Supporting Highway Infrastructure Through the Use of Green Steepened Slopes as an Environmentally Sustainable Method of Construction on the Canadian Landscape

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ABSTRACT

This presentation will focus on actual examples of the practical application of environmentally responsible, steepened-slopes to support major highway infrastructure across the Canadian Landscape.

The author's intention is to impart to the audience the current level of sophistication these designs currently demand, so that stakeholders making decisions in public infrastructure know exactly where such slope designs may integrate with Future Infrastructure Needs.

The objective is to demonstrate that such slopes are a viable engineering alternative to more traditional concrete facing methods, where grade separations are requisite. With an increased mandate on engineering teams to provide cost effective transportation solutions, coupled with public demand for minimizing the environmental footprint, this presentation will focus on the practical benefits realized when slopes are employed.

The presentation will provide a brief background on design methodology, ease of construction, and more specifically; emphasis on habitat enhancement as it pertains to sensitive creek or wetland crossings. Successful slope design is contingent on harnessing the collective efforts of all civil engineering disciplines involved on such projects, and should not be solely considered as a geotechnical challenge designed in isolation.

Past and Present examples will be provided where recent consortiums have selected the Sierra® Vegetated Slope as a productive method to construct approach slopes leading up to bridge supporting structures. Practical construction benefits for advancing construction schedules in poorer bearing soils will also be emphasized, and illuminated for the audience. A comparative example of a typical green-slope versus a traditional concrete-faced option will be demonstrated to illustrate the benefit in minimizing the carbon footprint when green solutions are employed.

Such facing systems are comprised of a combination of synthetic structural face-wrapping, erosion or turf reinforcement mats, and carefully selected topsoil in combination with suitable planting species to make such structures a success for all stakeholders. A description of typical slope systems ranging from 69 to 45 degrees (inclined to the vertical); will be highlighted during the course of the discussion.

Canada has the unique challenge of varied climatic conditions, and a mosaic of Nilex Inc. and Tensar® International projects will be featured during the course of the presentation.

1.0 INTRODUCTION

Reinforced Steepened Slopes (RSS) have increasingly become a popular grade separation choice on key infrastructure projects across the Canadian Landscape.

Steepened slopes are a composite soil system containing planar geogrid reinforcements that are arranged in a horizontal fashion. The reinforcements consist of geogrids which are contained either within a compacted granular soil, or alternatively, native soils when soil and design conditions permit.

For the purpose of this paper, the author will draw the readers attention to the two common facing inclinations, whereby facing is inclined at a 45° or 70° angle, as measured from the horizontal.

RSS 45 ° FACING INCLINATION

A common form of steepened slope is best illustrated in Figure 1 below.

