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DEVELOPMENT OF STANDARD TWO HIGH SEGMENTAL CONCRETE BLOCK RETAINING WALL DESIGN AID

For Ministry of Forests Lands Resource Operations and Rural Development

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1. Introduction

At the request of the Ministry of Forests Lands Natural Resource Operations and Rural Development (MFLNRORD), SNT Geotechnical Ltd. (SNTG) developed a retaining wall design aid. The design aid is intended for use adjacent to the cut slopes of forestry roads and utilizes two high segmental concrete blocks as a gravity retaining wall structure with each concrete block 750mm high by 750mm wide by 1500mm long: referred to as an SRW2. The purpose of the design aid is to provide a set of generic (non-site specific) drawings and notes that can be used as a guide by a qualified Professional of Record (POR) who could be a Professional Engineer (P.Eng.), Professional Geoscientist (P.Geo.), Registered Forest Technologist (RFT), Registered Professional Forester (RPF), or Applied Science Technologist (AScT) and who is responsible for the design of the segmental concrete block retaining wall. Although the POR will utilize the design aid, he/she will still be required to prepare and seal site specific design drawings.

A retaining wall as per Engineers and Geoscientists of BC (EGBC) 2020, is a vertical or near-vertical structure constructed to hold back 'geotechnical materials' and safely deal with any hydrostatic pressure. Retaining walls can be created out of a variety of structural and geotechnical materials. Geotechnical materials include soil, rock, mineral ore, and lightweight fill such as pumice or bottom ash. Retaining walls typically stabilize soil and rock against downslope movement and provide lateral support for steep to vertical grade changes.

A Segmental Block Gravity Wall is defined (as per EGBC 2020) as a soil-retaining system utilizing manufactured interlocking blocks, usually of concrete, including lock-block walls and other proprietary walls. A gravity wall as per EGBC 2020 is a structure providing lateral support for a mass of soil that owes its stability primarily to its own weight and to the weight of the soil located directly above its base. It depends entirely on the weight of the stone or concrete masonry and of any soil resting on the masonry or concrete foundation slab for its stability.

2. Existing Regulatory Requirements

The following are key items noted in the referenced technical documents.

2.1. Engineers and Geoscientists of BC (EGBC) 2020

EGBC developed a professional Practice Guideline titled "Retaining Wall Design, Civil and Transportation Infrastructure, Version 1.1." Key applicable items discussed as follows:

Guidelines do not apply to walls less than 1.2m high unless failure would impact a structure or impact life safety. It is noted that walls less than 1.2m high would still benefit from engineering design, especially if future access to replace these walls will be limited.

For walls 1.2m to 3m high, typical maximum allowable static plus seismic related wall movement is such to prevent negative batter. Field reviews required and the use of yielding or non-yielding lateral earth pressures required, designed not to collapse, and independent reviews not required.

For the case of a retaining wall with a retained fill slope angle or toe slope steeper than 2H:1V, or where soil conditions merit, the global stability needs to be addressed and the slope needs to be considered in the wall design.

The top 300mm of material in front of the wall is disregarded (passive resistance).

Adequate drainage is required unless the backfill is free draining (defined as less than 5% by mass passing 0.075mm sieve on the fraction smaller than 2mm).

Typical Factors of Safety (FoS)

- Global long-term:
  - 1) static:1.5
  - 2) 1 in 475 seismic event: 1.2
  - 3) 1 in 2475 seismic event: 1.1
- External: Sliding 2.0 if passive resistance in front of wall is included, Sliding 1.5 if passive resistance is excluded, Overturning 2.0, Bearing 3.0 to 4.0

2.2. American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges

AASHTO global resistance factors are as follows:

- 0.75 where parameters are well defined and the slope does not support or contain a structural element
- 0.65 where the parameters are based on limited information or the slope contains or supports a structural element
- Methods of Limit Equilibrium Analysis: Modified Bishop, simplified Janbu or Spencer.
- The weight of filling material directly over an inclined or stepped rear face may be considered as part of the effective weight of the abutment
- Passive resistance shall be neglected unless base of the wall extends below the depth of maximum scour, freeze-thaw or other disturbances
- 2002 Chapter 5 – Minimum global FoS of 1.3 to be used for walls designed for static loads except 1.5 for walls that support abutments, buildings and critical utilities

