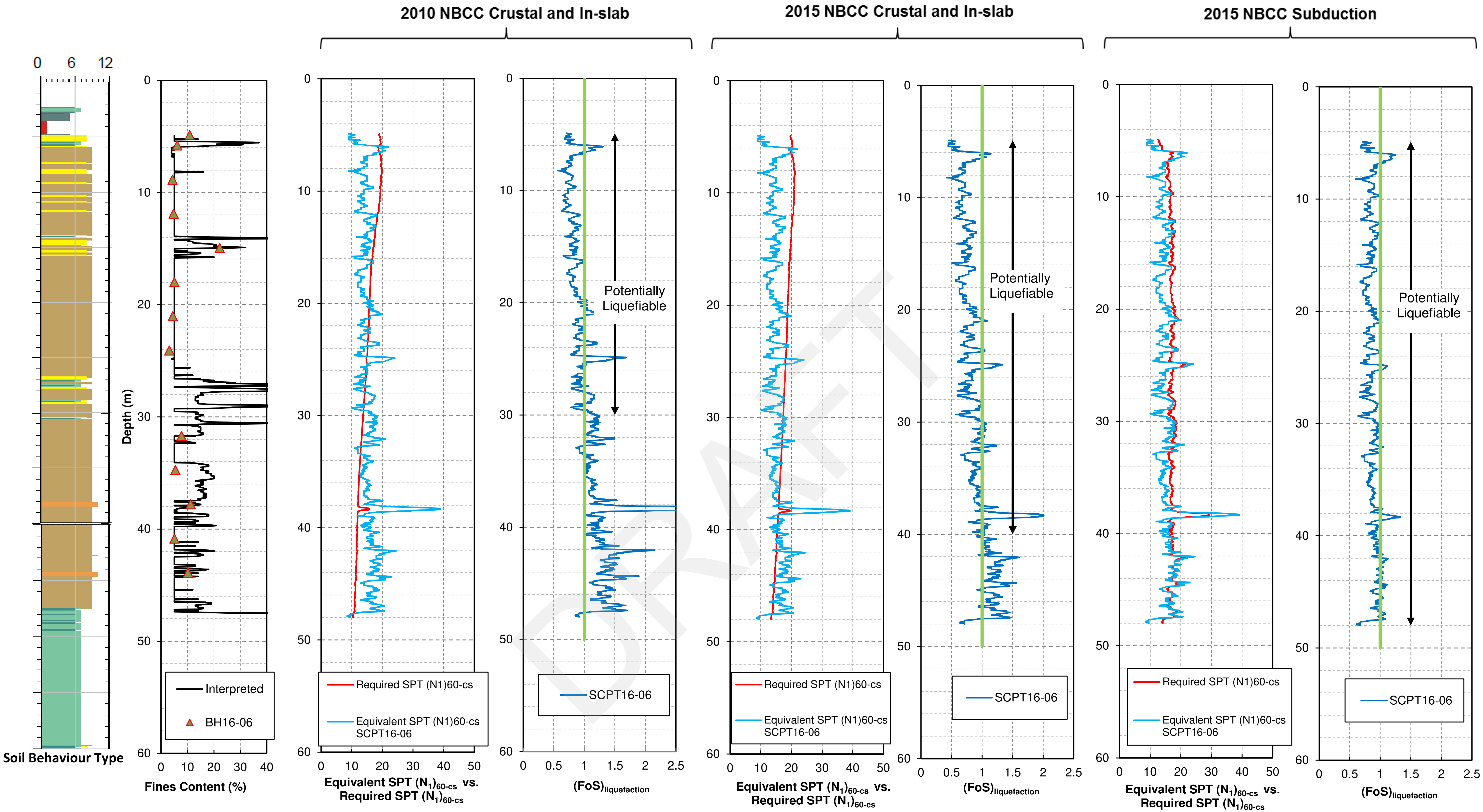
CLIENT	CDM SMITH CANADA ULC	PROJECT	AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM DELTA, BC
CONSULTANT	YYYY-MM-DD: 19 DEC 2017	TITLE	RESULTS OF SITE RESPONSE ANALYSES 2015 NBCC INTERFACE - RISER SHAFT
Golder Associates	PREPARED: YEW		
	DESIGN: YB		
	REVIEW: ---		
	APPROVED: ---		