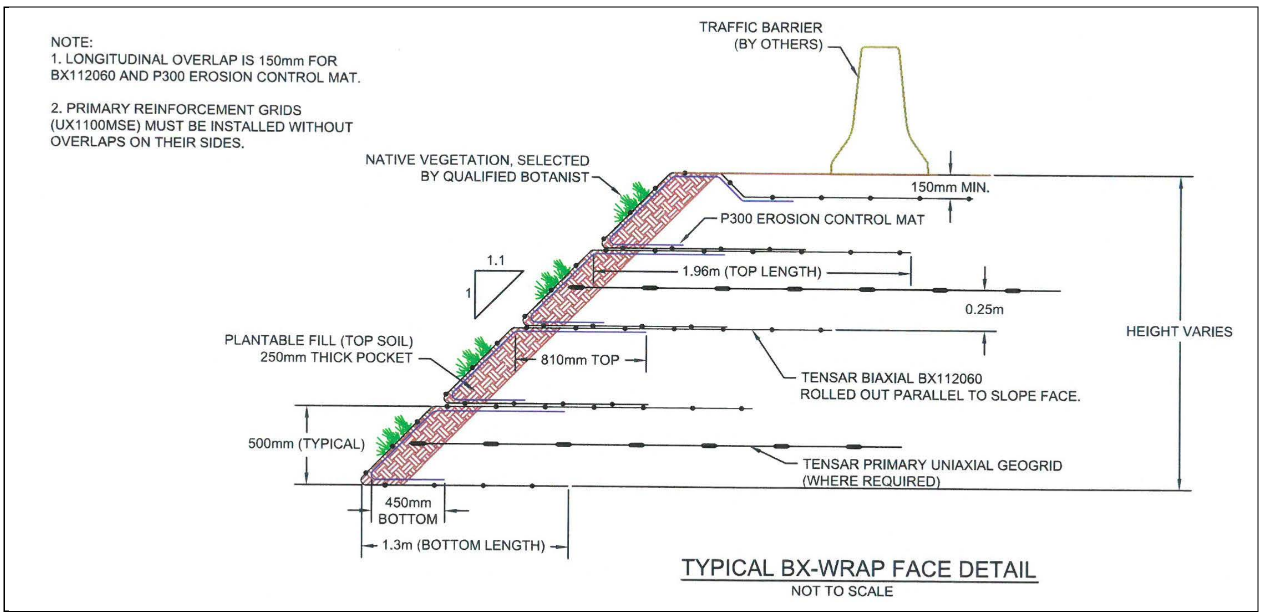

Figure 1: Typical section of a Tensar® Sierra Slope at 1.1H : 1.0V

Upon immediate review of the above figure, the reader may note the facing is inclined at just less than 45 degrees, and more specifically, at 1.1 Horizontal: 1.0 Vertical. Based on the author's experience, this face inclination is more attainable during the course of construction by field crews which may have a diverse skill set in the erection of RSS systems.

From a geometric point of view, it is also a practical inclination to ensure the final top of slope is correctly situated to achieve the overall design road widths. This is primarily due to the fact that RSS slopes are effectively a soft or soil facing material, as opposed to more of a hard-scape facing element.

2.0 SUSTAINABILITY IN ACTION and EARLY VEGETATION ESTABLISHMENT

The initial signs of vegetation are noted to poke-through the biaxial facing wrap as observed in photo A below. As part of the Port Mann Highway One (PMH1) project, Kiewit Flatiron forces constructed this particular slope in the fall of 2009, as part of the highway widening through this Coquitlam, BC road section.

The author captured this photo six months after initial slope construction. The viewer will note that the vegetation has commenced growing within the facing surface, which is comprised of what is more commonly known as a biaxial facing wrap amongst geotechnical engineers.

This sustainable construction method provides supporting landscape for a variety of species, which are proximal to this construction site, and in the general vicinity of Popeye Creek.

Photo A: RSS at PMH1 Project [Westbound Highway One Lane Widening, April 2010]

At the identical RSS location below, an abundance of early grasses bloom during early spring as observed in the picture below. Nature ultimately takes control as the root structure working in concert with the biaxial geogrid, become entwined, as one supporting landscape option for a variety of aquatic and bird species.

Photo B: RSS at PMH1 Project [Westbound Highway One Lane Widening, May 2010]

Like most engineers, the author himself a geotechnical engineer by training, is not a specialist with specific expertise in selecting a suitable “local planting species”. The most important lesson we have all learned in our early engineering studies is to “know what we don’t know”. Our engineering and construction communities at large have a wealth of knowledge, experience, and expertise; we can utilize to develop projects in sensitive areas.

This emphasizes the importance, that if the initial design intent is to “embark on an engineered vegetated slope structure”, then it is crucial, at the early design phase that all the key members are on the design team at project conception.

It would be fair-minded to state that these projects, especially those on the Pacific Coast where seismic is a strong influencer, that a typical engineering team will often be comprised of the following disciplines:

- Geotechnical Engineer [foundation, settlement, and global stability].
- Civil Engineer [geometric layout, design loads, and construction conditions].
- Hydraulic Engineer [maximum design flood elevations, scour, or toe protection].
- Slope Engineer [specialty proprietary provider as the E.O.R for slope design].
- ***Landscape Architect*** [to ensure the wall aesthetics meet local design expectations].
- ***Professional Agrologist*** [to ensure successful vegetative establishment].
- ***Aquatic Biologist*** [when adjacent to / impacting wetland].
- ***Specialty Engineers*** [with advanced skills in seismic and numerical analysis].

It is suggested by this author and his professional colleagues, that for the disciplines***(in bold italics above)***, that local knowledge of climate, seasonal variations, optimum planting times, and site specific soil knowledge, should be requisite, and developed by the project management team at early project conception. The vegetated RSS systems that will be explored in this paper have been developed as a direct result of the implementation of a collective design approach.

In the previous Photo B, the grow-in was successful considering slope construction occurred in the fall of 2009, and then subjected to over-wintering and demonstrated excellent vegetation development only 8 months after initial slope construction. This is the success we strive to achieve during early vegetation development.

This is simply not a water-filled ditch along the roadside, but more specifically an important supporting landscape upon which we ultimately "all rely". The particular vegetated swale observed in the previous photos is proximal to the "Popeye Creek System", in Coquitlam, BC.

If the reader is so inclined, a comprehensive description of the extensive environmental standards engaged on this specific project can be located at this website location.