2.3. Canadian Foundation Engineering Manual

The Canadian Foundation Engineering Manual (CFEM) 2006 recommends a safety factor of 1.5 to 2.0 for earth-retaining structures and the following load and resistance factors (ultimate states):

- Dead loads 1.25
- Live loads 1.5
- Water Pressures 1.25
- Friction 0.8

2.4. Ministry of Transportation and Infrastructure (MoTI) Technical Circular T-04/17 and Supplement to Canadian Highway Bridge Design Code (CHBDC) S6-14

MoTI 2017 considers slope angles steeper than 70 degrees to be designed as retaining walls and the design must follow the methods outlined in the MoTI Supplement and CSA CHBDC S6-14. The typical design life for time dependent components shall be 100 years. The factor of safety for pseudo static analyses shall be 1.1. The following Factors of Safety are recommended:

- Global Stability 1.24 to 1.85 (depending on consequence factor and degree of understanding). For sites of low understanding and low consequence the recommended global FoS is 1.45.

2.5. Canadian Highway Bridge Design Code (CHBDC) CAN/CSA-S6-19

The CHBDC refers to a consequence factors for Ultimate States and Serviceability states that varies from 0.9 for high consequence to 1.15 for low consequence.

Recommended geotechnical resistance factors vary depending on the degree of site understanding as follows:

- Bearing 0.45 to 0.6
- Overturning 0.45 to 0.55
- Sliding (frictional) 0.7 to 0.9
- Facing interface sliding 0.75 to 0.95
- Passive resistance 0.4 to 0.55
- Settlement or lateral movement 0.7 to 0.9
- Global permanent 0.6 to 0.7

2.6. MFLNRORD

The MFLNRORD Engineering Manual provides design guidance for retaining structures greater than 1.5m high. It also states that similar requirements and processes should be considered for retaining structures 1.5m high and less. The design life for retaining walls must be at least 45 years. The following Factors of Safety are recommended:

- Bearing 2.5
- Sliding 1.5
- Overturning 2.0
- Global Stability 1.5

3. Specific Requirements and Constraints of the Design Aid

The recommended design assumptions and constraints for the SRW2 are as follows:

3.1. Design Factors of Safety

The typical degree of information collected and analyzed for small forestry walls adjacent to cut slopes is low. In addition, there are typically no structural elements in the slope downslope of the wall. The failure consequence is typically considered to be low (slumping onto the road) with the primary consequence being required clean up and repair/replacement of the blocks. There are some situations where failure may result in environmental damage (adjacent to a stream or other site where sediment input may cause environmental damage or where failure may initiate a landslide that has impact outside the road right of way). These sites require specialized geotechnical review.

Considering the above discussion and the various technical guidance documents noted in Section 2 it is recommended the following approximate FoS are utilized for an SRW2:

- Bearing 2.0: Represents the typical FoS for limit states failure and not serviceability – as these small block structures are tolerant of significant deformation
- Sliding 1.5: Consistent with guidelines particularly if the passive resistance in front of the wall is not considered; however, see discussion in Section 4.2
- Overturning 2.0: Consistent with guidelines
- Global Stability - see discussion in Section 4.2
- Interblock 1.5: Consistent with sliding FoS
- Consistent with other MFLNRORD guidelines seismic is not considered

3.2. Retaining Wall Drain Requirements

The design aid will assume no pore pressures are developed above the road grade elevation. To achieve this free drainage state, drains will be required for all sites not considered free draining. Free draining sites are defined as sites having retained and in-situ soils with less than 5% by mass passing 0.075mm sieve on the fraction smaller than 2mm.

3.3. Free Draining Road Surface and/or Ditch

Drainage under or behind the SRW2 may be required in order to convey water along the inside road surface (for example to connect a ditch from either side of the wall) or to prevent surface erosion from the road surface runoff at the block-road surface contact. The drainage requirements for these sites are referred to as road drainage instead of wall drainage as they don't typically have an effect on the wall stability (other than potentially impacting the available passive resistance). The requirement for road drainage will depend on a number of factors including the presence of the retained fill slope angle, seepage, requirement for ditchline continuity, ability to in-slope the road, road surfacing quality, extent of road draining toward the site (i.e., is the site at the top of a convex grade change), length of the SRW2 and road grade.

3.4. Soil Types

The design aid is intended for non-cohesive soils – classified as sands and gravels as per the Unified Soil Classification System. Fine grained soils classified as silts or clays require site specific design and the design aid should not be used for such soils or sites.

