Golder Associates

TECHNICAL MEMORANDUM

DATE October 19, 2015 **PROJECT No.** 1314470516-044-TM-Rev0

TO Greg Beaveridge, P. Eng., Struct.Eng., M.I.Struct.E / Craig Work, P. Eng.
Herold Engineering Ltd.

CC Bruce Downing, P. Eng. / Toby Seward, City of Nanaimo

FROM Thomas Madden, E.I.T./
Richard C. Butler, P. Eng., FEC **EMAIL** tmadden@golder.com

SECANT PILE WALL ANALYSIS
AUXILIARY SPILLWAY, LOWER COLLIERY DAM
NANAIMO, BC

This technical memorandum presents the basis of design Golder Associates Ltd. (Golder) has adopted for the proposed secant pile wall at the auxiliary spillway at Colliery Dam, Nanaimo, BC. The purpose of the geotechnical analysis presented herein is to estimate the minimum pile embedment required to achieve cantilever conditions and provide the structural engineer with the bending moment, shear stress and deflection profiles along the pile as input to the overall design of the secant pile wall. Design assumptions and key constraints associated with the design of the retaining wall are also presented herein.

This technical memorandum should be read in conjunction with the **"Important Information and Limitations of this Report"** which is attached following the text of this memorandum. The reader's attention is specifically drawn to this information as it is essential for proper use and interpretation of this report.

1.0 INTRODUCTION

Excavation for the foundations of the weir and bridge structures of the proposed auxiliary spillway will be in the range of four to five metres below the groundwater table and the adjacent reservoir level. The sandy soils which will be encountered in the excavation will be unstable when excavated at these depths below the groundwater table, and must be controlled by incorporation of measures to maintain the stability of the upstream "soil plug" and limit groundwater ingress into the excavation.

A number of options for controlling the groundwater have been considered as part of the project design. Following consultations between Golder, City of Nanaimo, Herold Engineering Ltd. (Herold) and Copcan Civil Ltd., the secant pile wall option was selected for detailed design. The secant pile wall will act as both a temporary retaining wall (during construction) and as a permanent (long term) cut-off wall for seepage control.

The cut-off wall will extend from about 72 m elevation (at or above the groundwater table) through the sandy soil layers into the lower permeability underlying glacial till. The cut-off wall will extend across the west side of the excavation, required for construction of the labyrinth weir and bridge structures, and will provide temporary support of the upstream "soil plug" during construction of the permanent structures. The cut-off will also be incorporated into the permanent structure as a means to reduce uplift pressures on the foundations and slabs on grade, and to reduce groundwater seepage to the drainage system and the downstream spillway channel.

The proposed secant pile cut-off wall will require the excavation to be carried out in a staged manner:

- Stage 1 excavation – Excavate to a suitable elevation from which the cut-off wall would be constructed.
- Stage 2 excavation – Excavate downstream of the cut-off wall to subgrade level (top of till-like material) to permit construction of the labyrinth weir and bridge structures.
- Stage 3 excavation – Removal of the soil plug and cut-off wall in the forebay area following erection of the weir, the bridge, and related downstream structures. The section of secant pile wall extending outward on either side of the forebay is to be retained as a permanent wing wall of the weir structure.

The proposed secant piles, or caissons, are 900 mm diameter cast-in-situ concrete piles constructed within the overburden, and typically constructed using a large drill rig with a cutting head. The proposed secant pile, or caisson, wall is approximately 29.4 m long. It will consist of a row of overlapping primary (reinforced) and secondary (unreinforced) cast-in-situ concrete piles forming a continuous retaining and seepage cut-off structure. The primary caissons are cast-in-situ concrete piles with steel "I" or "H" section reinforcements and are embedded into the till. The secondary caissons are cast-in-situ unreinforced concrete piles and are also embedded into the till.

The centreline to centreline horizontal spacing between primary and secondary caissons is typically 750 mm and the spacing between consecutive primary caissons (or secondary caissons) is 1.5 m. The minimum overlap required between adjacent primary and secondary piles or caissons is 150 mm on both sides of the caissons (with the exception of end caissons).

2.0 SUBSURFACE CONDITIONS

Based on available testhole information (TP15-01, BH15-01 and BH15-02) from our geotechnical investigations carried out in August 2015, the subsurface conditions underlying the proposed secant pile wall comprises compact sand and gravel soils to elevations ranging from 72.2 m to 72.0 m, approximately 3 m below original ground surface. Compact sand deposits, with minor amounts of silt, underlie the coarser granular soils and extend to elevations of about 71.1 m to 68.0 m at individual testholes, which in turn are underlain by soft to stiff silty clay, with varying proportions of sand. Test pit TP15-01 was terminated within this clayey deposit at an elevation of approximately 70.3 m. A dense to very dense sand stratum or layer, with varying amounts of silt and gravel, was encountered underlying the fine-grained deposits within BH15-01 and BH15-02 at elevations of 69.5 m and 68.6 m, respectively.