> http://www.pmh1project.com/about-the-project/environmental-projects/Pages/Environmental-Projects.aspx#sthash.9ntfTyT8.dpuf

A brief summation of the principal environmental measures engaged on recent Canadian Infrastructure Projects, as observed by this writer is as noted:

> **Enhancement through** *environmental improvements.*
> **Compensation by** *the creation of new habitat.*
> **Construction Scheduling thereby** *avoiding conflicts at sensitive periods*.
> **Protection of** *existing habitat.*
> **Restoration whereby** *"vegetated steepened slopes are one available option".*

3.0 FUTURE INFRASTRUCTURE and SUSTAINABLITY

This author would encourage designers to contemplate RSS methods of grade separation along our future highway system, as our engineering community continually evolves on the “path of enhanced sustainability in future design and construction”.

Photo C: RSS at PMH1 Project [Westbound Highway One Lane Widening, April 2014]

Approximately 4 ½ years after initial construction, this green steepened slope is an excellent performer. The writer noted during this visit that vegetation is well established within the creek, and on both RSS slope faces (left and right hand side of photo C).

This truck is travelling westbound on the new widened section at this location, and the use of such “green slope solutions” is a benefit to this industry as they travel along our improved highway system.

4.0 SUSTAINABILITY and ENGINEERING

An interesting quote by Robert Swan, OBE, which appeared on the cover of the Association of Consulting Engineering Companies | Canada, is skillfully stated as:

> "The greatest threat to our planet is the belief that someone else will save it." (1)

As published within the Association of Professional Engineers and Geoscientists of British Columbia article, entitled "Sustainability Guidelines" professionals within their scope of practice have a responsibility to remain current with respect to the following bullets as borrowed by this author and summarized below.(2)

1. Maintain a Current Knowledge of Sustainability
2. Integrate Sustainability into Professional Practice
3. Collaborate With Peers and Experts from Concept to Completion
4. Develop and Prepare Clear Justifications to Implement Sustainable Solutions
5. Assess Sustainability Performance and Identify Opportunities for Improvement

5.0 DESIGN SOPHISTICATION

The level of design complexity inherent on this particular RSS structure involved a number of key design requirements. The prominent design elements are illustrated below in Table 1, which the viewer may want to read while concurrently viewing Photo C.

Item of Interest	RSS(Left Hand Side)	RSS(Right Hand Side)
Slope Height (vertical)	3000 mm	3000 mm
RSS Location	North Side at Fence / P.L.	South Side at Highway One Shoulder
Design Loading	12 kPa	16 kPa
Preload	Not required	27 kPa
Design Flood Elevation	Submerged to top of slope	Submerged to top of slope
RSS Facing Wrap	Biaxial 112060(UV stabilized)	Biaxial 112060(UV stabilized)
Turf Reinforcement Mat	North American Green P300	North American Green P300
Primary Grid Length	3000 mm long [or 1.0 H *]	4500 mm long [or 1.5 H]
Primary Grid [Ult Strength]	Uniaxial 1100 [58 kN/m]	Uniaxial 1100 [58 kN/m]
* 1.0 H refers to the ratio of Horizontal Primary Grid Length / Vertical Slope Height In the 2nd column example noted above, we have 3000 mm / 3000 mm = 1.0 H or grid length equals slope height.		

Table 1: Key Design Requirements relative to RSS Slope at PMH1 Project.

6.0 VIEWPOINT OVER A LONGER TERM

The slope illustrated in the following photo D, is an excellent example of the benefit an RSS can provide to decision makers whom are tasked with, increased sustainability efforts, while more importantly; protecting/improving habitat during the course of construction.

The intent of this photo is to demonstrate to the audience that it is possible to achieve future green grade separations that can achieve all of the above objectives, when the right team approach is employed at project onset.

This RSS slope has been in service for 15 years at the time of this writing. The photo is looking westward along what is locally known as Lougheed Highway (Highway 7) on the left hand side, and Highway 1 (just barely visible over the right hand side of this photo).

Photo D: Looking Eastbound [Cape Horn I/C along Hwy 7 / 1, Coquitlam, BC Year 2002]

This photo illustrates a steepened slope that was initially constructed in 1999, and only three years later, an abundance of varied vegetation is well established, and in particular within the watercourse. For those not familiar with the Vancouver Region, it is significant to note that this particular slope is proximal by location, to the preceding PMH1 slopes illustrated earlier in this report. They are all within the Pacific Coast climatic region.

As cited in a US Environmental Protection Agency Fact Sheet (3), *" A conservative estimate would say that a properly designed vegetated swale may achieve a 25 to 50 percent reduction in particulate pollutants, including sediment and sediment-attached phosphorous, metals, and bacteria. Lower removal rates (less than 10 percent) can be expected for dissolved pollutants, such as soluble phosphorous, nitrate, and chloride".*

7.0 STEEPER RSS FACING OPTIONS [> 45 ° and < 70 °]

With the simple addition of what is commonly referred to as a "wire facing cage" to the exterior of the RSS slope face, now allows for a steeper slope face design. This facing variation allows the slope to now exceed 45° and trend upwards to no greater than 70°(in most cases). This welded wire form is best illustrated in the following Figure 1.