3.5. Intersection of the Soil Retained Fill Slope Angle with Top Block

It is assumed the retained fill slope angle will typically intersect the centre of the top block (375mm from the road side edge of the top block). This provides a balance between allowing for some additional retained fill sloughing and maximizing the utility of the SRW2. If additional cut slope catch volume is desired or required (to store potential soil sloughing) the soil/wall intersection can be shifted upslope; however, the long-term design requirements will remain as it is assumed, over time, the available catch volume will eventually be reduced and the geometry will eventually match the design assumed geometry. Note the soil immediately behind the SRW2 will generally be looser than the in-situ soils unless compacted.

3.6. Retained Fill Slope Angle

Sites adjacent to forestry roads where low height cut slope retaining walls are constructed typically have extensive retained fills that are at or near their repose angle (as a result of raveling behind the proposed wall locations). These loose soil repose angles often range from 60% to 75%. Once the retained fill height exceeds about 5m the stability of a wall located at the toe of these raveling cuts is essentially governed by the global stability. However, it is difficult to achieve the recommended global FoS (as per Section 2) when the retained fill behind the wall is as steep as the design soil internal friction angle. As such, in low risk applications, there can be a reliance on the lower block burial (passive resistance) to achieve a higher FoS. Note for cut slope excavations applicable Occupational Health and Safety Regulations and guidelines must be followed. See Section 4.2 for further discussion on tolerable global stability FoS.

3.7. Levelling Pad

For SRW2 walls the placement and alignment of blocks is typically not critical (within reason). If the local soils have a cobble/boulder content less than 10% such that the oversized cobbles and boulders can easily be discarded during preparation of the sub-base, then a specialized levelling pad is not required (i.e., raking and smoothing the primarily local sand and gravels to match design longitudinal grade angle and batter angles is sufficient). The design aid is not intended for silts and clays and so a bearing surface constructed on top of these soil types is not covered in this design aid. Where a drain is required (in non-free draining soils) the drain and levelling pad should be integrated and be comprised of the same material to avoid sourcing and placing two different material types.

3.8. Design Internal Friction Angle

As per Day 2006 and reference to Navfac DM 7.1, SM and SP soils (see Appendix A) at 25% to 50% relative density typically have internal friction angles ranging from 29° to 33° (the internal friction angle is also a function of the particle angularity, mineralogy, and other factors). SW, GP, and GW soils at similar relative densities typically have friction angles between 30° and 36°. It is assumed little to no in-situ or laboratory shear testing will be conducted for the walls installed using this design aid.

3.9. Applied Soil Pressures

Segmental concrete block walls are relatively tolerant of deformations and as such it is assumed that wall rotation is sufficient to mobilized active and passive earth pressures.

4. Design and Site Conditions

4.1. Batter

The wall batter is defined as the wall face angle from vertical. Positive batter angles are denoted when the wall is angled in the upslope direction and negative batter angles when the wall is angled downslope. The greater the batter angle the more stable the wall is in rotation and sliding (see Figure 4.1) and a greater wall batter results in lower active soil pressures. The trade-off in batter is a reduction in wall height and an encroachment into the available road width. The height reduction is minimal for batter angles less than 15° (1.45m height at 15° batter verses 1.5m height with vertical wall); however, road encroachment is significant beyond batter angles of 10° (0.26m road encroachment at 10° batter and 0.39m road encroachment at 15°).

A SRW2 battered at 9.5° retaining soil with assumed effective angle of internal fiction of 30° degrees and sloped at 30° behind the SRW2 will have a FoS near 1.5 in sliding. If the wall batter is reduced to 3° the FoS reduces to less than 1.0. The FoS in rotation also reduces to below 2.0 at wall batter angles of less than 2°.

A minimum wall batter angle of 9.5° is recommended as it provides a good compromise between the FoS and road encroachment.