Very dense glacial till-like soils, containing cobbles and possible boulders, were encountered underlying these deposits within BH15-01 and BH15-02, with both boreholes terminated within these glacial deposits at elevations of 57.5 m and 61.7 m, respectively.

Groundwater was encountered at elevations ranging from roughly 70.1 m to 71.3 within TP15-01, BH15-01 and BH15-02.

The subsurface conditions of the general site are presented in the Golder report titled "Auxiliary Spillway – Preliminary Design Report, Colliery Dams, Nanaimo, BC", dated September 4, 2015".

3.0 PARAMETERS FOR DESIGN

Based on the results of the recent geotechnical investigation outlined above, the ground conditions and soil parameters considered for the secant pile wall design are summarized below in Tables 1 and 2.

Table 1: Stratigraphic Units for Secant Pile Wall Design

Approximate Top of Unit Elevation	Sand and Gravel Mixtures, to Sand	Sandy Silty Clay	Silty Sand with varying proportions of Gravel	Till-Like Soil
BH15-01	74.7 m	70.0 m	69.5 m	67.8 m
TP15-01	74.7 m	71.1 m	Not Confirmed	Not Confirmed
BH15-02	74.4 m	70.0 m	68.6 m	67.3 m

Groundwater conditions for the design of the secant pile wall have been assumed to be equal to elevation 71.6 m, corresponding to the normal operating water level for the adjacent reservoir.

Table 2: Soil Parameters for Secant Pile Wall Design

Soil Parameter	Sand and Gravel to Sand	Silty Clay to Clayey Silt	Silty Sand	Till-Like Soil
Unit Weight (kN/m^3)	18	17	17.5	20
Angle of Friction (degrees)	35	28	35	38
Coefficient of active earth pressure (K_a) – Coulomb theory	0.22	0.30	0.22	0.20
Coefficient of passive earth pressure (K_p) (Factor of Safety = 2 on peak) – Coulomb theory	4.6	2.4	4.6	6.4
Pile-Soil Interface Friction Angle (degrees)	23	19	23	25

4.0 SECANT PILE WALL GEOTECHNICAL DESIGN

The secant pile wall shall consist of essentially vertical cast in-situ concrete caissons constructed with the following characteristics:

- Top of secant caisson/pile wall will be elevation 72.1 m.
- Diameter of secant caisson/pile is 0.9 m.
- Steel reinforcement (“I” or “H” sections) will be installed in primary caissons, as indicated in Herold’s drawings.

Two cases were considered for design:

- Case A - The central section of the secant pile wall, with soil supported on the upstream side of the wall, and the excavation taken down to the top elevation of till-like soils on the downstream side. This represents the temporary loading condition during construction.
- Case B - The sections of secant piles at either end of the secant wall, will support soil on the downstream side of the secant piles, corresponding to the backfill of the weir, and hydrostatic pressure, corresponding to the reservoir water level, on the upstream side.

The secant pile wall analysis was carried out for the two cases outlined above, based on the subsurface conditions and soil properties presented in Tables 1 and 2. The penetration depth of the cantilever wall was determined by calculating the active, passive, surcharge and water pressures acting on either side of the wall until static equilibrium was satisfied, where the sum of all horizontal forces and the sum of all moments about any point equaled zero.

The pile analysis was carried out using the software program LPILE (Version 2013.7.05) by Ensoft Inc., based on the results of the earth pressure analysis and select pile properties. The structural pile properties, presented in Table 3, were selected in consultation with Herold as input to the assessment.

Table 3: Structural Properties of Secant Pile used for Design

Design Parameter	**Value**
Pile Outside Diameter	900 mm
Core Diameter*	406 mm
Core Wall Thickness*	19.6 mm
Concrete Compressive Strength	30 MPa
Max. Coarse Aggregate Size	19.05 mm
Yield Stress of Core	345 MPa
Elastic Modulus of Core	200 GPa

* The core diameter and core wall thickness were provided by Herold based on an equivalent moment of inertia for a W460x97 wide flange beam, in order to satisfy the input conditions of the LPile software.

A uniform surcharge load of about 52 kPa was applied to the wall in the analysis, equivalent to the stresses induced by soil backfilled to elevation 75 m, adjacent to the secant pile wall.