All other RSS slope components are effectively unchanged, with the arrangement of geogrid and erosion control blanket being equivalent.

The function of the wire facing is not solely limited to a greater facing inclination, but more importantly; provides a vertical confining surface along the slope face, so the desired soil strengthening through compactive energy, can be achieved at this interface.

This upper limit of 70 degrees is defined by many highway authorities such as The U. S. Department of Transportation and Federal Highway Administration (FHWA) as being a transition point, which makes the technical distinction between slope design versus a vertical wall design. The former(RSS) is best assessed with the use of slope stability tools, since slope design is dictated by the geotechnical driving or restraining forces inherent for the site specific soil conditions.

This is an important distinction for specification writers since AASHTO is often cited in tender documents, and tender documents will often defer to FHWA in geotechnical slope design.

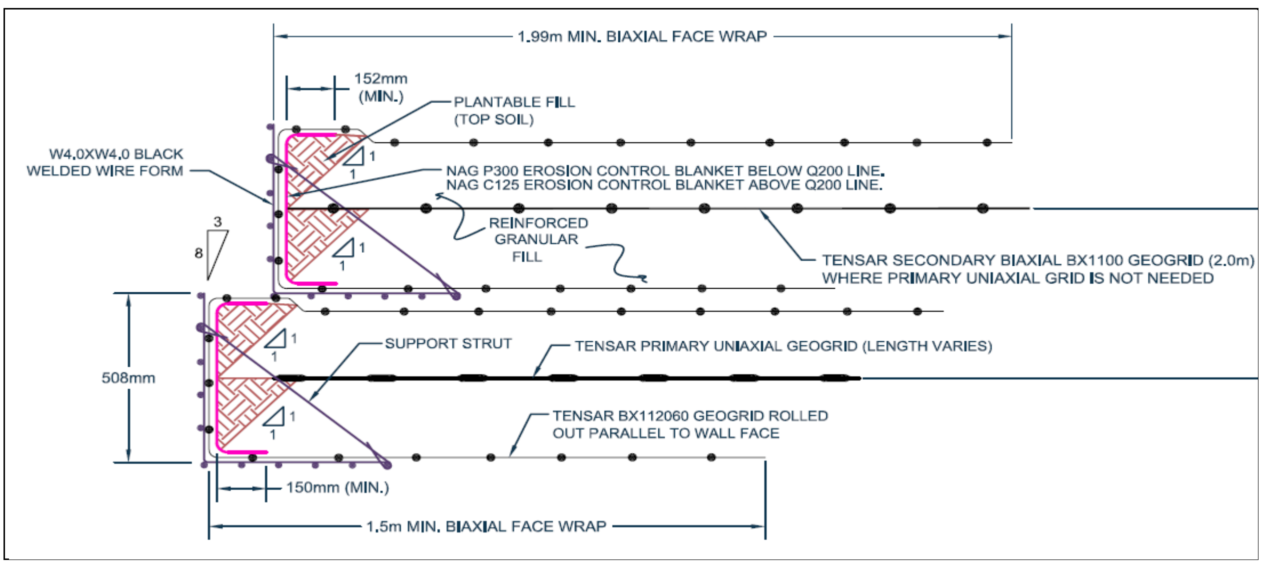

Figure 2: Typical Section for an 8V:3H vegetative facing with face-wrap and topsoil.

8.0 PRACTICAL BENEFITS WHEN RSS / STEEPENED SLOPES ARE EMPLOYED

To further expand on this steeper facing variation, the reader's attention is now drawn to the left hand side of photo E. It will be noted that the slope facing inclination is observed to be steeper at 69° (as measured from the horizontal). This steeper face is formed by a series of wire facing cages offset (horizontally) at the design value to achieve the desired facing angle prescribed by the design engineer.

Photo E: Cape Horn I/C at Highway 7[Left Hand Side], and Highway 1[Right Hand Side] [2000]

The one key advantage in this system approach is that in many instances when soil and design conditions permit, these RSS systems allow for the immediate advancement of road approach fills over settlement prone soils.

This is best demonstrated by looking visually along the wire facing where it is noted that the wire facing rises up to higher elevation in the distance(when sighting along the same wire cage element). Settlement on this slope was generally noted up to approximately 500mm. The greatest amount of settlement is observed closest to the viewer.

A typical approach is that the approach fills are advanced in stages, and monitored by the geotechnical engineer of record (E.O.R.). When the E.O.R advises that settlement is complete or congruent with the design approach for the structure, then the final road grades can be constructed. Adjustments in the final top grade to make up for settlement are easily accommodated by the addition of an added cage (which can also be countersunk) to achieve the exact final construction grade.