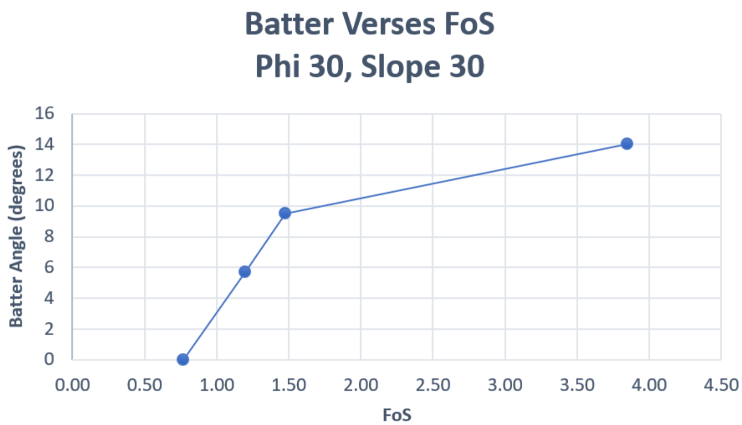

Figure 4.1 Wall batter angle verses FoS in sliding

4.2. Retained Fill Slope Angle

The steeper the retained fill slope angle above the SRW2 the lower the FoS of the wall in overturning and sliding for a given effective angle of internal friction (Figures 4.2A through 4.2E). For the range of effective angle of internal friction of 26.5° through 35° (assuming wall batter of 9.5°) retained fill slope angles can match the effective angle of internal friction angles and the FoS (sliding) will remain above 1.5 (note FoS in overturning are typically higher than 2.0 for these cases).

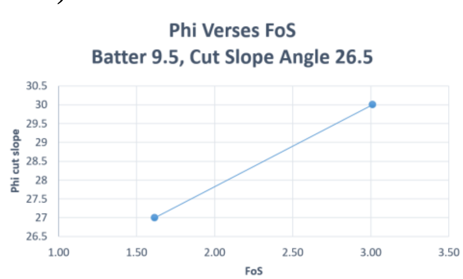

Figure 4.2A. Phi verses FoS (sliding) with retained soil fill angle of 26.5 degrees

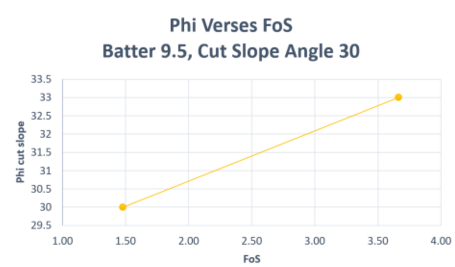

Figure 4.2B. Phi verses FoS (sliding) with retained soil fill angle of 30 degrees

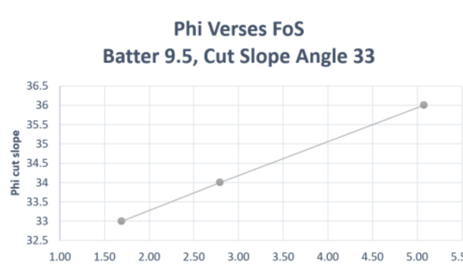

Figure 4.2C. Phi verses FoS (sliding) with retained soil fill angle of 33 degrees

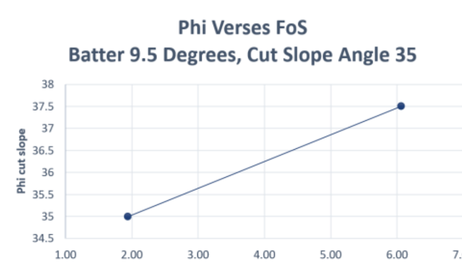

Figure 4.2D. Phi verses FoS (sliding) with retained soil fill angle of 35 degrees

