Use of Geosynthetic Fabric Reinforced Soil on Mainline Railways – Design and Construction

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ABSTRACT: CN is one of the largest Class I railways in North America. In recent years, CN has lengthened many existing sidings to accommodate increased rail traffic and train length. In British Columbia, widening the railway grade for additional track often means potentially encroaching on environmentally sensitive areas or land that is not part of the CN right-of-way, filling over unfavourable soils or into riparian areas of rivers, lakes, small streams and wetlands, or constructing high soil or rock cut slopes to traverse sloping ground. Grade widening also requires extension of culverts in streams that are often important fish habitat. Additional construction considerations include remote sites, site access that is often only by rail, distant fill borrow sources, and the difficulty of working next to an active railway. Efforts to minimize the environmental impact, physical footprint, and cost of siding extensions have led to the use of geosynthetic fabric reinforced soils (GRS) to steepen fill slopes, buttress and steepen cut slopes, for retaining walls, and for culvert head walls. While GRS structures have been in use for many years, examples of geotextile (as opposed to geogrid or steel) reinforced structures in a heavy freight railway environment are few. This paper reviews the general approach used for GRS retaining wall design in a railway environment, and uses case histories to illustrate the use of one type of GRS system for retaining walls and culvert head walls. The costs and benefits of the GRS techniques are discussed.

Key words: railway, GRS, geosynthetic, retaining wall, design,

INTRODUCTION

CN is one of the largest Class I railways in North America. In recent years, increases in rail traffic combined with longer trains have necessitated lengthening of sidings and addition of new longer sidings. In British Columbia, CN's main line tracks traverse valley bottoms in mountainous terrain and are confined by valley slopes and major rivers. Widening the railway grade for additional track often means potentially encroaching on environmentally sensitive areas or land that is not part of the CN right-of-way, filling over unfavourable soils or into riparian areas of rivers, lakes, small streams and wetlands, or constructing high soil or rock cut slopes to traverse sloping ground. Grade widening also requires extension of stream culverts that are often important fish habitat. Additional construction considerations include remote sites, site access that is often only by rail, distant fill borrow sources, and the difficulty of working next to an active railway. Efforts to minimize the environmental impact, physical footprint, and cost of siding extensions have led to the use of geosynthetic fabric (geotextile) reinforced soils (GRS) to steepen fill slopes, buttress and steepen cut slopes, for retaining walls, and for culvert head walls. While GRS structures have been in use for many years, examples of geotextile (as opposed to geogrid or steel) reinforced structures in a heavy freight railway environment are few. This paper reviews the general approach used for GRS retaining wall design in a railway environment. The paper then uses case histories to illustrate the use of one type of GRS system for retaining walls and culvert head walls. The costs and benefits of the GRS techniques are discussed.

INTRODUCTION TO GEOSYNTHETIC REINFORCED SOIL

Geosynthetic Reinforced Soil (GRS) is a term used to describe a particular type of internally-supported soil mass. Reinforcing elements of geosynthetic (polymer) textiles are placed on top of each lift of compacted soil as the mass is constructed to create the composite system. Each soil lift is relatively thin (8 to 16 inches or 0.2 to 0.4 m) and subjected to a high degree of compaction. GRS has been shown experimentally to exhibit an apparent shear strength that is greater than the the simple sum of the individual components [1]. Unconfined compression testing of GRS columns by Adams et al (2008) [2] demonstrated unconfined compression strengths in excess of 1 MPa. These results suggest that GRS composites can be compared to reinforced concrete in that soil, as with concrete, is strong in compression, but weak in tension. Reinforcing steel adds tensile resistance that increases the flexural, shear and tensile strength of the reinforced concrete composite. Similarly, the addition of tensile elements (geosynthetics) in soil add tensile and shear strength to the soil composite. In GRS, the closely-spaced reinforcing layers also provide confinement to the compacted layers of soil, and through interaction with the soil grains, resist dilation of the soil, thereby limiting the formation of failure surfaces through the soil mass.