Based on the results of the analysis, the required pile embedment depth will depend on the ground conditions encountered during construction, primarily the top elevation of the till-like soils. Considering the lateral loading requirements, the estimated pile embedment depths into the dense to very dense till-like soils are presented in Table 4 below based on the available subsurface information combined with a range of assumed elevations of top of till. It should be noted that this table is provided for information purposes only and that the actual final embedment depth of each secant pile should be confirmed in the field by the Engineer, and as per the technical specifications, referenced in Section 5.3.

Table 4: Estimated Pile Embedment Depths of Secant Piles

Approximate Top Elevation of Very Dense Till-Like Soil	Total Pile Embedment	Minimum Embedment into Till-like Soils
+68.5 m	8.6 m	5.0 m
+68.0 m	9.7 m	5.6 m
+67.5 m	10.7 m	6.1 m
+67.0 m	11.8 m	6.7 m
+66.5 m	12.9 m	7.3 m

The temporary loading condition, Case A, was considered to be the critical case for design. Based on the lower top elevation of till of +67.3 m, as encountered during Golder's subsurface investigations, it is estimated that a pile embedment of 6.3 m is required in order to achieve the pile fixity conditions noted above. The point of fixity for the pile is estimated to be approximately 7.6 m below the top of the pile, or roughly 2.8 m below the top of the very dense till-like soils based on this model. The profiles of the corresponding estimated pile deflection, shear force and bending moment within the pile are shown in Figure 1.

4.1 Performance Criteria

A performance-based approach has been considered for the detail design of the proposed secant pile wall. The design has taken the following into consideration:

- The design is in general compliance with the Canadian Foundation Engineering Manual (2006).
- Design life of secant pile wall is 50 to 100 years as a permanent cut-off for seepage control.
- The maximum total lateral deflection of the secant pile wall during temporary construction conditions, considering loss of soil support downslope of the proposed retaining wall is up to 50 mm.

5.0 REFERENCE DOCUMENTS

The following information has been considered for detail design of the secant pile wall:

5.1 Codes and Guidelines

- Canadian Geotechnical Society (2006), "Canadian Foundation Engineering Manual", 4th Edition.

5.2 Geotechnical Data

- Golder Associates Ltd., "Auxiliary Spillway – Preliminary Design Report, Colliery Dams, Nanaimo, BC", September 4, 2015.
- Golder Associates Ltd., "Technical Memorandum: Geotechnical Design Recommendations, Auxiliary Spillway, Lower Colliery Dam, Nanaimo, BC", September 4, 2015.

5.3 Specifications

- Golder Associates Ltd., "Secant Caisson Wall Technical Specifications, Nanaimo Colliery Dam Auxiliary Spillway, Nanaimo, BC", October 19, 2015.

5.4 Drawings

- Herold Engineering Ltd., "General Notes", Drawing No. S101, Rev. 1 – Issued for Coordination, October 15, 2015.
- Herold Engineering Ltd., "Cut Off Wall Plan – Secant Pile Layout and Details", Drawing No. S202, Rev. 2 – Issued for Coordination, October 15, 2015.

6.0 CLOSURE

We trust that the contents of this technical memorandum meet your immediate requirements. Please contact the undersigned should you have any queries or require clarification of the contents.

GOLDER ASSOCIATES LTD.

Thomas Madden, E.I.T.
Geotechnical Engineer

Richard C. Butler, P. Eng., FEC
Principal

PROVINCE OF BRITISH COLUMBIA
R.C. BUTLER
PROFESSIONAL ENGINEER

TBM/RCB/kn

Attachment: Figure 1: Secant Pile – Lateral Deflection, Shear and Moment

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Important Information and Limitations of this Report

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder can not be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder can not be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

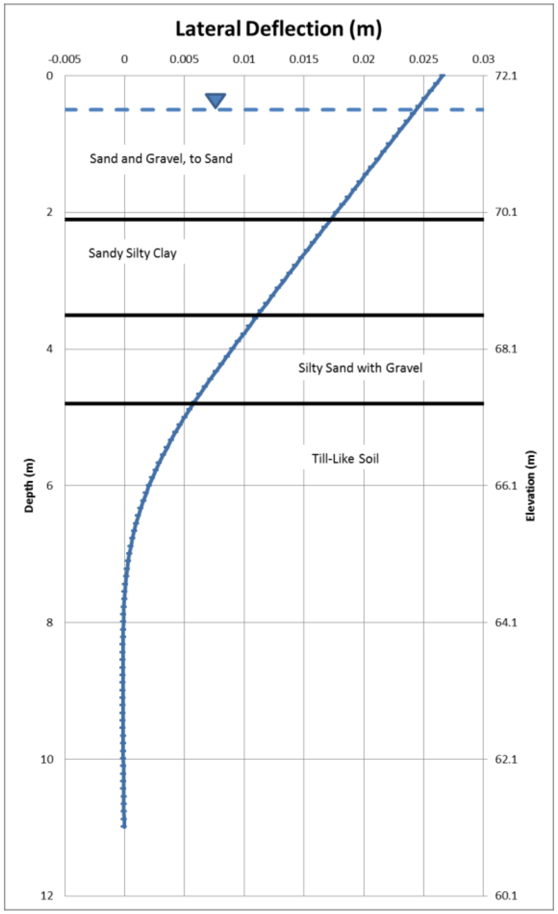
Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