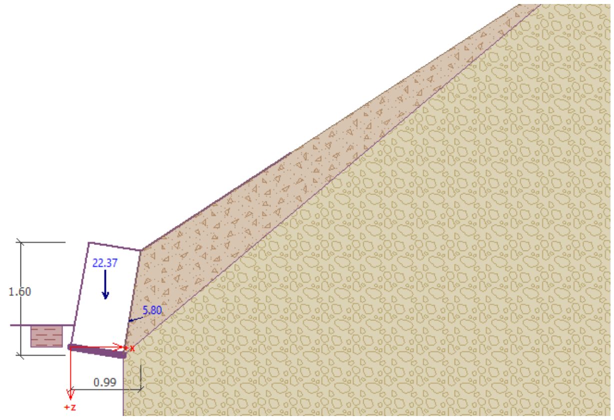

Figure 4.2E. Typical gravity wall analyses geometry

4.3. Soil Types, Shear Strength and Global Stability

The global stability is sensitive to the soil shear strength and slope angles. The drained shear strength (τ) can be expressed in terms of the effective stress parameters c' (effective cohesion intercept) and ϕ' (effective angle of internal friction) with the equation $\tau = c' + \sigma' \tan \phi'$. The design aid is intended for non-cohesive, non-cemented soils so c' is assumed to be negligible. Generally, to achieve a FoS of 1.5 (global stability) for an SRW2 the ϕ' needs to be approximately 10° higher than the slope angle up to a limited slope height (see Figures 4.3A through 4.3D). This requirement would limit the retained fill slope angle to below 26.6° (2H:1V) which is impractical for most situations requiring an SRW2 adjacent to a forestry road. Since many forestry roads are constructed with steep cut slope and fill slope angles that result in FoS marginally above 1.0 it is proposed the target FoS at least match the local adjacent FoS (see Figure 4.3E for typical analyzed global stability slip circle). Ideally the SRW2 FoS would be at least 15% higher than adjacent slopes. For slope angles of 29°, a ϕ' of 31° is required (within a reasonable slope height) to achieve a global FoS of 1.15. For retained fill slope angles of 31° and 33° a ϕ' of 35° and 37° generally achieves a FoS of 1.15.

The acceptance of global FoS approaching similar values as the adjacent slopes of similar soils is only recommended where the consequences of block movements or wall failure is considered low. Where the consequence of block movements or failure is moderate or high then the global FoS of 1.5 is required and SRW2 should be designed by qualified geotechnical engineers.

For relatively loose and rounded sand and gravel soils (25% relative density) ϕ' approximates 30° to 32° (Day 2006). To achieve a global FoS of 1.15 (for limited slope heights) the retained fill slope angle must be 29° or less. In areas of dense and angular sands and gravels where the SRW2 is constructed close to in-situ soils (limited fill behind the wall) or with the material behind the wall comprised of well compacted angular sands and gravels the ϕ' could range from 34° to 37°

(or higher) which would allow for retained fill slope angles of up to 33° (or 1.5H:1V). In areas of blocky angular cobble/boulder size colluvium retained fill slope angles could be increased to 37°.

The above discussion is provided for information and aid design justification purposes only. It is considered beyond the scope of most non-geotechnical engineers to accurately estimate the effective shear strength of exposed soils. However, it is expected that the POR for SRW2's will be able to estimate typical adjacent stable retained fill slope angles for non-cohesive soils based on local site conditions.

It is noted that interblock resistance against sliding and rotation has a high FoS (>2) and does not control the design process.

Since the wall stability is a function of the local soil shear strength and retained fill slope angle the target global FoS of 1.15 is generally achieved when the retained fill slope angle is 3° to 4° lower than the applicable internal angle of friction. It is recommended that the soil fill slope angle behind the SRW2 be a minimum of 3 degrees flatter than local stable cut slope angles.