The principle of GRS is an ancient technology, and examples of GRS using plant fibre mats as reinforcement still exist in the vertical walls of the Ziggurats of ancient Mesopotamia and the Great Wall of China [3]. The technology has been making a resurgence in the geotechnical engineering community within the past 25 years [4], and GRS design methodology is being used for bridge abutments, retaining walls, arches, steepened slopes, rock fall barriers, and abutments for debris flow barriers.

The internally-supported GRS system is distinct from externally-supported soil retaining systems commonly used in the railway environment. Retaining walls that are traditionally used in the railway environment, including tie-back walls that use H-pile and lagging or sheet piles with whalers, as well as Mechanically Stabilized Earth (MSE), gravity walls, and cantilever walls externally support the retained soil mass and surcharge loads. They rely on a stiff facing element (e.g. gravity and cantilever walls) or a tied-back facing element that resists the lateral pressures of the soil. Although they may appear similar to GRS, MSE walls actually support a soil mass with a stiff facing that resists the lateral earth pressures of the soil and surcharges. The stiff facing elements are supported by steel strips or polymer grids that anchor the stiff facing to the stable soil behind the active soil wedge. In the GRS system, the facing can be flexible because it is not meant to support the lateral earth pressures of the soil. The GRS facing is required to facilitate compaction of the soil, after which, it is only required to contain the soil between reinforcing layers (i.e. prevent ravelling of the soil out of the face), and is not a significant load bearing element [5]. The fundamental difference in potential failure modes between GRS and MSE was studied numerically by Leshchinsky and Vulova using a finite-difference approach [6]. This work clearly demonstrated the inherent internal stability offered by closely spaced layers of geosynthetic reinforcement within a soil mass.

GRS RETAINING WALLS IN A RAILWAY ENVIRONMENT

When properly designed and constructed, GRS can be more economical, stronger, and faster to construct than externally supported retaining wall systems in many railway applications, including:

- Steepening cut slopes
- Steepening fill slopes
- Bridge abutments
- Culvert headwalls to reduce encroachment onto riparian zones
- Load dispersion and grade stabilization on soft soils
- Control of slope ravelling
- Rock fall barriers

The railway environment is subject to many unique constraints that are not common to other infrastructure, including:

- Project sites are often remote and construction materials such as concrete and steel, as well as large construction equipment can be expensive to transport to site.
- Limited staging areas and limited access to work areas
- Requirement to keep trains running during construction dictates that new construction cannot damage or interfere with operating tracks

GRS can be used cost effectively and efficiently within these constraints. The materials required for GRS can be as simple as a couple of rolls of geosynthetic fabric. Many different types of facing can be suitable, including locally available boulders, large concrete blocks, dry cast masonry units (CMU's), corrugated steel, or weld wire mesh forms such as described in the case studies below. Also, the fabric itself can be wrapped around each lift to form the facing. This lack of structural importance of the facing is a principal advantage of GRS over other systems for many applications where staging area is limited and construction materials are expensive to deliver to site.

Additional advantages of GRS are that locally available fill materials can often be used (provided the materials can be readily compacted), the construction utilizes a limited number of materials (facing elements, fabric, soil), is a simple and repetitive procedure, and is readily adapted to actual site conditions during construction.

A potential disadvantage of GRS is the requirement for some strain to occur in the structure to mobilize its strength. However, much of this occurs during construction, and horizontal strain has been shown through case histories to be typically less than 1.5% of the height of the structure [7]. Another often cited disadvantage of GRS is the perceived tendency for the geotextile to be susceptible to long-term creep. The rationale is that plastic subjected to stress will undergo continued strain under constant load over time. This is true for isolated testing of geotextiles in a laboratory test apparatus, where the potential for creep increases with the ratio of load to the ultimate load of the material. Accordingly, GRS structures are typically designed to use a small percentage of the ultimate capacity of the material. However, strain of a geosynthetic within a soil-geosynthetic composite requires that the soil also strain. This requires dilation of the soil, which is resisted in a GRS structure by both the tight spacing of the geotextile layers and the degree of compaction of the soil [7].