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-28



After Robertson

Zone	Soil Behavior Type
9	Very stiff fine-grained soils
8	Very stiff Sand to clayey Sand
7	Gravelly Sand to Sand
6	Sands: Clean Sand to Silty Sand
5	Sand Mixtures: Silty Sand to sandy Silt
4	Silt Mixtures: Clayey Silt to Silty Clay
3	Clays: Clay to Silty Clay
2	Organic Soils and Peats

CLIENT
CDM SMITH CANADA ULC

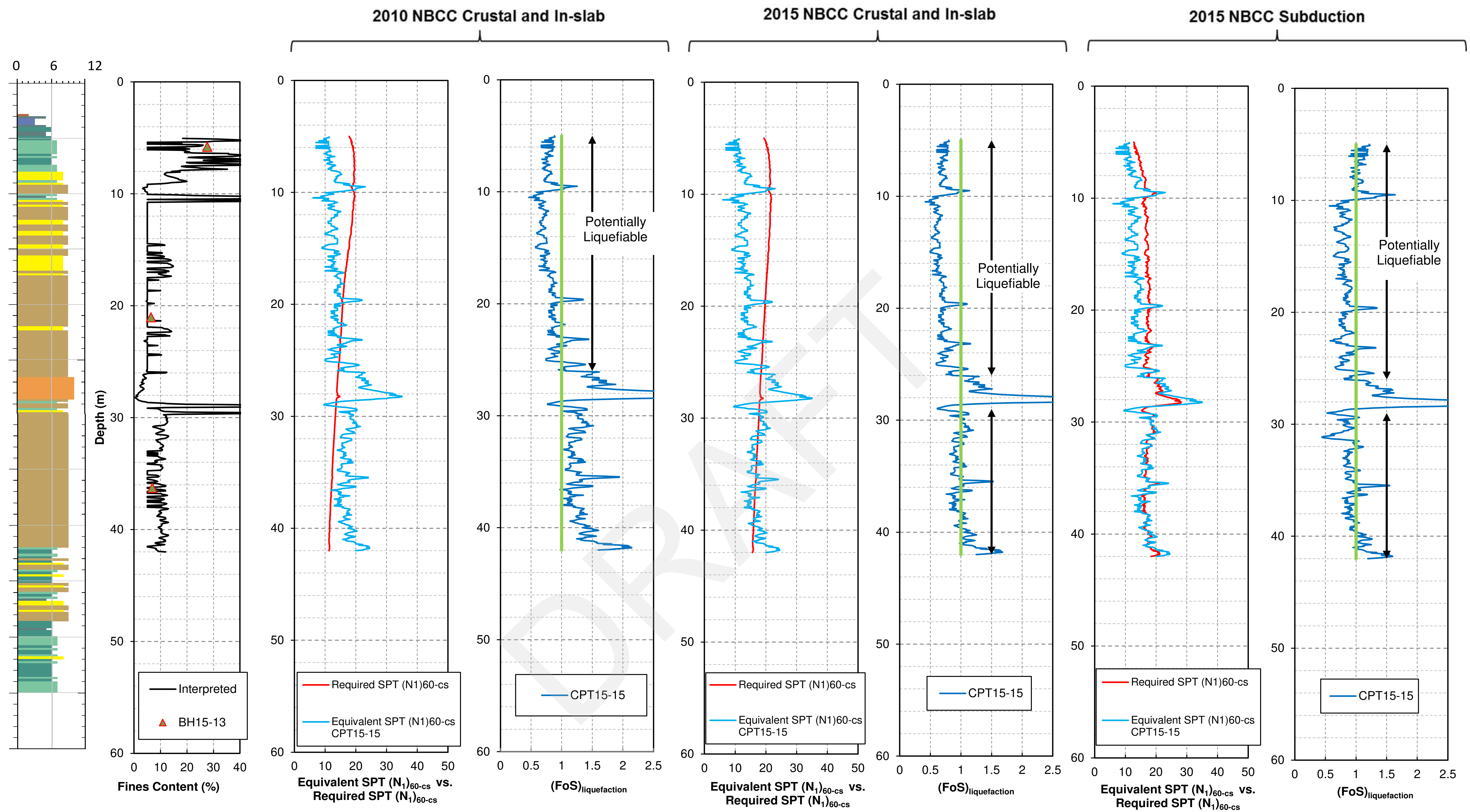
PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
DEPTH OF LIQUEFACTION OUTFALL SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-29