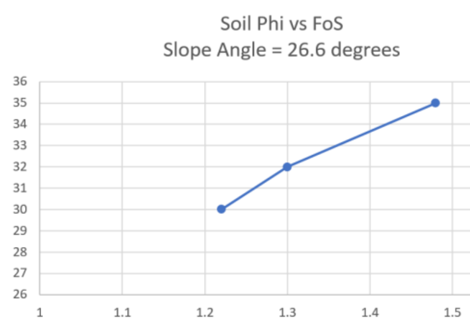

Figure 4.3A. ϕ'verses FoS (Global) retained fill slope angle= 26.6°

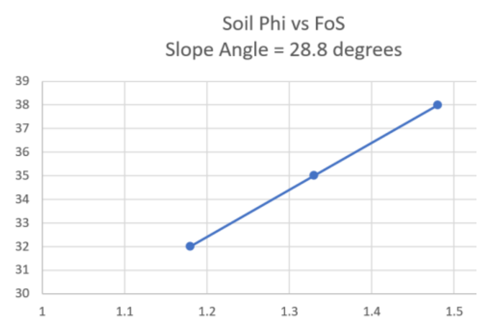

Figure 4.3B. ϕ' verses FoS (Global) retained fill slope angle= 28.8°

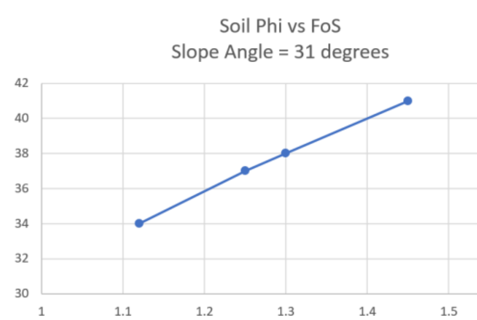

Figure 4.3C. ϕ'verses FoS (global) retained fill slope angle= 31°

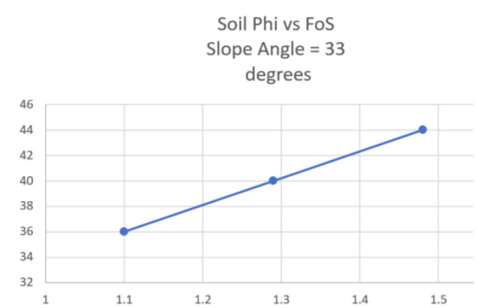

Figure 4.3D. ϕ' verses FoS (global) retained fill slope angle= 33°

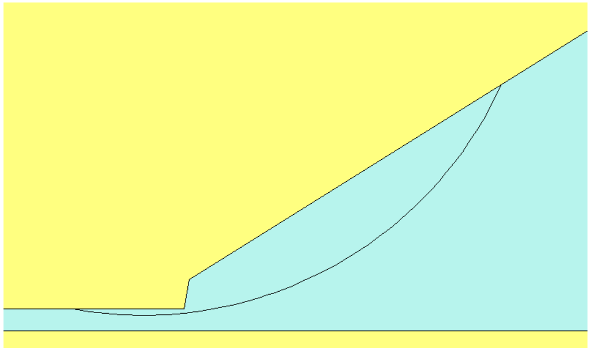

Figure 4.3E. Typical global stability analyses slip plane

4.4. Silt and Clay

The wall design aid is not intended for clay (cohesive) or silt (cohesive or non-cohesive) soils. These soil types are typical poorly drained, can result in forces behind the SRW2 far exceeding the forces applied by granular soils, and can fail in rotation with an SRW2 having little stabilizing influence.

4.5. Block Burial and Levelling Pad

The recommended burial depth of the lowest block is 0.3m to generally provide some passive resistance. For simplicity the levelling pad should be constructed of the same material as the drain rock (where required) and should be angular crush rock to ensure high basal friction. Where drain rock is not required (see discussion on drainage) then the levelling pad can be constructed with in-situ angular materials if the local soils have a cobble/boulder content less than 10% such that the oversize can easily be discarded during preparation of the sub-base.

4.6. Drainage

The design aid assumes no pore pressures are developed above the road grade elevation. To achieve this free drainage state, drains will be required for all sites not considered free draining. Free draining sites are defined as sites having soils with less than 5% by mass passing 0.075mm sieve on the sample fraction smaller than 2mm.

The drain height should extend to at least the top of the lowest block and be at least 300mm wide at the top. The drain should extend under the wall base for at least 150mm (becomes part of the leveling pad). Where road water is directed towards the wall (in-sloped or crowned road) then the drain should extend up the road side of the lowest block. The drain should be wrapped in non-woven geotextile (typically minimum 7oz geotextile). A 100mm diameter perforated drain pipe should be installed behind the wall in areas where the ditch flows require connectivity or if the wall length is greater than 10m.

4.7. Soil to Block Intersection

Analyses have assumed the conservative case of the soil block intersection at the upslope corner of the highest block.

5. Construction and Materials

Construction of the SRW2 shall be as noted on the SRW2 design aid and as per site specific requirements determined by the POR. Construction shall be as per the specified batter, drain, geotextile specification, compaction, and segmental block quality determined and stated by the POR (see Section 6).

6. Professional of Record

The SRW2 design aid is intended for use by qualified registered professionals who are typically non-geotechnical engineers (typically RPF's, RFT's, or AScT's) in BC. The qualified registered professional taking responsibility for the SRW2 is referred to as the Professional of Record (POR). The POR must be familiar and knowledgeable with the following:

- Forest Road Standards
- MFLNRORD Engineering Manual
- Forest Road Engineering Guidebook
- Forest and Range Practices Act
- Forest Planning and Practices Regulation
- APEGBC and ABCFP Guidelines for Professional Services in the Forest Sector - Roads
- EGBC Professional Practice Guidelines - Retaining Wall Design
- Typical industrial haul road requirements
- Identification of free draining and granular soils
- Identification of stable (long-term) retained fill slope angles and respective retained fill slope angles
- Identification of appropriate drain rock

The POR for each wall installation prepared using this design aid is responsible for ensuring the wall design utilize parameters that do not exceed the design parameters of this aid. Each POR, for each wall design prepared using this design aid must determine for themselves when local site conditions meet, or exceed, the criteria of this design aid.