GRS WALL DESIGN

Currently there is not a universally accepted design guide or manual dedicated to GRS design. The design methodology used in the case studies described in this paper is generally based on the commonly accepted methods for MSE wall design such as the U.S. Federal Highway Administration guideline [8] with modifications that have been proposed by several GRS researchers. The MSE wall design approach is considered to be conservative for GRS design because the MSE approach considers failure mechanisms that do not govern the internally supported soil geotextile composite systems as demonstrated by full-scale, unconfined compression tests.

The GRS wall is dimensioned to resist external failure modes that are common to all retaining wall designs including failure by: global stability, overturning, base sliding, and bearing capacity. For GRS walls placed on slopes, the global stability is usually most critical and controls the overall geometry of the wall.

For GRS walls the width of the geosynthetic reinforcement (back from the wall face) is generally between 0.7 and 1.1 times the wall height; however, depending upon external stability constraints, truncated base designs utilizing a base width to height ratio of 0.1 can be considered. The batter of the wall face can be any batter, including a reverse or negative batter (overhanging), but a slight positive batter of about 80° is recommended for improved appearance and greater flexibility during construction. Negative batter (overhanging) GRS walls have been built for a highway grade-widening project in the United States and New Zealand [4]. Locally available soils can often be used as GRS backfill. General requirements for soil backfill are well-graded granular (sand and gravel) that has less than 20% fines. A lower percentage of fines (7% for example) should be specified for applications where it is critical to minimize wall deformation, such as when GRS is used beneath the rail grade. The fines should be low to non-plastic with a liquid limit less than 35 and plasticity index less than 8 [9]. Adequate compaction of the GRS lifts is critical for the GRS performance, and generally 95% of Standard Proctor maximum dry density is a specified minimum with placement moisture within 2% of the optimum moisture content for the soil. Depending on the percentage of fines in the fill and the potential for water inflow into the wall, drain elements are often included to prevent excess pore pressure developing in the wall.

The internal components of the GRS, including reinforcement type, strength, and spacing are designed to resist the lateral earth pressure of the soil mass and surcharge loads. The same method as used in MSE wall design [8] is used to estimate the lateral earth pressures that are exerted on the reinforcing layers. The assumed lateral earth pressure is due to the active wedge of soil over the entire wall height. Although this is not considered a realistic mode, it is used in the absence of a more correct or accepted method because it has been experimentally shown to over-estimate lateral earth pressure, and is considered conservative [5]. Reinforcement layers (geosynthetic textiles or grid) are evenly spaced in horizontal sheets so that the horizontal load assumed for the soil does not exceed the design tensile strength of the fabric. A maximum spacing of 0.4 m between reinforcement layers is recommended so that adequate fabric-soil interaction is achieved. However, using a fabric spacing of less than 0.3 m (12 inches) facilitates a high level of compaction during construction and typically permits the use of more economical geotextiles.

The geosynthetic reinforcement is chosen based on its ultimate tensile strength and tensile stiffness. The tensile stiffness is usually the controlling value and is important because strain compatibility between the soil and reinforcement limits wall deformation [10]. The maximum lateral load (T_{max}) is the tensile load exerted on a single layer of geosynthetic, and is equal to the maximum lateral stress in the reinforced fill, (σ_{hmax}) times the vertical reinforcement spacing, (s) [11].

$$T_{max} = \sigma_{hmax} * s \tag{1}$$

Tensile stiffness is the fabric resistance at the working strain. Researchers have shown that typical strain in GRS bridge-supporting structures is between 0.2% and 1.6%, and recommend that reinforcement strain not exceed 2% for typical structures and be limited to 1% in critical structures with significant surcharges [5, 11]. For design, the minimum required reinforcement stiffness at selected design strain level (1% or 2% strain) must be greater than the maximum tensile load at each reinforcement level.

$$T_{@1\%E \text{ or } 2\%E} \geq T_{max} \tag{2}$$

Additionally, to ensure satisfactory long-term performance, T_{max} must be less than the ultimate tensile strength of the fabric (T_{ult}) reduced by a cumulative long-term reduction factor, k. The ultimate tensile strength is the Minimum Average Roll Value (MARV) wide-width tensile strength of the fabric. The cumulative long-term reduction value accounts for uncertainties affecting the fabric strength with time, including weathering, creep, construction damage, and degradation, and ranges from 0.15 to 0.45 depending on reinforcement type, spacing, and backfill soil properties [7,9].

$$T_{max} \leq k * T_{ult} \tag{3}$$

CASE STUDIES - EXAMPLES OF GRS USE BY CN

Introduction

In 2008, CN extended Poser and Matheson Sidings on the CN Fraser Subdivision. This subdivision follows the Fraser River along the Rocky Mountain Trench between McBride (Mile 0) and Prince George (Mile 146.1) in Central British Columbia (Figure 1). The subdivision is an important link between CN mainline traffic from across Canada to the former BC Rail system, which is now operated by CN. The subdivision is also a part of the CN North Line that routes rail traffic to the Port of Prince Rupert. Increased rail traffic on the subdivision as a result of a new container terminal at the Prince Rupert port, as well as routing of former BC Rail line traffic, necessitated siding extensions. Traffic on the subdivision averages about 10 to 12 trains per day and 34 million gross ton miles per year.

The siding extensions required grade widening by cutting into natural slopes and adding fill along slopes and at locations where the railway crossed tributary streams to the Fraser

River. BGC was retained by CN to carry out a geotechnical investigation along the right-of-way, and use this information to design and provide construction engineering review of the necessary cut and fill slopes. BGC worked closely with CN, UMA Engineering Ltd. who was CN's general consultant for the design and construction, and other consultants providing environmental assessments and monitoring.

Geosynthetic Reinforced Soil (GRS) retaining walls were designed and constructed to steepen fill slopes and cut slopes, allowing CN to minimize encroachment into riparian zones and avoid encroachment onto adjacent private land. At Poser Siding, four GRS walls were constructed ranging from 230 ft (70 m) to 330 ft (100 m) in length and 5 ft (1.5 m) to16 ft (5 m) in height. Two walls were constructed that steepened and drained cut slopes subject to high levels of seepage, and two walls were used to steepen fill slopes immediately above the Fraser River. At Matheson Siding, two GRS walls were constructed as culvert headwalls where the new siding fill would otherwise have required culvert extensions. These walls, at Starbaby Creek and Bittner Creek, were approximately 16 ft (5 m) and 20 ft (6 m) tall, respectively. All of the fill slope walls were designed to retain the fill slope and surcharge of two Cooper E90 train unit loads. In all cases, the siding and GRS walls were constructed while the adjacent mainline track was operating at normal train traffic levels. Details of the design construction and performance to date of these walls are described in the sections below.

Poser Wall 1

Poser Wall 1, located at Mile 12.48 of the Fraser Subdivision, was constructed on a fill slope that traverses natural moderately-steep slopes approximately 65 ft (20 m) above the Fraser River. The natural slope is comprised of glacio-lacustrine silty-sand, overlying sandy gravel near the base of the slope. The purpose of the wall was to steepen the fill slope on the outside of new grade to avoid encroaching on riparian areas and private property. The wall was constructed with a weld wire mesh form facing stepped to form an overall wall face angle of

45 degrees, and it has a maximum wall height of approximately 16 ft (5 m). GRS fabric reinforcement width back from the wall face is 20 ft (6 m) in the top 8 ft (2.5 m) below the top of sub-grade, and 15 ft (4.5 m) wide below this. Resistance to global instability under train loading was maximized by extending the GRS fabric width as far as possible beneath the siding and mainline tracks. The reinforcement width in the upper section extends beneath the entire width of the siding track, ending as close as consistent with adequate temporary cut stability next to the operational mainline track. Figure 2 and Figure 3 illustrate the wall during construction. Figure 4 and Figure 5 are views of the completed wall.

All GRS walls at Poser siding used pit run sand and gravel from a local gravel pit. This material was considered free-draining, and only the geotextile and weld-wire mesh form facing elements required shipping to site.

Poser Wall 5

Poser Wall 5 is located near Mile 13.60 of the Fraser Subdivision, and includes two sections of wall that are designed to steepen and drain new cut slopes for grade widening. The purpose of steepening the cut slope was to avoid long sliver cuts and avoid cuts extending outside of the right-of-way. Figure 6 illustrates the typical section for these walls. The walls helped minimize the cut width in two ways: shortening overall ditch width by steepening the ditch slopes with wall elements while maintaining the full standard ditch cross section area, and steepening the overall slope angle with a low height wall at the toe of the slope. The walls were constructed with weld wire mesh forms bent at 80 degrees and an overall wall face angle of 80 deg to a maximum wall height of 6.5 ft (2 m) and maximum width of 15 ft (4.5 m).

The cut slopes are composed of glacio-lacustrine silty sand and gravel. During construction of the cut, local seepage areas caused shallow slumps and flows. The GRS is constructed of locally available free-draining sand and gravel that acts as a drain at the toe of the slope, allowing seepage water to drain, but preventing migration of the finer native soils behind the wall. The GRS wall also supports the cut slope against global failure, and prevents ravelling, slumping and earth flows from the natural slope while minimizing the requirement for long-term ditch maintenance and the risk of culverts becoming blocked with sediment.

Figure 7 provides two views of the wall construction that illustrate the flexibility of the wall system to be adjusted to fit local conditions. Foundation preparation does not require a surveyed, level pad, and the wall direction and slope can be changed to suit local conditions. At this site, the wall was adjusted in the field to create a culvert intake head wall and basin (Figure 7), and the wall fill was adjusted to include coarser, clean drain rock elements and geosynthetic wrapped French Drains at specific cut slope seepage zones. Figure 8 shows the wall geometry relative to the new siding grade and existing mainline grade.

Matheson Siding - Starbaby Creek

Starbaby Creek is a tributary creek to the Fraser River and is crossed by the Matheson Siding at Mile 139.63 of the Fraser Subdivision. The siding extension crosses on the downstream side of the mainline. Design for the crossing included installation of additional thick-wall culverts installed by pipe jacking, re-design of the culvert outfall elevation and stilling basin, and the requirement that the new culvert arrangement not extend further downstream than the existing culverts to maintain current riparian areas. These measures were partly to improve flood management at the crossing, but mainly to enhance fish passage and culvert outfall habitat.

To maintain the current offset of the culvert outfalls from the mainline, GRS was used to form a headwall for the culverts. The final wall was 16.5 ft (5 m) high and 100 ft (29 m) long and was built around and over the pipe culverts and integrated with the large size rip rap at the culvert outfall. Figures 9, 10, and 11 illustrate the typical cross section for this wall, its geometry, and its appearance near completion. The wall fill was reject material from screening of crushed rock for ballast, and was brought to site by work train and air-dumps. This wall illustrates the flexibility of the GRS system to adjust to site conditions. In this case, the

GRS was integrated with large rip rap placement for the foundation of the wall and also used base support provided by the cluster of thick-wall (1 inch) pipe culverts. The wall was built in about 6 working days. This included incorporation of environmental measures for existing fish stock preservation, work to re-shape the fisheries habitat and channel downstream of the culverts and to rip rap the channel, and wall construction.

Matheson Siding – Bittner Creek

Bittner Creek is a tributary creek to the Fraser River and is crossed by the Matheson Siding at Mile 141.45 of the Fraser Subdivision. The siding extension crosses on the downstream side of the mainline. The existing mainline crossing included a 9 ft (2.7m) wide by 6 ft (1.84 m) high concrete box culvert and a 6 ft (1.8 m) diameter corrugated steel pipe (CSP) overflow culvert located about 30 ft (10m) track-north of the box culvert. The outlet invert elevation of the CSP was about 5 ft (1.5m) higher than the box culvert outlet invert elevation. Design constraints at this crossing included the requirement to preserve the existing riparian zone downstream of the culvert, which had been assessed as prime habitat for 7 species of fish. Design constraints were that the vegetation at the culvert outlets could not be disturbed, and the culverts could not be extended.

GRS was used to form a headwall for the culverts. The final wall was 20 ft (6 m) high and 115 ft (35 m) long and was built around the concrete box culvert and the existing CSP. Figure 12 illustrates the typical cross section for this wall at the box culvert centerline, and a completion photograph looking track-north. Figure 13 is a completion photograph looking track-south. The wall fill was from the same source as for the Starbaby Creek wall, but was brought to site by highway dump trucks along the prepared new siding grade.