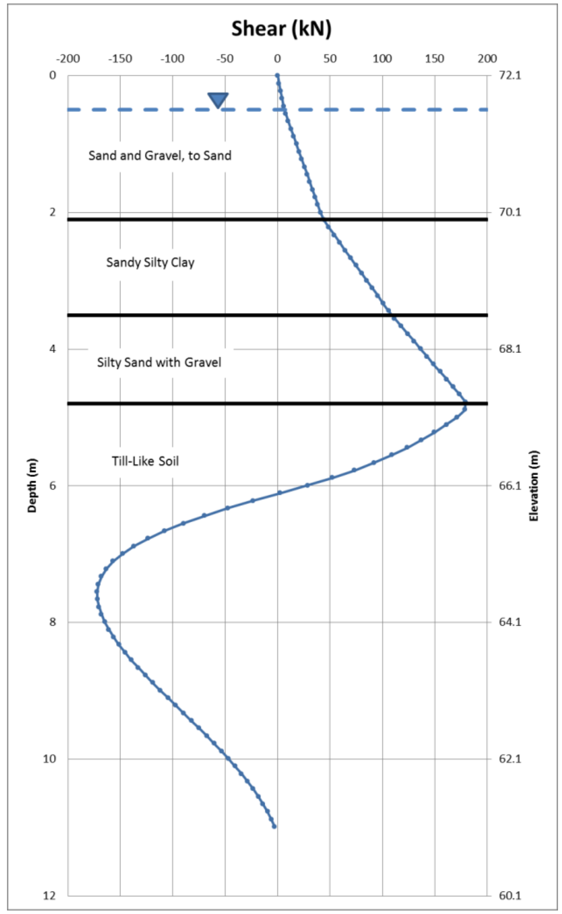
Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

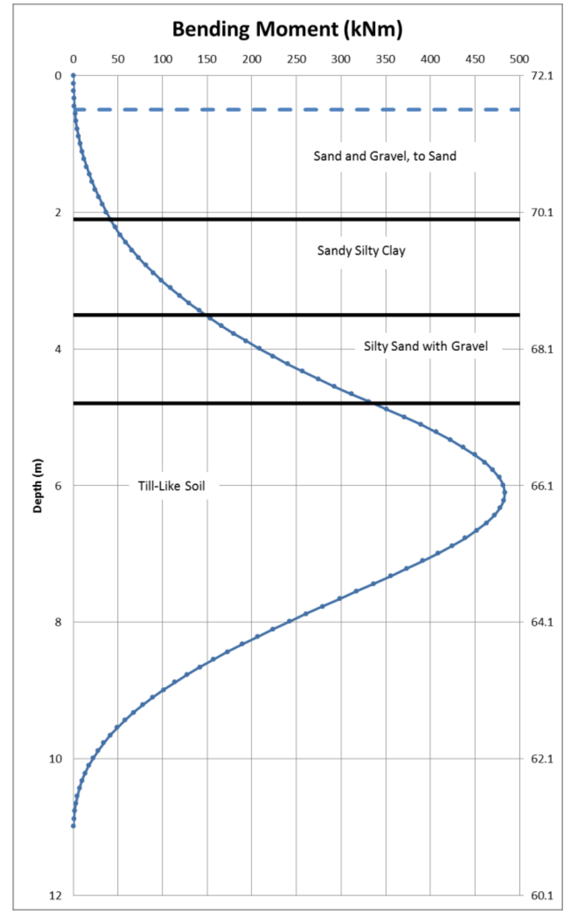
During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.







Note: Subsurface soil conditions based on BH15-02.

See Technical Memorandum 13-1447-0516, dated October 19, 2015 for pile details

PROJECT

CITY OF NANAIMO
COLLIERY DAM AUXILIARY SPILLWAY
NANAIMO, BC

TITLE

SECANT PILES
LATERAL DEFLECTION, SHEAR AND MOMENT

Golder Associates

PROJECT No. 13144470516			PHASE No. 4500	
DESIGN	TM	18OCT15	SCALE NTS	REV.
CADD	--	----	**FIGURE 1**	
CHECK	RCB	19OCT15		
REVIEW	RCB	19OCT 15		