9.0 RSS PHOTOGRAPHIC PROGRESSION SERPENTINE RIVER, SURREY, BC

A brief summary of an interesting project as part of a municipal four lane-widening project complete with pedestrian sidewalks.

Essentially this involved the construction of 5m high RSS approach ramps, located immediately downstream of the Tynehead Fish Hatchery, along the sensitive Serpentine River. The bridge structure consisted of a cast in place bridge structure on this project.

Photo G: Serpentine River [2010]

Photo H: Vegetation Established [2012]

Photo I: 96TH Avenue, Surrey, BC

Photo J: Vegetated RSS Approach Ramp

The initial photo in the above series, illustrates the 69° approach ramps nearing completion up to the river crossing. Photo H is looking eastwards and sighting along the approach ramp which is well vegetated at this time.

Photo I is from topside, and shows the new alignment/widening, where the reader will note the RSS (just beyond the bridge deck) is well cloaked within the vegetation of the adjacent forest.

Photo J is a close-up at river level, which is a sensitive spawning, and rearing habitat for both trout and salmon. A demonstration of sustainable possibilities for infrastructure engineers.

10.0 SOUTH FRASER PERIMETER ROAD (SFPR / Hwy 17) and GOODS MOVEMENT

This major infrastructure project recently opened to traffic in December of 2013 is one project, which employed a multiple of both RSS and MSE (Mechanically Stabilized Earth) systems to achieve the overall project completion on this large-scale highway improvement project.

In the context of this paper, an 8m high Sierra® RSS slope with a facing inclination of 69.3 ° is in the midst of construction as illustrated in Photo K. The slope is more specifically; located to the right of the heavy rail corridor, and is located beneath the upper cut-slope excavation.

For those not familiar with this project, this vegetated slope supports a new 4 lane roadway which primarily moves industrial truck traffic along proximal to the Fraser River Foreshore, and safely directs traffic destined for the Canada/USA border.

This slope is also noted to extend on a right hand curve as viewed in the far distance.

Photo courtesy of Fraser Transportation Group

Photo K: SFPR and CONSTRUCTION OF AN 8M HIGH RSS SYSTEM, LOOKING EAST

11.0 RSS BENEFITS TO TRUCKING INDUSTRY and TRANSPORTATION NETWORK

As opposed to benefits expressed solely by this author, a summary list is provided below of recent citations obtained from one reference source (4), but by a variety of stakeholders, as expressed in italics below.

> *"The SFPR will allow goods to move more freely around the region by truck," said Trace Acres, vice president, BC Trucking Association. "In addition to increasing the efficiency of the Gateway, it will help lower emissions by limiting the number of stops trucks have to make travelling between ports, ferries, businesses, and borders." (4)*
>
> *"The SFPR is a key part of our commitment to expanding our markets and improving the safe and efficient movement of goods and people," said Stone. "This new route is a game -changer for industry, commuters, and tourists – it will cut commute times for families and make B.C. more competitive by connecting key port and rail facilities with access to borders, the Tsawwassen ferry terminal, and the B.C. Interior."(4)*
>
> *"Our community will benefit hugely from the opening of the South Fraser Perimeter Road," said Delta Mayor Lois E. Jackson. "The new route provides greater access to the Tilbury industrial area, taking commercial trucks off Highway 99 and River Road. This will make for safer, smoother travel for our residents throughout the community. (4)*

In the following photos(L1 and L2), the benefit is now realized by the Trucking Industry as westbound truckers head along the perimeter road towards the awaiting Industrial, Rail, Port, and Ferry facilities which abound along this area of the Fraser River / BC Lower Mainland Region.

Photo L1: SFPR / Hwy 17 over RSS, [2014]

Photo L2: SFPR 69° RSS EARLY GREEN- UP, [2014]

All the preceding RSS examples are from the Canadian Climatic Region known as the Pacific Coast Climate as defined by Environment Canada.

RSS benefits as it relates to Goods Movement

- RSS slopes allow for future road widening, while building beyond past/present road networks. This allows optimization of existing infrastructure while advancing future road widening efforts to improve corridor highway networks.

- Projects such as PMH1/SFPR have utilized RSS slopes for success in partnership projects, as well as innovation in the use of sustainable infrastructure.

- RSS slopes are an integral component for current infrastructure, and should be contemplated by engineers for future highway needs. As cited below, such projects improve goods movement, enhance safety, while improving the Canadian economy.

  "The completion of the South Fraser Perimeter Road is good news for the Metro Vancouver region. It means a better road network and more capacity to transport goods to and from fast - growing markets throughout the Asia-Pacific region," said Findlay. "This project demonstrates that when we work together with our partners through the Asia Pacific Gateway and Corridor Initiative, we can develop projects that ***facilitate international trade and create jobs and economic growth in local communities across Canada****." (4)*

  "Improve access to and egress from the corridor for goods movement - In addition to new truck-only ramps connecting Highway 1 and the United Boulevard commercial/industrial area of Coquitlam, the project also includes improved vehicle height clearance at interchanges along the corridor. ***Goods movers also benefit from efficiency, safety and travel time savings offered by highway widening and improved highway and bridge capacity****". (5)*

  *"****Improve safety for vehicle operators and passengers, cyclists, and pedestrians***
  In addition to capacity and efficiency improvements , the project includes highway and interchange designs that improve sight lines and reduce curves . In addition, design improvements at key locations will reduce congestion and traffic weaving, providing for improved safety". (5)

The original citations within this section of the paper can be found at the following web link locations below:

http://www2.news.gov.bc.ca/news_releases_2013-2017/2013TRAN0092-001938.htm

http://www.pmh1project.com/about-the-project/project-overview/Pages/Benefits.aspx

12.0 RSS EXAMPLES HEADING EASTWARD ACROSS CANADIAN LANDSCAPE

The author intends to convey to this engineering audience, that successful RSS systems are not solely isolated to the Pacific Region, but to demonstrate that success in other regions of Canada exist. In this section, I will illustrate successful examples within a more traditional Canadian Climate, with four distinct seasonal variations throughout the year.

Photo M: Highway 28 Improvement, North of Edmonton Alberta, Northwestern Forest [2011]

Photo M illustrates a 69° RSS slope supporting infrastructure improvements along a section of Highway 28. Initial construction of this slope originally occurred in the year 2010. One year after the RSS grade separation is supporting the abundance of wetland habitat as seen to the right of the fence line.

Photo N1: Wascana Creek Rehabilitation Project, Regina, SK, RSS in Prairie Climate [2003]

Photo N2: Wascana Creek, Regina, SK, RSS in Prairie Climate [2012]

Photo N3: Wascana Creek, Regina, SK, RSS in Prairie Climate [2013]

The Wascana Creek Project noted in Photos N1 to N3, forms the Flood Protection Works between Albert Street and Elphinstone Street. It used creative open space planning, with geotechnical and bio engineering technology. It forms an important part of the local drainage system, with geometry common to large conveyance structures of linear infrastructure.

This dike structure is included as it offers an excellent time series of photos, to illustrate RSS success in a more traditional Cold Canadian Climate. The author thanks careful Nilex photo documentation since construction to provide a detailed photo log of this site from the years 2002 to 2013, such that this record can now be shared with the reader.

Photo O: Constructed 2011 Appleby Line Regional Rd 20, ON RSS [Photo 2012]

Photo P: Constructed 2009, Fundy National Park Trails, NB, [Photo 2014]

This last photo completes at least one type of RSS slope utilized on a secondary road system within our National Park System within the Climatic Region of Atlantic Canada.

This concludes the visual overview of RSS possibilities across the Canadian Landscape as one practical alternative for designers and stakeholders to contemplate for future grade separations.

13.0 CARBON EMISSIONS COMPARISON

A comparison between an RSS system versus a precast modular facing system is completed in this section, as illustrated in the following Figures 3 and 4. Traffic loading remains constant in both cases, and is specifically set at 16 kPa. As a *Canadian Provider* of both types of systems the author has the additional benefit of utilizing in-house emissions inputs, with respect to the materials utilized.

An equal vertical facing area of 1000 m2 was selected for both slope and wall systems comparisons, as a mid-sized project scope, based on the authors extensive RSS/MSE engineering experience.

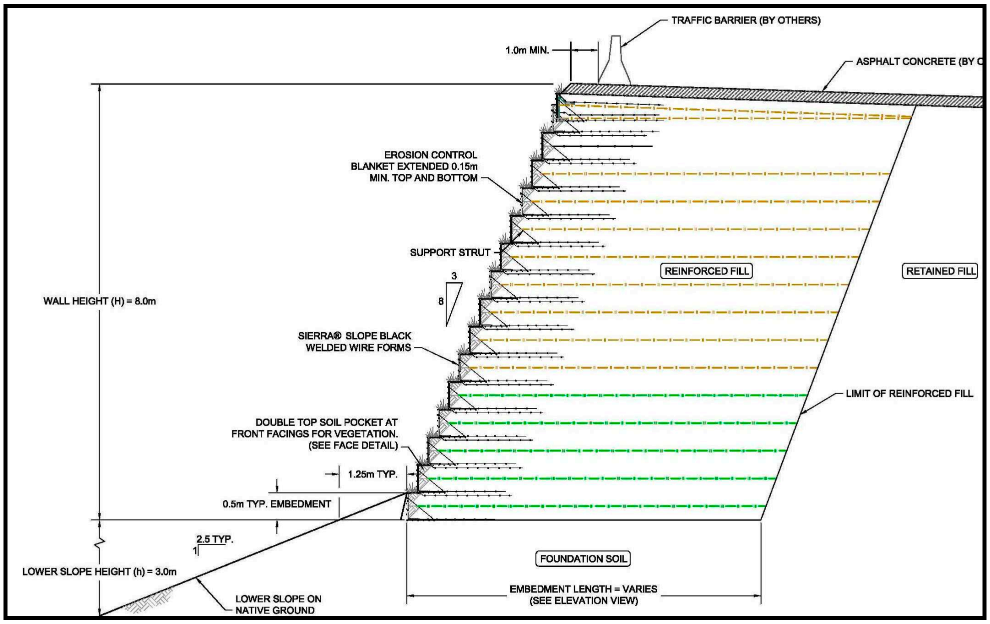

Figure 3: RSS 8m high section [6.5m long geogrid embedment lengths per design].

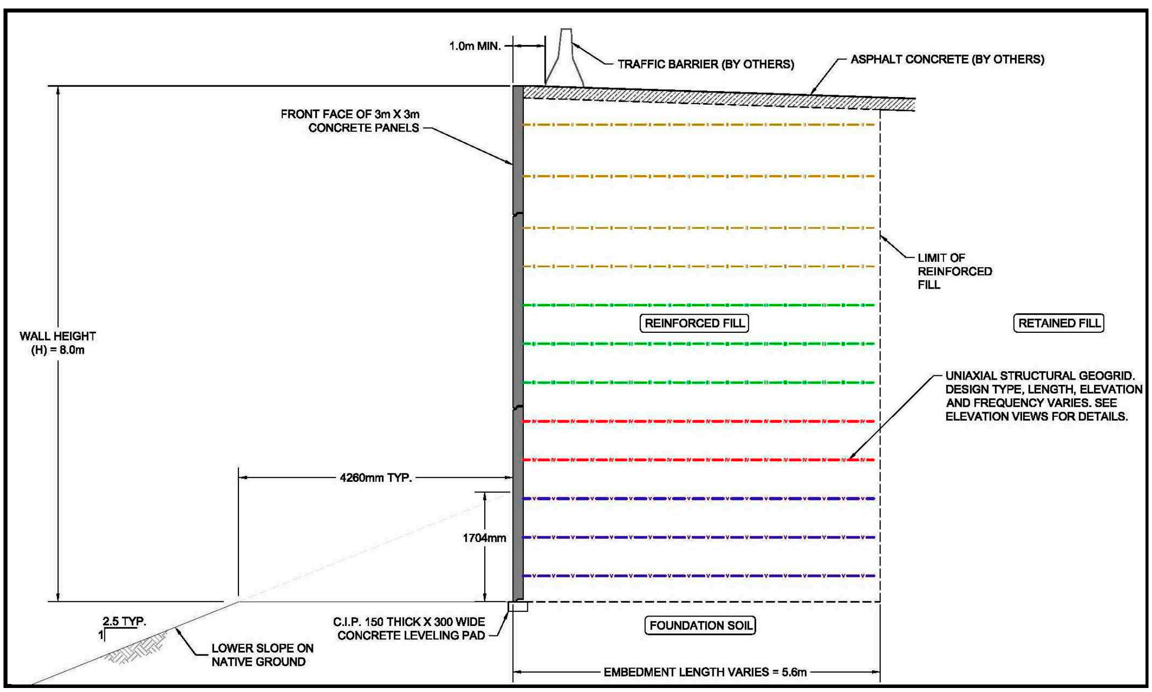

Figure 4: Precast panels 8m high section [5.6m long geogrid embedment lengths per design].

The reader will note that the soil reinforcement/geogrid lengths are slightly longer for the RSS system. This is common, since RSS slope design is governed by the geotechnical parameters of the soils on site, and hence; predominantly controlled by global stability factors.

The graphical and numerical results of this comparison are presented below.

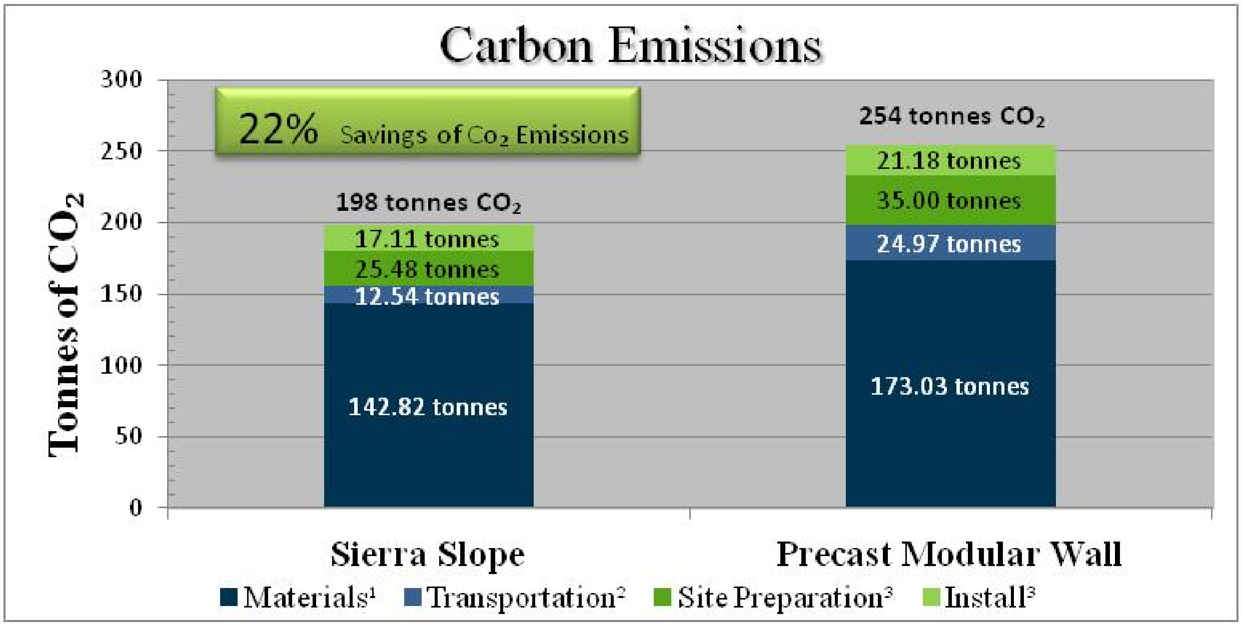

Figure 5: Graphical comparison of carbon emissions

A positive benefit is realized for the RSS(Sierra® Slope) vegetated system in terms of a total 22% savings in carbon emissions. RSS offers one method of incorporating sustainability in future road designs.

<u>Notes:</u>

RSS calculations above allowed the re-use of native/back cut soils as RSS back fill, versus trucked-in river sand for the precast modular wall option.

For the case of identical excavation and backfill(river sand), being trucked-in locally, and used for both slope and wall systems. The CO_2 savings would decrease from 22% to 12%, but still afford a positive benefit to the RSS system. .

Transportation factors are based on a project site located in Surrey, BC. Different locations, and construction scenario's would be expected to yield varied results dependant on project specific factors.

15.0 ACKNOWLEDGEMENTS

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15. REFERENCES

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White Paper Published

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Specific Citation References

The following references were specifically cited or paraphrased within the text of this white paper as noted.

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2. Association of Professional Engineers and Geoscientists of British Columbia (APEGBC), Sustainability Guidelines, V 1.0 May 30, 2013. Page 4.

3. United States Environmental Protection Agency, Office of Water, Washington, D.C. 832-F-99-006 September 1999, "Storm Water Technology Fact Sheet Vegetated Swales".

4. NEWS RELEASE COMMUNIQUÉ, Ministry of Transportation, and Infrastructure, 2013 TRAN0092-001938, Dec. 21, 2013, Transport Canada, "*South Fraser Perimeter Road, B.C.'s newest highway opens".*

5. Transportation Investment Corporation, Suite 210–1500 Woolridge Street Coquitlam BC, V3K 0B8, "Port Mann / Highway 1 Improvement Project Benefits" as Retrieved July 6, 2014 from this link location: http://www.pmh1project.com/about-the-project/project-overview/Pages/Benefits.aspx

Specific Carbon Emissions References Cited In Figures 5

[1] Embodied Carbon For all Products (including aggregates) are based on the University of Bath Inventory of Carbon and Energy. (ICE) Report, Version 1.6a.

[2] Carbon emission from material transportation is calculated using conversion factors for diesel fuel (Canadian Fuel Consumption guide, 2012). Fuel consumption for haul trucks is based on class 8 vehicles as defined by the US department of energy. Carbon emission for aggregates is calculated using the distance from source to site. Carbon emission for transport of Nilex products were calculated using the distance from manufacture to nilex warehouse, then from nilex warehouse to site.

[3] Carbon emissions for construction were calculated using conversion factors for diesel fuel from fuel consumption and production rates that were gathered from the Caterpillar Performance Handbook. (Ed.42)