The wall was built in about 6 working days without entering the wetted perimeter of the stream downstream of the box culvert outlet.

Equipment and Construction Costs

Equipment used to build GRS walls varies depending on the size and location of the wall. For the siding extensions, large excavators and haul trucks were available to transport, place and spread fill. Compactors ranged from hand-held jumping jack type compactors, a 1,000 lb vibrating plate tamper and a 10 ton dual smooth drum vibratory roller compactor. The smaller compactors were used to compact adjacent to the wall face. Additional hand tools such as shovels, rakes, bolt cutters and a supply of utility knives for cutting fabric are also required. A manual labour crew of about three or four people, plus equipment operators is optimum.

Construction costs for the walls were difficult to track as contractor personnel moved around throughout the siding extension site, costs were mixed with other environmental measure costs, and work was done on a lump sum basis. The clearest example for cost assessment is likely the Bittner Creek wall. This wall was built in six working days with fill delivery by highway dump trucks, one full time Cat 350 Excavator, and a second similar excavator for 2 days. Additional full time equipment included a 10 ton vibrating drum roller compactor and a 1,000 lb plate tamper. Additional manpower was typically four labourers for wall assembly. The wall system was developed by Terratech Consultants Ltd. and is manufactured by Armtec. It uses #4 gauge, hot dipped galvanized weld wire mesh forms as a facing. These forms are 10 ft (3.0m) long and are bent in an “L” shape so that the facing height is 1 ft 10 in (0.56 m) tall and the horizontal portion is 1 ft 6 in (0.46 m). The bend angle on the forms was 80 degrees. Pre-formed struts are clipped to the forms and hold the forms in place during compaction. The reinforcing geosynthetic was Tencate Mirafi HP370 and is placed in two layers per form, for a vertical spacing of 11 in (0.28 m). The lower fabric layer for each form level is used as a facing to retain the fill (Figure 2). Typical weld wire mesh facing costs vary depending on the level of corrosion protection from about $45 to $75 per form. Typical combined system fabric and facing costs per square yard (0.83 square meters) of wall face are $50 for no corrosion protection to $83 for hot dip galvanized facing elements. Typical construction costs for materials and contractor effort vary with the scale of construction and the price of fill, and range between $200 and $500 per square yard of constructed face. All costs are given in Canadian dollars.

CONCLUSIONS

During construction of 2008 siding extensions, CN utilized Geosynthetic Reinforced Soil (GRS) structures for fill and cut slope retaining walls. This paper summarizes the design basis of the systems, and case histories for four of the walls that are up to 20 ft (6 m) high and up to 330 ft (100 m) long. The use of GRS provided a simple construction system that could be readily adapted to site conditions. It provided an innovative solution for culvert head walls that allowed culvert extensions to be avoided and high value riparian areas to be maintained. Use of the system for cut slope steepening allowed long sliver cuts that would have extended outside of the CN right-of-way to be avoided, and readily allowed incorporation of drainage elements within the walls, and culvert catch basins, to collect and control cut slope seepage. With only four parts (fill, fabric, facing elements and facing support struts), the system was inexpensive to mobilize to site, simple to install and could be readily adapted to site conditions by changing the alignment, wall depth, wall length, or facing slope as required.

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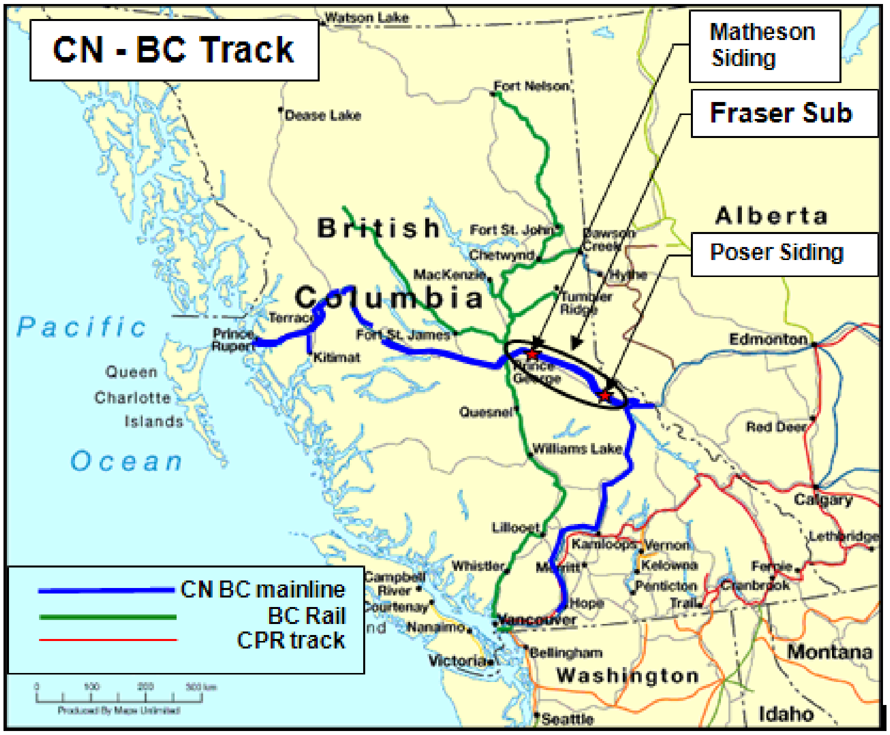

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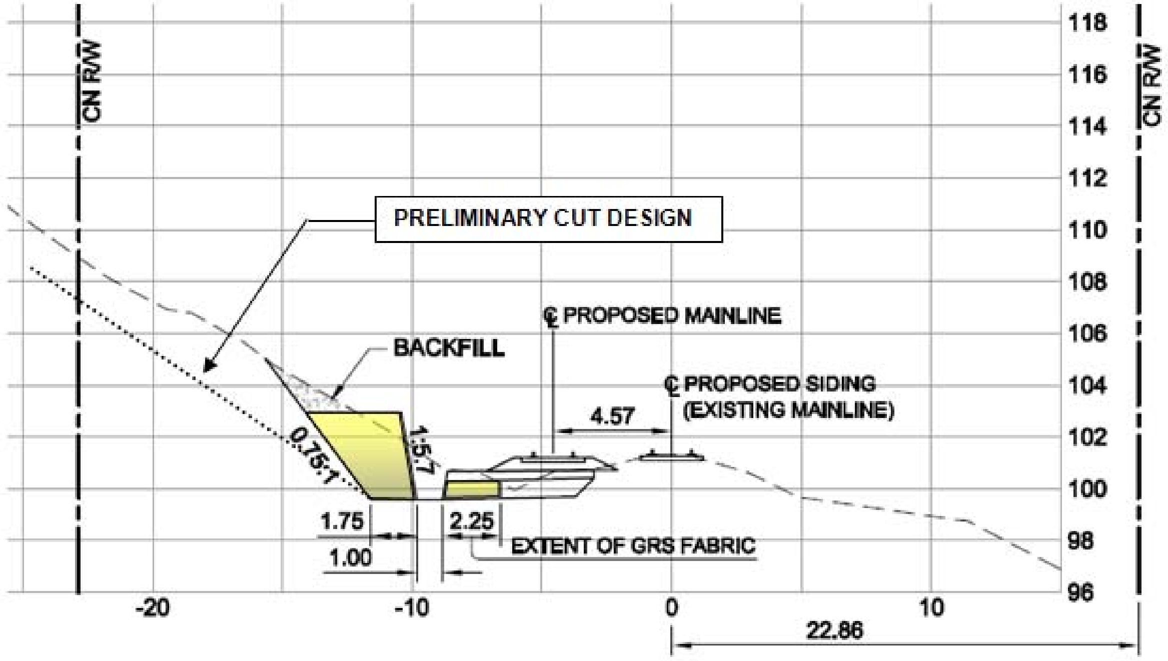

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Figure 8 – Poser Siding Wall 5. View Looking Track-north Showing Temporary Cut, Wall Construction, Construction of New Grade, and Existing Grade. GRS Beneath New Grade has not yet Been Placed.

Figure 9 – Matheson Siding: Starbaby Creek Typical Section. All Dimensions are in Metres.

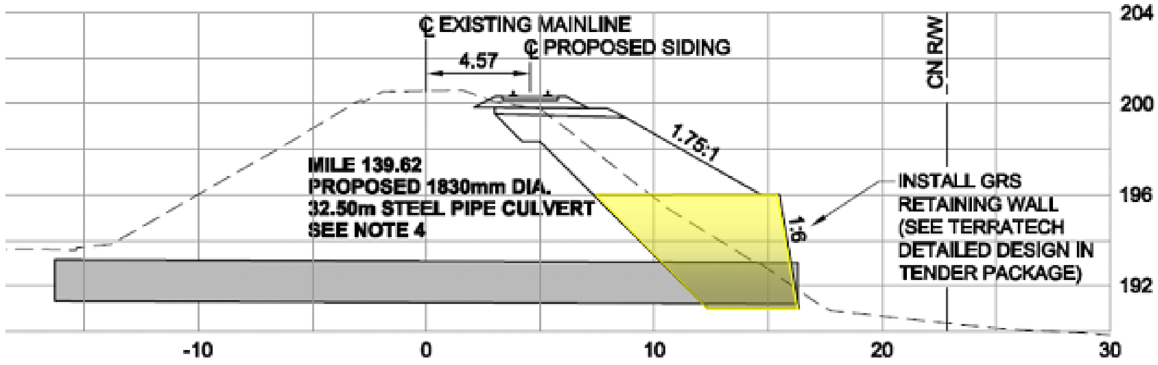

Figure 10 – Matheson Siding: Starbaby Creek Looking Track-north Illustrating Wall Geometry and GRS System.

Figure 11 – Matheson Siding: Starbaby Creek Looking Track-north Near Wall Completion. Note Culverts That Were Installed by Pipe-jacking Prior to GRS Construction and are Visible in the Lower Right of the Photograph.

Figure 12 – Matheson Siding: Bittner Creek. Typical Section at Culvert and View Looking Track-north at Completed Wall. Note Zero Encroachment on Riparian Zone at the Pre-Existing 9 ft Wide by 6 ft (2.7m x 1.84m) High Concrete Box Culvert Outlet. System Facing Weld Wire Mesh Form Height is 1 ft 10 inch (0.56m) per Form. Geotextile Spacing is 11 inches (0.275m). All dimensions are in metres.

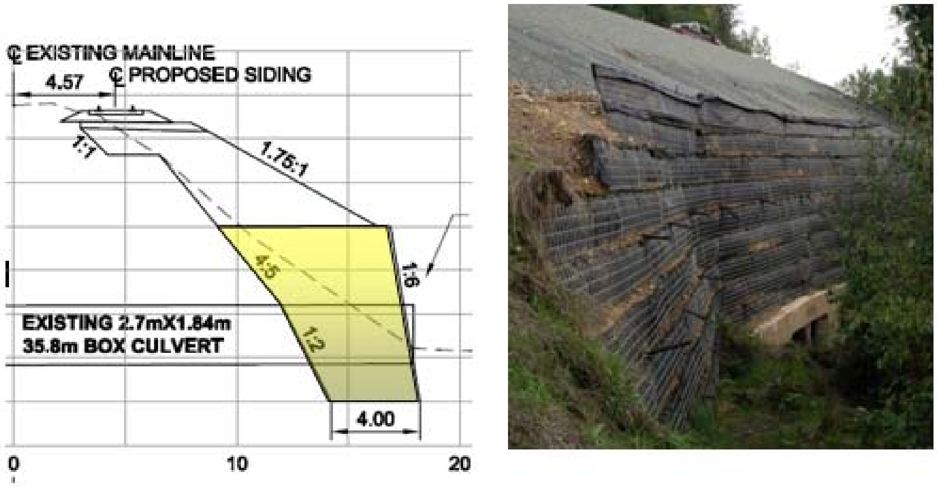

Figure 13 – Matheson Siding: Bittner Creek. View Looking Track-south at Completed Wall Illustrating how the Wall Blends into the Standard Fill Slope Section.