After Robertson (1990)

Zone	Soil Behavior Type
9	Very stiff fine-grained soils
8	Very stiff Sand to clayey Sand
7	Gravelly Sand to Sand
6	Sands: Clean Sand to Silty Sand
5	Sand Mixtures: Silty Sand to sandy Silt
4	Silt Mixtures: Clayey Silt to Silty Clay
3	Clays: Clay to Silty Clay
2	Organic Soils and Peats

CLIENT
CDM SMITH CANADA ULC

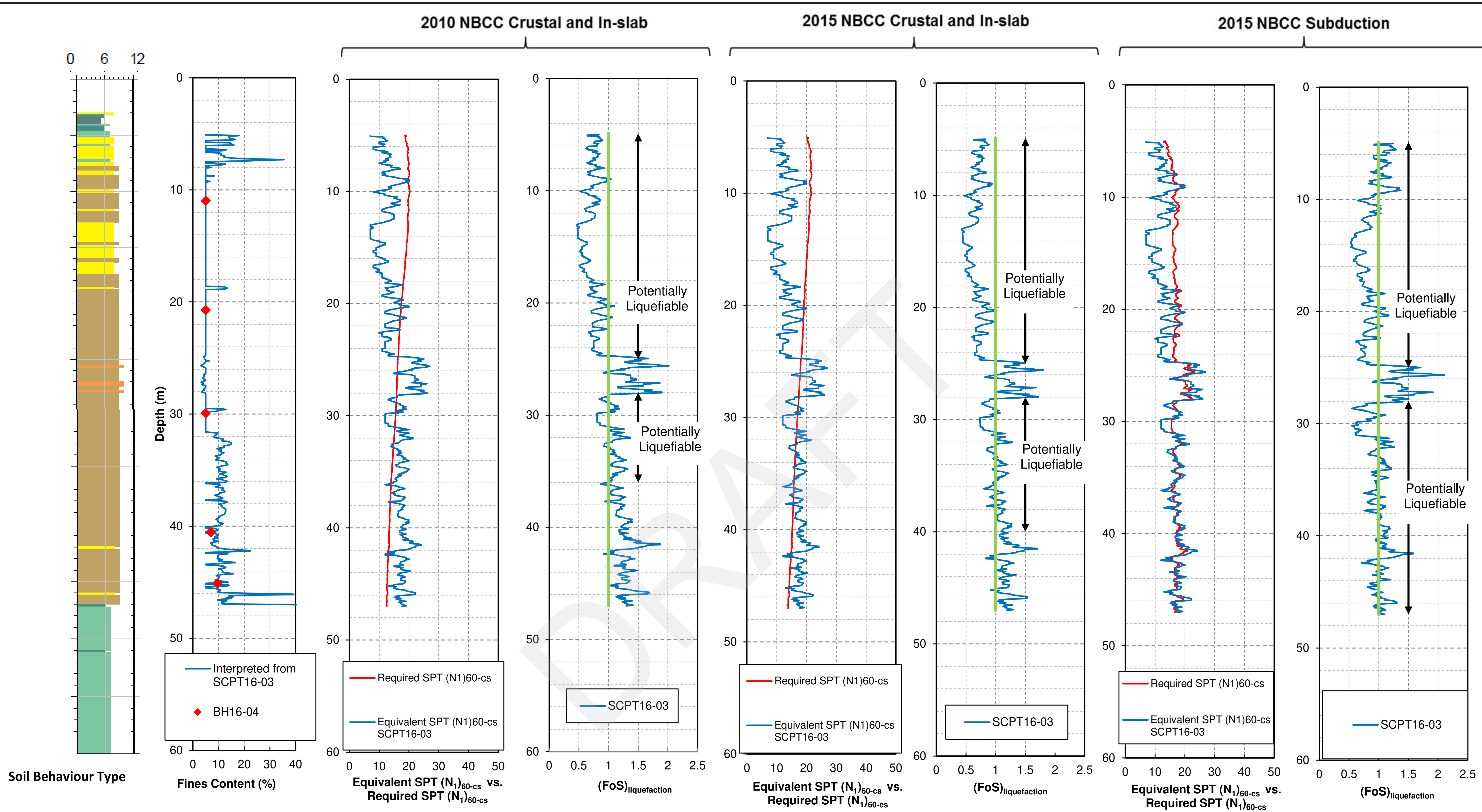
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

TITLE
DEPTH OF LIQUEFACTION EFFLUENT SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-30



After Robertson (1990)

Zone	Soil Behavior Type
9	Very stiff fine-grained soils
8	Very stiff Sand to clayey Sand
7	Gravelly Sand to Sand
6	Sands: Clean Sand to Silty Sand
5	Sand Mixtures: Silty Sand to sandy Silt
4	Silt Mixtures: Clayey Silt to Silty Clay
3	Clays: Clay to Silty Clay
2	Organic Soils and Peats

CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

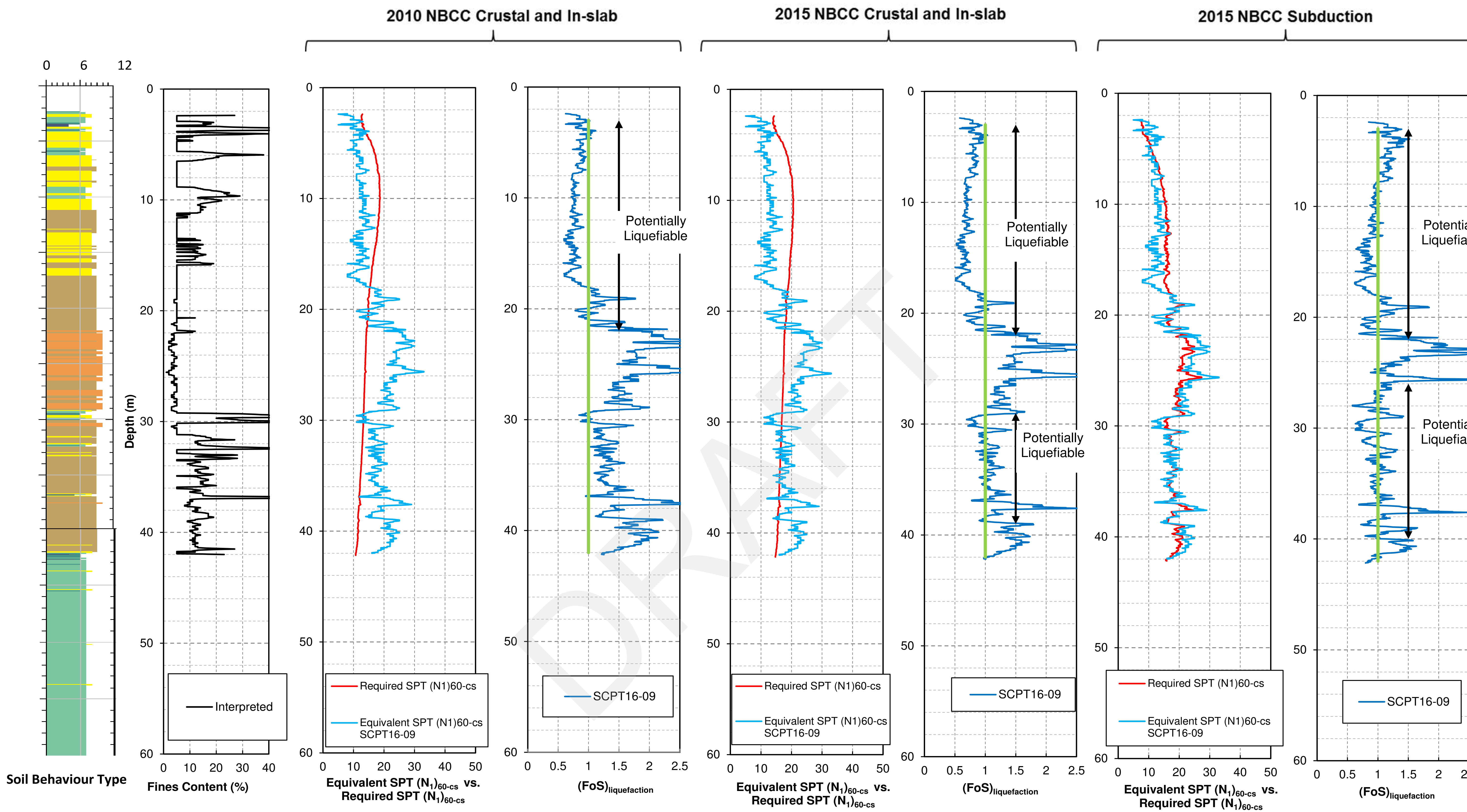
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
DEPTH OF LIQUEFACTION FUTURE SHAFT

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-31

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



After Robertson

Zone	Soil Behavior Type
9	Very stiff fine-grained soils
8	Very stiff Sand to clayey Sand
7	Gravelly Sand to Sand
6	Sands: Clean Sand to Silty Sand
5	Sand Mixtures: Silty Sand to sandy Silt
4	Silt Mixtures: Clayey Silt to Silty Clay
3	Clays: Clay to Silty Clay
2	Organic Soils and Peats

CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

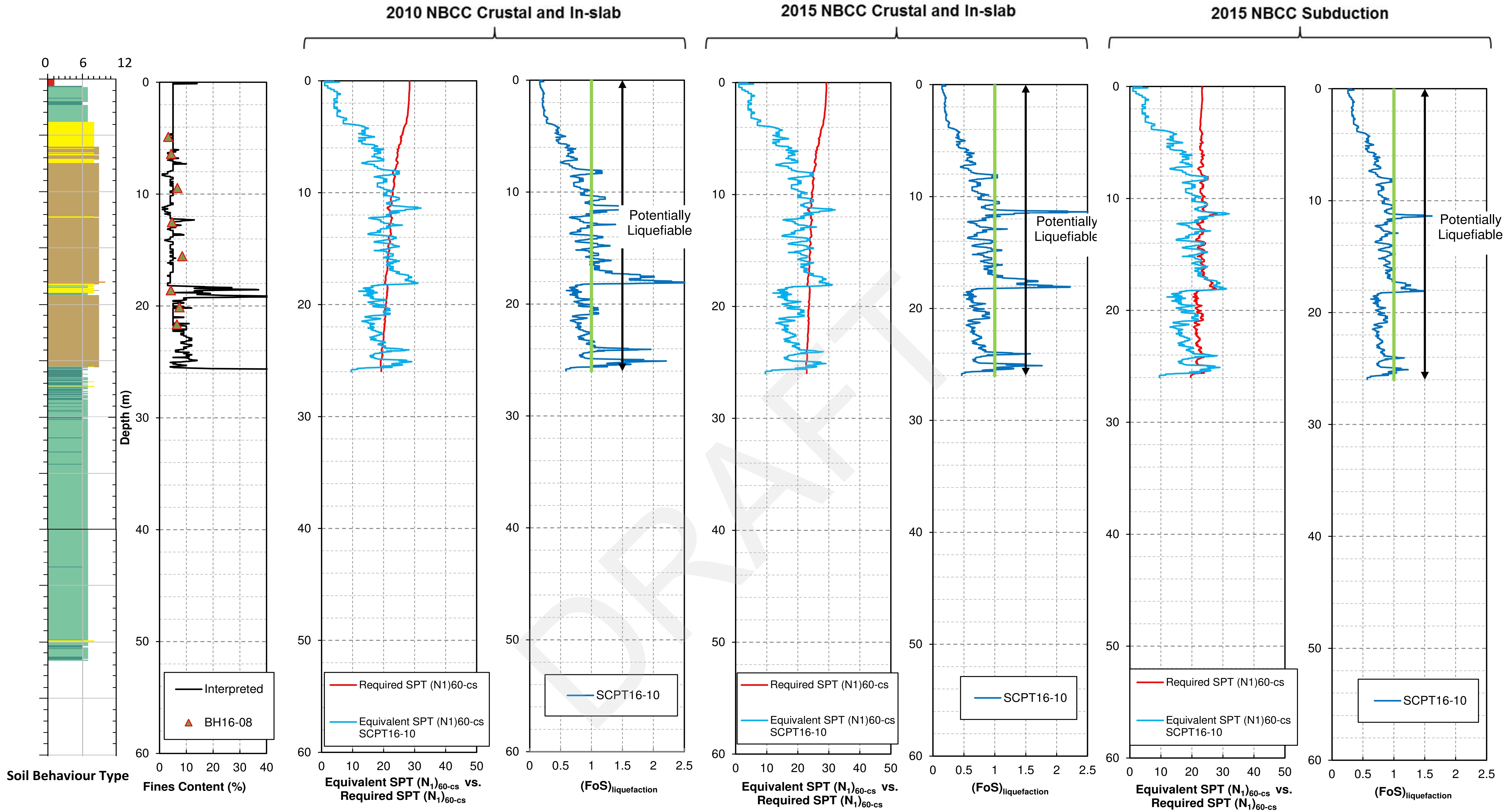
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
DEPTH OF LIQUEFACTION NEARSHORE

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-32

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



After Robertson (1990)

Zone	Soil Behavior Type
9	Very stiff fine-grained soils
8	Very stiff Sand to clayey Sand
7	Gravelly Sand to Sand
6	Sands: Clean Sand to Silty Sand
5	Sand Mixtures: Silty Sand to sandy Silt
4	Silt Mixtures: Clayey Silt to Silty Clay
3	Clays: Clay to Silty Clay
2	Organic Soils and Peats

CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

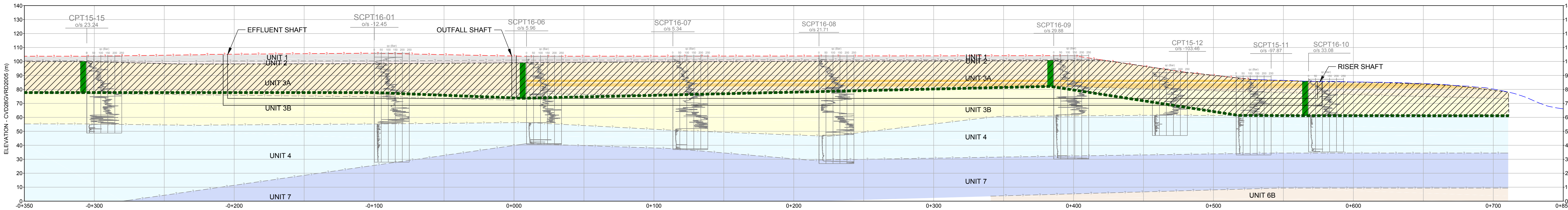
CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
DEPTH OF LIQUEFACTION RISER SHAFT

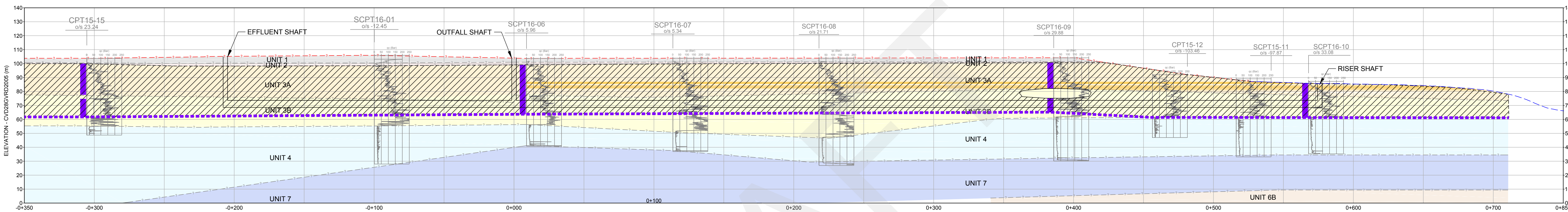
PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-33

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures



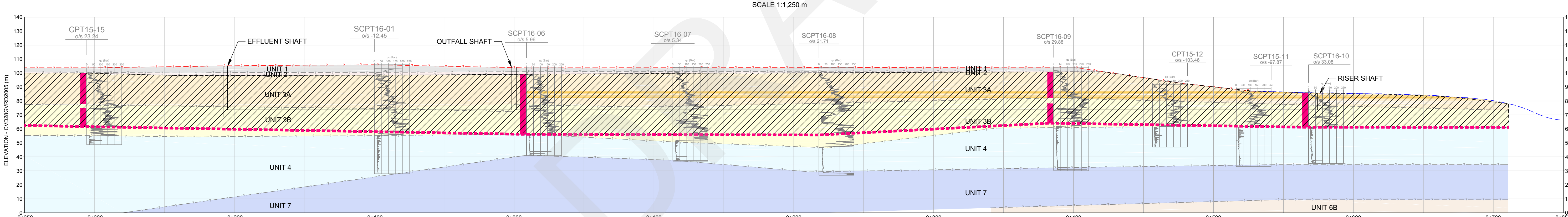
2010 NBCC - CRUSTAL AND INSLAB

SCALE 1:1,250 m



2015 NBCC - CRUSTAL AND INSLAB

SCALE 1:1,250 m



2015 NBCC - SUBDUCTION

SCALE 1:1,250 m

DRAFT

0 50 100

1:1,000 METRES

NO VERTICAL EXAGGERATION

LEGEND

CPT15-15 — DENOTES TEST HOLE TYPE, INVESTIGATION YEAR AND ID NUMBER

o/s 23.24 — DENOTES PERPENDICULAR DISTANCE FROM TEST HOLE TO SECTION LINE IN METRES

qc (Bar) 0 50 100 150 200 250 — DENOTES CONE PENETRATION TEST TIP RESISTANCE (Bar)

LIQUEFACTION EXTENT

2010 NBCC - CRUSTAL AND INSLAB

2015 NBCC - CRUSTAL AND INSLAB

2015 NBCC - INTERFACE

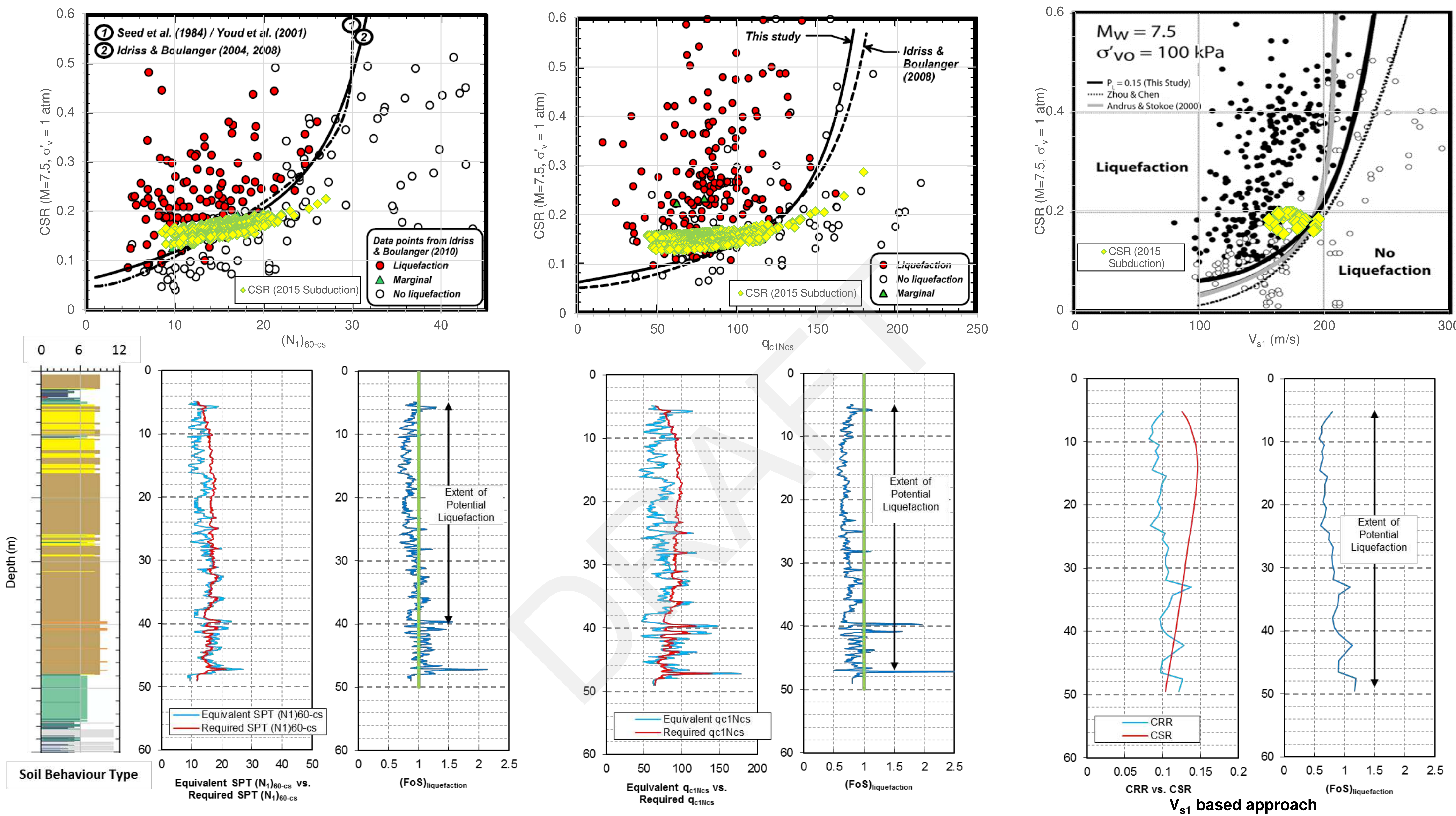
STRATIGRAPHY LEGEND

- UNIT 1 - FILL
- UNIT 2 - OVERBANK DEPOSITS
- UNIT 3A - FRASER RIVER SAND (LOOSE TO COMPACT)
- UNIT 3B - FRASER RIVER SAND (COMPACT TO DENSE)
- UNIT 4 - MARINE DEPOSIT
- UNIT 6B - GLACIAL DEPOSITS
- UNIT 7 - GLACIOMARINE DEPOSIT

NOTE

1. ELEVATIONS ARE IN METERS AND REFER TO CVD28GVRD2005 = 100 METERS PLUS GEODETIC DATUM.

CLIENT	CDM SMITH CANADA ULC
PROJECT	ANNACIS ISLAND WWTP TRANSIENT MITIGATION AND OUTFALL DELTA, B.C.
CONSULTANT	Golder Associates
YYYY-MM-DD	2017-12-22
DESIGNED	V. FERNANDO
PREPARED	A. WONG
REVIEWED	V. FERNANDO
APPROVED	V. FERNANDO
TITLE	EXTENT OF LIQUEFACTION
PROJECT NO.	1525010
PHASE/TASK	2200
REV.	A
FIGURE	3-34



After Robertson (1990)

Zone	Soil Behavior Type
9	Very stiff fine-grained soils
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3	Clays: Clay to Silty Clay
2	Organic Soils and Peats

CLIENT
CDM SMITH CANADA ULC

PROJECT
AIWWTP TRANSIENT MITIGATION AND OUTFALL SYSTEM
DELTA, BC

CONSULTANT
Golder Associates

YYYY-MM-DD	19 DEC 2017
PREPARED	YEW
DESIGN	YB
REVIEW	---
APPROVED	---

TITLE
EXTENT OF LIQUEFACTION – VARIOUS APPROACHES

PROJECT No.	PHASE	Rev	FIGURE
1525010	2100	C	3-35

O:\Active\2015\3 Proj\1525010 CDM_Annacis Island WWTP\GEO\6.0 Deliverables\6.2 Tech Memos\3 1D Ground Response Analyses\Rev 0\Figures

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CDM Smith
cdmsmith.com