7. Coordinating Registered Professional or Coordinating Member

The road design and construction and wall design and construction will be managed by a Coordinating Registered Professional (APEGBC 2012) or Coordinating Member (CM) who is responsible for planning and coordinating all professional services for the project in accordance with EGBC and ABCFP guidelines. The Coordinating Registered Professional (CRP) or CM will retain specialists to carry out assessments or design and will incorporate the specialist recommendations into the design.

8. Occupational Health and Safety Regulations and EGBC Guidelines

Some components of this design aid may not be consistent with Worksafe BC Occupational Health and Safety (OHS) regulations or guidelines and EGBC 2020 guidelines. For example, EGBC 2020 defines the retaining wall height as including the retained fill slope height if the retained fill slope angle is steeper than 2H:1V. This criterion would effectively require all retaining walls adjacent to forestry roads to be designed by a Professional Engineer. In addition, the minimum recommended EGBC global FoS is 1.5. OHS regulations Part 20.81 and Figure 20-1 requires that bulk excavations be sloped as per Figure 20-1 which limits the slope height to 6m unless instructions are provided by a Professional Engineer. Before this design aid is adopted the MFLNRORD will need to reconcile these differences with the agencies noted.

9. Field Reviews

The POR is required to conduct field reviews during the construction of an SRW2. Typical construction stages requiring field review are as follows:

- Upon site sub-excavation to grade before placement of levelling pads or drains
- During or upon completion of the drainage system
- During or upon completion of the first row of blocks with a review of fill compaction procedures and requirements
- Upon completion of the SRW2

10. Assurance Statement

The POR must complete and sign an FS 1481 – Retaining Wall Structure Field Reviews Construction Assurance Statement. The POR indicates he/she is the design professional – with a note that the SRW2 design aid was used as the basis for design. The POR also states he/she is also the review POR responsible for the field reviews. The CRP/CM will ensure the POR completes the required assurance statement.

11. Acknowledgements

SNTG would like to acknowledge and thank the valuable contributions to this design aid provided by the following:

Hardy Bartle, P.Eng., Area Engineer, Coastal Engineering Group
Sey Choi, P.Eng., Area Engineer, MFLNRORD, Northern Engineering Group
Brian Chow, P.Eng., Chief Engineer, MFLNRORD, Branch
Emily Findlay, P.Eng., Area Engineer, MFLNRORD, Southern Interior Group
Shelley Higman, P.Eng., Senior Area Engineer, MFLNRORD, Coastal Engineering Group
Samuel Lyster, P.Eng., Area Engineer, MFLNRORD, Southern Interior Group
Jamie Rupar Gilliatt, P.Eng., Senior Structures and Roads Engineer, MFLNRORD, Branch

12. Closure – Report Use and Limitations

The SWR2 design aid is intended for use by qualified registered professionals (Non-Geotechnical Engineers, P.Geo., P.Eng., RPF, RFT, or AScT) in BC who act as the Professional of Record (POR) . The role of the POR is to confirm the site conditions are representative of all of the assumptions noted in the SRW2 design aid and to ensure construction and materials are consistent with the design aid. Sites where conditions vary from those assumed in the SRW2 design aid must be referred to a qualified geotechnical engineer. The MFLNRORD acknowledges and accepts the low Factors of Safety inherent in the SWR2 design aid. The basis for this acceptance is the low wall height (less than 1.2m), the use of the design aid on low consequence sites, and the generally low Factors of Safety that are typical of forestry road cuts and fills and are accepted throughout BC by government and industry.

Prepared by:

21.05.01.02
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SNTG Permit 1001083

Reviewed by:

Mike Walsh, P.Eng.
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13. References

AASHTO Standard Specifications for Highway Bridges 2002 Seventeenth Edition Section 5 "Retaining Walls"

AASHTO 2017 LRFD Bridge Design Specifications 8th edition

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Appendices

Appendix A – Unified Soil Classification System

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
	Clean Gravels (Less than 5% fines)	
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
	Clean Sands (Less than 5% fines)	
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

LABORATORY CLASSIFICATION CRITERIA

GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART