Nadahini Creek Geosynthetic Reinforced Soil Integrated Bridge System

Luke Wadey, E.I.T., Project Engineer
Transportation Engineering Branch
Highways and Public Works, Government of Yukon

Muhammad Idrees, M.Eng, P.Eng, Geotechnical Program Manager,
Transportation Engineering Branch
Highways and Public Works, Government of Yukon

Paper prepared for presentation at the
Low Volume Road Construction Session
of the 2014 Conference of the
Transportation Association of Canada
Montreal, Quebec

ABSTRACT:

In the fall of 2013 Government of Yukon constructed a geosynthetic reinforced soil integrated bridge system (GRS-IBS) at Nadahini Creek. The geosynthetic reinforced soil bridge constructed at Nadahini Creek is the first geosynthetic reinforced soil abutment bridge constructed by the Government of Yukon. This paper describes the project background, design and analysis of alternatives, construction of the selected alternative as well as lessons learned through project implementation.

The Haines Road starts in Haines, Alaska, passes through British Columbia and ends at kilometre 246 in Haines Junction, Yukon Territory. The road serves as the only land route to Haines, Alaska which provides a ferry terminal for residents in central Alaska. Nadahini Creek is located at kilometre 109.2 of the Haines Road in British Columbia. The Government of Yukon maintains the Haines Road from the Canadian Border to Haines Junction.

Nadahini Creek is a highly turbid glacial fed stream with alluvial fan morphology. Twin structural plate corrugated steel pipe arches (SPCSPA) were installed at Nadahini Creek in 1968. Throughout their life span aggraded material was occasionally cleaned out of the culverts by Highways and Public Works maintenance workers. In the summer of 2012 the culverts were aggraded with material and Highways and Public Works cleaned them out. When the bottoms of the culverts were exposed it was discovered that high amounts of sediment transport had worn through large portions of the inverts, compromising their structural integrity and posing a safety concern for traffic. Jack post supports were installed in the north culvert and Highways and Public Works began investigating design alternatives to replace the structures.

Government of Yukon considered various alternatives including installing new SPCSPAs, open bottom arch culverts, a bridge on piles and a geosynthetic reinforced soil integrated bridge system (GRS-IBS). Many design factors were considered in the analysis of alternatives including formidable stream discharge values, large sediment transport and scour depths, as well as the need to accommodate fish passage. After completing a life cycle cost analysis, the GRS-IBS alternative with concrete precast box girders was selected and Government of Yukon began the design of the bridge. The GRS-IBS incorporates abutments constructed of closely spaced layers of high strength geosynthetic reinforcement in-filled with compacted granular material. The beams are seated directly on the compacted GRS abutment; no pile driving or pile caps are needed.

The construction of the GRS-IBS at Nadahini Creek was constructed successfully and resulted in the conclusions that the construction of GRS-IBS are well suited for remote locations with low anticipated scour as there would be minimal excavation, minimal materials and construction time required for implementation. Using a straight facing wall opposed to a corrugated facing may also lend to ease of construction.

1. BACKGROUND AND HISTORY:

The Haines Road is 246 kilometres long and runs from Haines, Alaska through British Columbia to Haines Junction, Yukon Territory. The road is the only land route to Haines, Alaska and is commonly used by residents of central Alaska to access the ferry system from Haines. The route was originally a trail used by the Chilkat and Tlingit First Nations. The trail later became known as the Dalton Trail after Jack Dalton who made improvements to the trail and charged a toll to use it during the Klondike gold rush. The road was built by the United States army in the 1940's roughly following the Dalton Trail alignment. Revisions were completed by Public Works Canada in the 1960's and the highway was reconstructed in the 1970's and 1980's as part of the Shakwak Highway Project, a project funded by the United States government. In 2011 the annual average daily traffic count (AADT) for the Haines Road was 227 vehicles.

Nadahini Creek is located in British Columbia at kilometre 109.2. During its original construction the Haines Road crossed Nadahini Creek via a timber bridge approximately 200 metres upstream of the current alignment. In 1968, this section of the highway was realigned to its current location and the timber bridge was replaced with two structural plate pipe arches each 15 feet 4 inches wide and 10 feet 4 inches high.

Nadahini Creek is a remote location approximately 137 kilometres from Haines Junction, Yukon Territory a town of approximately 600 people. Whitehorse, Yukon Territory is the Territorial capital with a population of approximately 30,000 people. The Yukon Territory has a population of approximately 37,000 people.

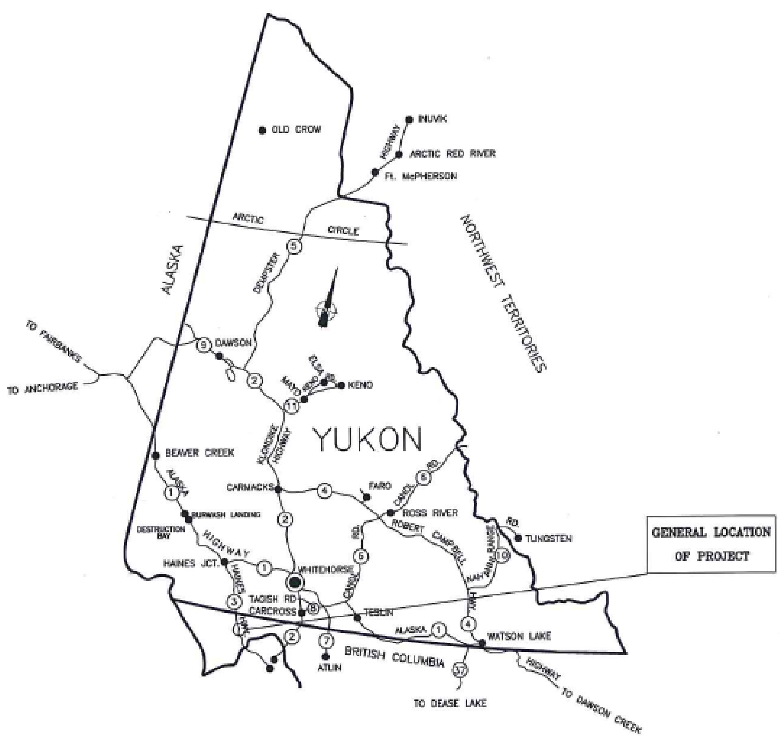

Figure 1: General Location of Project

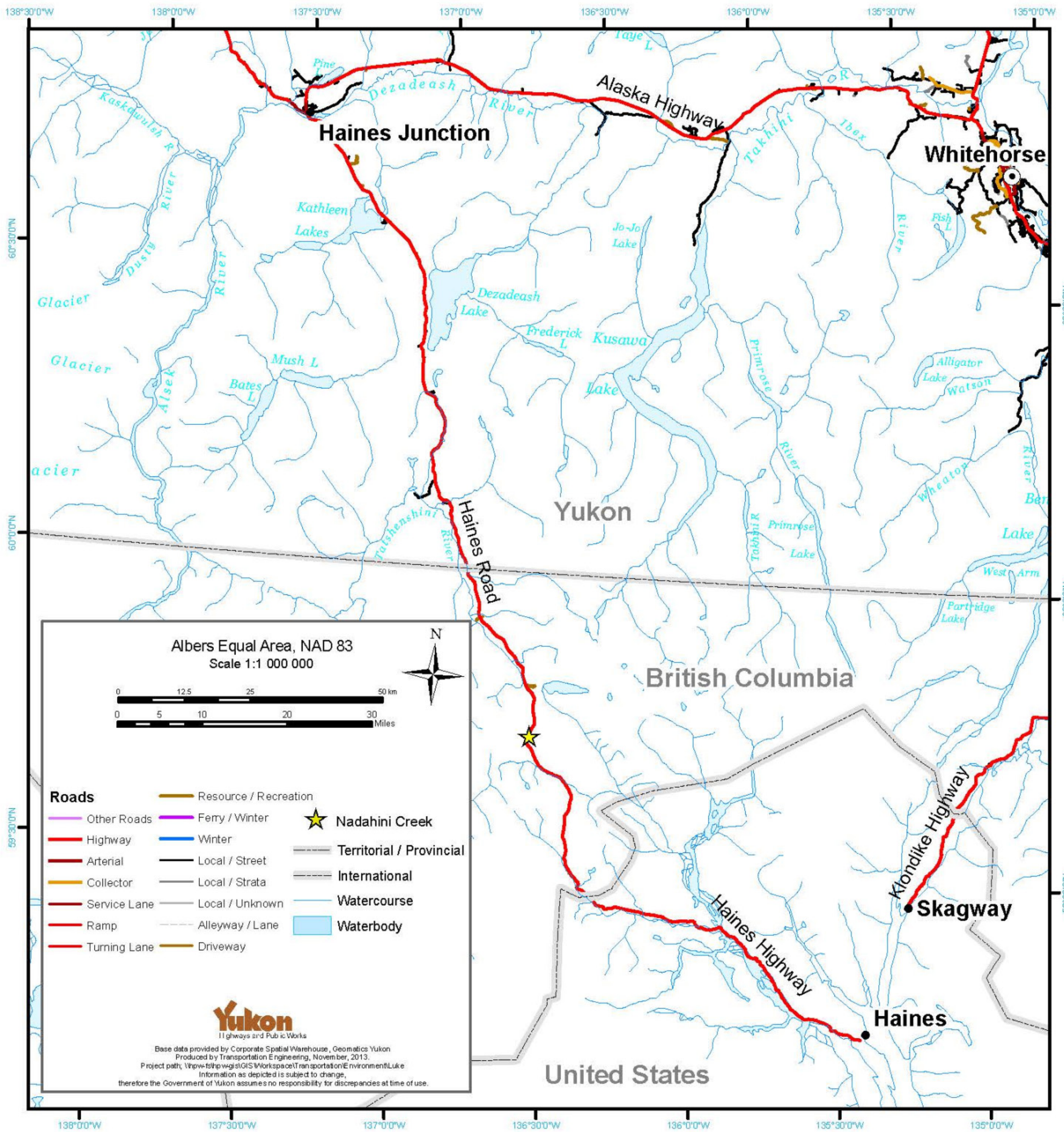

Figure 2: Location of Project at Nadahini Creek, kilometre 109.2 on the Haines Road

Figure 3: Fall 2012 Nadahini Creek Twin Structural Plate Pipe Arches (SPCSPA)

In August of 2012 the existing culverts were cleaned out of aggraded aggregate and the inverts of both pipes were noted to have experienced severe abrasion. The north culvert was noted to be more damaged than the southern one. Jack posts were installed in the north pipe as a safety precaution while design alternatives were considered.

Figure 4: Abrasion Damage on Bottom of North (left) and South (right) Culverts

Figure 5: Spring 2013, Jack Posts in North Culvert, Embankment Settlement Over North Culvert

2. Design Obstacles:

Table 1: Design Obstacles:

I. Minimal/Outdated Hydrology data:	Hydrology data taken from report published in 1978.
II. High Flows Predicted:	Nadahini Creek is glacial fed and flows can raise significantly in a short time during warm weather and/or precipitation. Nadahini Creek has an estimated average flow of 18 m^3/s with Q_{100} estimated at 98 m^3/s. Structure capacity was designed to estimated Q_{200} discharge of 122 m^3/s to meet British Columbia design guidelines.
III. Sediment Transport:	Constant movement of aggregate down creek, consider invert abrasion.
IV. Scour:	High flows on alluvial fan of glacial till, estimates predict possibility of high scour values.
V. Aggradation:	Bottlenecking wide alluvial fan down at highway crossing which may cause aggradation issues at certain discharges. Alluvial fan width approximately 120 m wide at ravine exit and 260 m wide at highway.
VI. Permitting Challenges:	Unfamiliar with permitting applications and processes as project location is outside of Yukon Territory.
VII. Remote Location:	Nadahini Creek 137km to Haines Junction (population approx. 600) and 290km to Whitehorse (population approx. 30,000). Can be difficult to get specific materials to site on short notice, under-estimating for materials and freighting can have significant cost implications.

3. Alternatives Analysis and Selection:

I. Replace Existing Culverts with Same

Pros	Cons
• Inexpensive • Fast Installation • Common Practice, Simple Installation • No snow drifting • Minimal excavation • Simple diversion • Possible to do without detour	• Shorter service life • Meet Q_{200} design flow difficult • Wear of invert • Fish passage difficult • Scour(at inverts and between culverts) • Difficult to install sheeting – boulders • Aggradation reduce CSP capacities – periodic clean outs may be required

II. Open Bottom Pipe Arch (considered with and without high tension cable barrier)

Pros	Cons
• Fast installation • Minimal snow drifting, if at all • Preferred by DFO • Minimal excavation	• Scour at footings • No local experience • Higher risk design (arch, cable barrier) • Difficult to install sheeting – boulders • Cost variances with footing casting

III. H Piles with Precast Concrete Box Girders

Pros	Cons
• Long service life • Preferred by DFO • Minimal excavation • Fast installation (probable) • Minimal maintenance	• Possible pile driving difficulties – coarse material, boulders • Detour • Snow drifting caused by guiderail

IV. GRS-IBS with Precast Concrete Box Girders

Pros	Cons
• Long service life • Minimal maintenance • Minimal materials and freight • Inexpensive with fast installation • Preferred by DFO • Joint-less (bridge to approach) • No settlement expected	• No local or government experience • Detour • Higher risk design • Deep excavation • Snow drifting caused by guiderail • Scour

After completing a life cycle cost analysis the geosynthetic reinforced soil-integrated bridge system (GRS-IBS) with concrete precast box girders was selected. The GRS-IBS is cost effective, utilizes minimal material and equipment, has a fast installation time and provides a long service life which made it an appealing option.

4. Detailed Design and Construction:

I. Specifications:

The "Geosynthetic Reinforced Soil integrated Bridge System Interim Implementation Guide" published by the U.S. Department of Transportation Federal Highway Administration (FHWA) was used to complete the design of the GRS. The Canadian Standard Association's (CSA) "Canadian Highway Bridge Design Code", the American Association of State Highway and Transportation Officials (AASHTO) "Roadside Design Guide" as well as the Transportation Association of Canada's (TAC) "Guide to Bridge Hydraulics" and "Geometric Design Guide for Canadian Roads" were also referenced during design.

II. GRS Concerns:

During research concerns arose regarding the effectiveness of GRS with respect to seismic loading and scour. Alaska's Department of Transportation and British Columbia's Ministry of Transportation informed Government of Yukon that they do not use GRS-IBS due to scour concerns and seismic loading issues respectively. Correspondence with FHWA indicated that they had constructed GRS structures in seismic areas and that the reinforced soil responds well to seismic loading. They referenced the National Highway Cooperative Research Program (NHCRP) report "Seismic Design of Geosynthetic-Reinforced Soil Bridge Abutments with Modular Block Facing" which includes seismic tests on GRS structures. To combat scour the abutments were designed to begin below the estimated Q_{200} scour elevation. In proposing alternate designs, similar scour depths were obtained by the contractor.

III. Design Guidelines and Materials:

Girder Design: CAN/CSA S6-06 CL625 (Ont.) Loading
GRS Design: FHWA GRS-IBS Interim Implementation Guide
Design Speed: 100 km/hr
Deck: 90 mm Asphalt Overlay
Girder Span: 15.3m Precast Concrete Box
Guardrail: Parapet Wall Meeting PL-2 Rating
Guiderail: W-Beam with Thrie Beam Connection at Guardrail
Discharge: Q_{200} (B.C. MOT Primary Road)
Freeboard: 1.5m (B.C. MOT Primary Road)
Contraction Scour: 2. 6m
Geotextile: High Strength Woven Polypropylene or Polyester Geotextile (See Table 2)
Facing Wall (Original Design): 8 ga. Galvanized Steel Sheeting & 28 MPa Concrete Masonry Units
Facing Wall (Alternate Design): 3.175mm thick, 5N Corrugated Aluminum Structural Plate

GRS Backfill: Granular “A” 20 mm Crushed Aggregate

Table 2: Geotextile Specifications:

Physical Properties	**Standard**			**Unit**	**Value**
Wide Width Tensile Strength	ASTM D4595	Minimum	Machine Direction	kN/m	70
			Cross Machine Direction	kN/m	70
Wide Width Tensile Strength @ 2%	ASTM D4632	Minimum	Machine Direction	kN/m	14
			Cross Machine Direction	kN/m	22
Wide Width Tensile Strength @ 5%	ASTM 4632	Minimum	Machine Direction	kN/m	35
			Cross Machine Direction	kN/m	52
Permittivity	ASTM D4491	Minimum		Sec^{-1}	0.8
Apparent Opening Size	ASTM D4751	Nominal		Microns	600
Roll Width		Minimum		m	4.5

IV. Design:

After some of the design parameters were set the design for the bridge began. Scour estimates and rip rap sizing were calculated referencing the TAC Guide to Bridge Hydraulics. HEC-RAS and the Lacey equation were also used to calculate anticipated scour depths and come up with an accepted scour depth. The bottom elevation of the GRS was established just below the estimated Q_{200} scour depth. Steel sheeting was selected to be used as the facing to a minimum height of 0.5m above the high water mark and the remaining wall was to be coped concrete masonry units as specified in the FHWA manual. The steel sheeting was chosen as much of the wall was embedded below the stream level and not visible. Another reason steel sheeting was chosen was to expedite the installation by being able to erect the majority of the facing wall at once. Guiderail length and tapers were designed referencing the TAC and AASHTO geometric design guides. A 15.3 metre girder span was selected with approximate beam seats of 1.3 metres at each abutment; the beam seat being the length of the girder that rests on the GRS abutment. The precast box girders were designed in accordance with the Canadian Highway Bridge Design Code CAN/CSA-S6-06. The stresses in the fabric layers were then calculated; spacing between fabric layers in the main soil column and beam seat were determined and the geosynthetic was specified as a woven high strength geotextile to meet the calculated stresses (See Table 2).

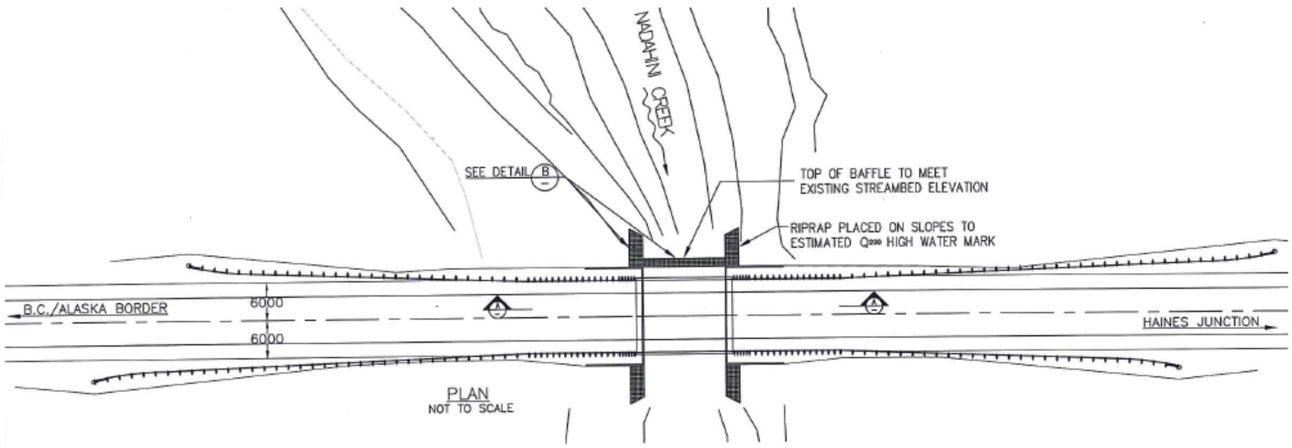

Figure 6: Nadahini Creek Bridge General Plan View

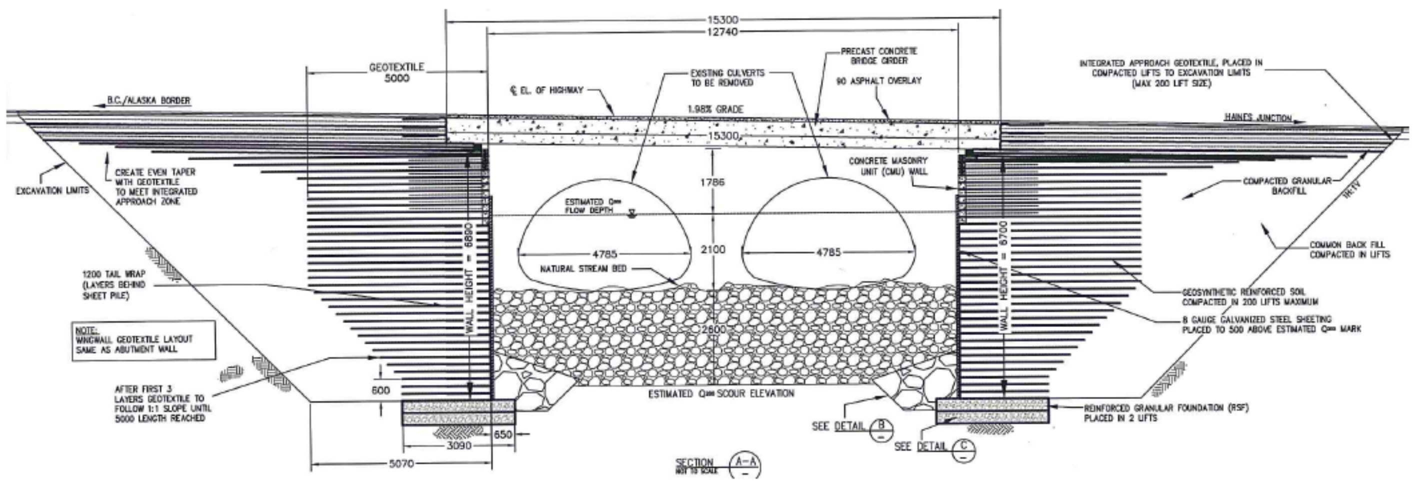

Figure 7: Government of Yukon Original Tendered Design, Section

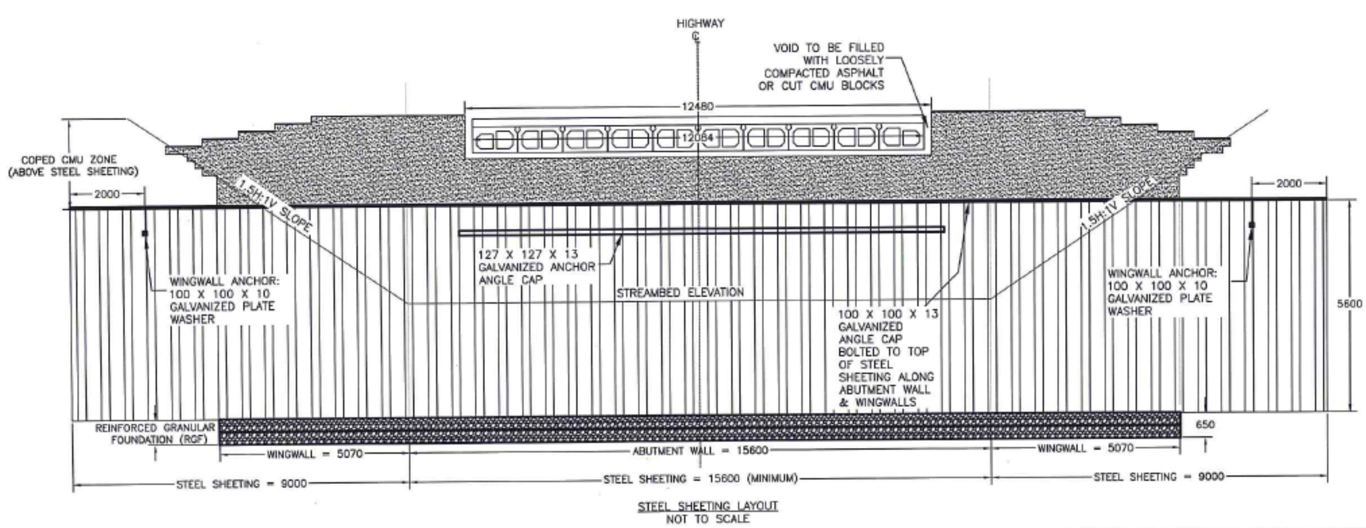

Figure 8: Government of Yukon Original Tendered Design, Wall Layout

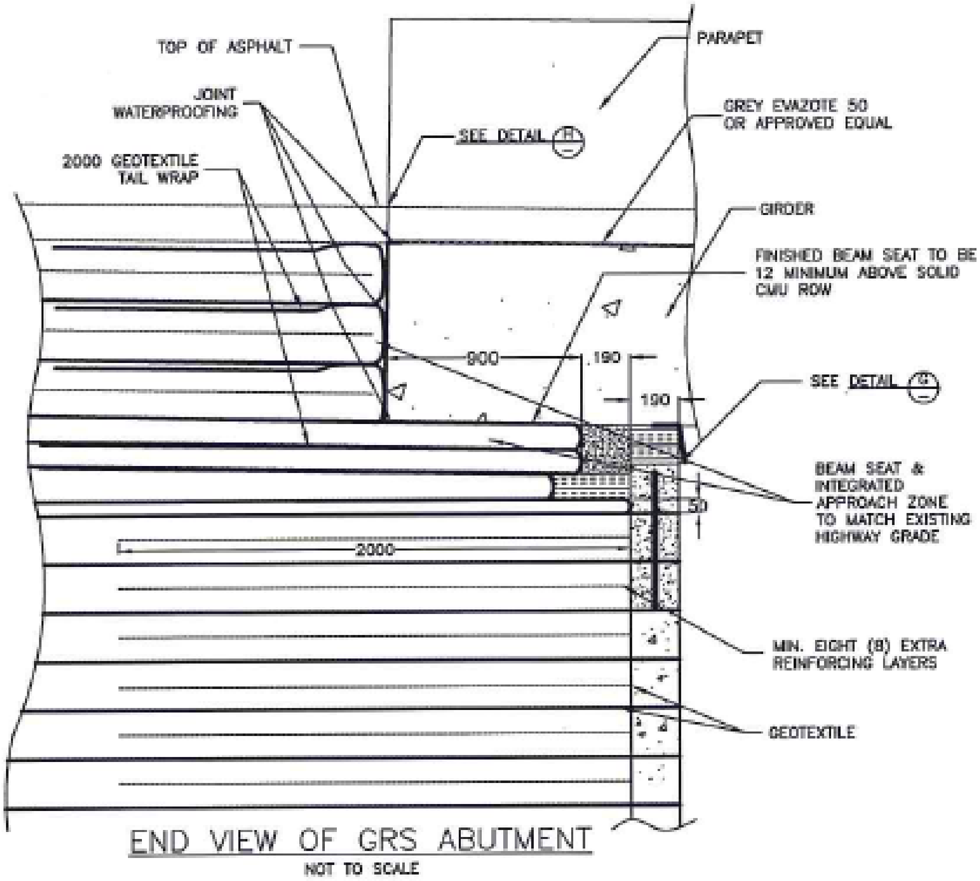

Figure 9: Government of Yukon Beam Seat Detail

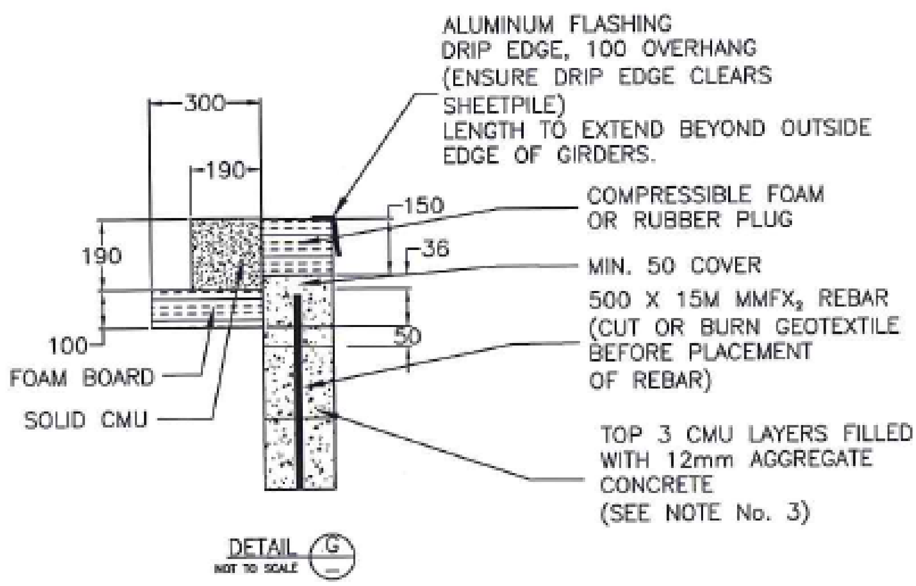

Figure 10: Government of Yukon Top of Facing Wall Detail

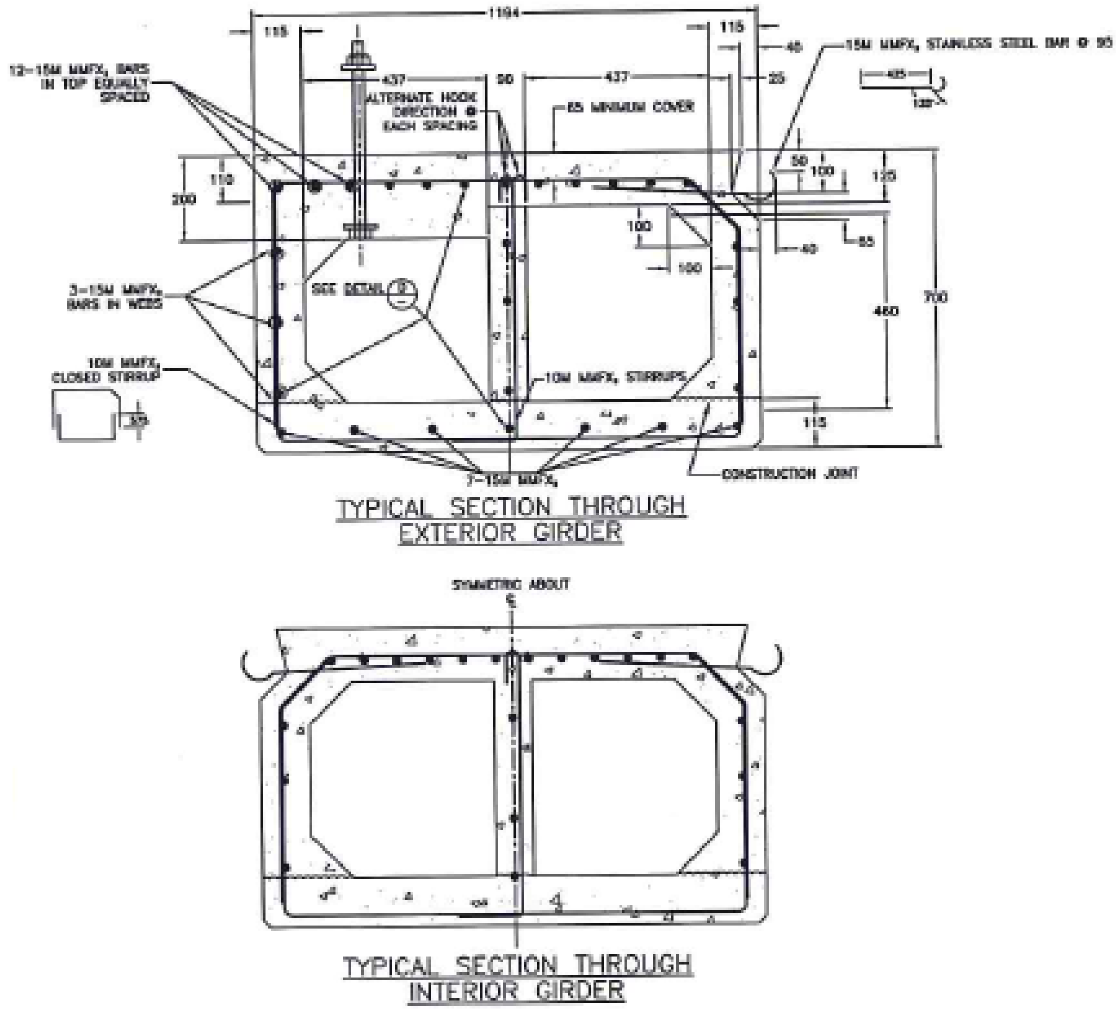

Figure 11: Typical Exterior and Interior Girder Sections

I. Tender of Design:

After the design of the Nadahini Creek Bridge was completed in house the bridge construction project was tendered as part of a warm mix asphalt paving job in the spring of 2013. After award the contractor proposed an alternate design utilizing corrugated aluminum sheeting panels in place of the steel sheeting and coped masonry blocks that were part of the original government design. The alternate design also utilized a geotextile spacing of 275 millimetres as opposed to the tendered conservative spacing of 200 millimetres. A compromise was attained using 200 millimetre geotextile spacing at all levels 5 metres below bottom of girder and 275 millimetres above that depth. The proposed alternate wall design was approved and construction of the bridge began in the fall of 2013.

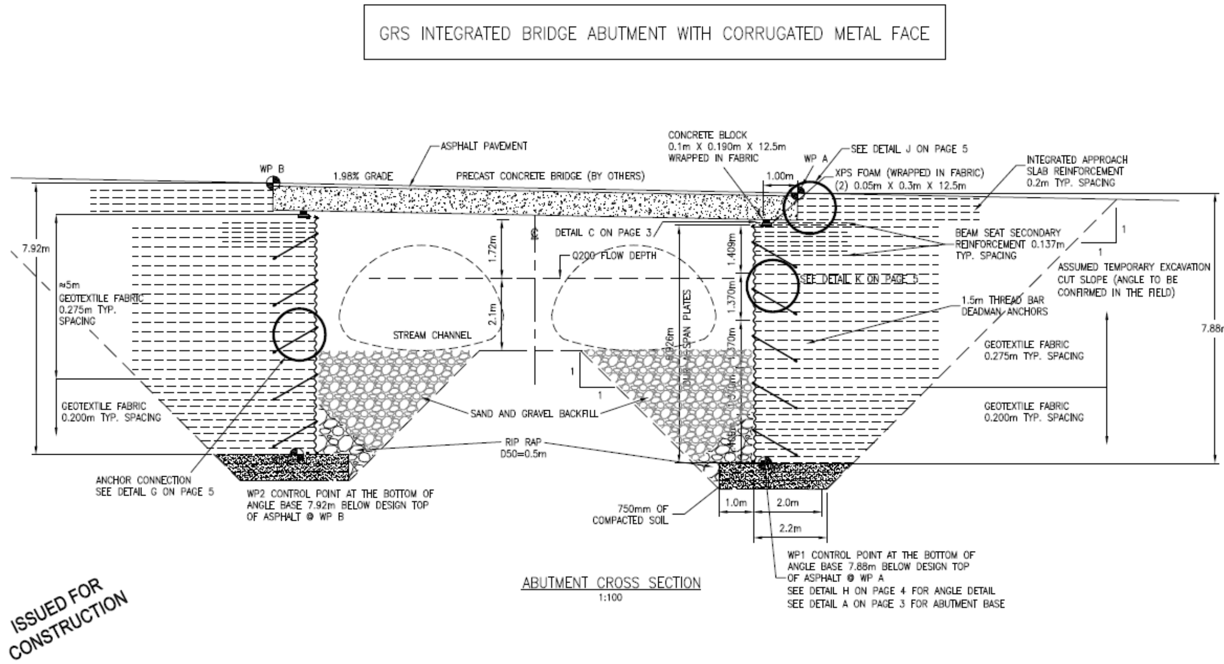

Figure 12: Approved Alternate Corrugated Aluminum Sheeting Wall Design, Section

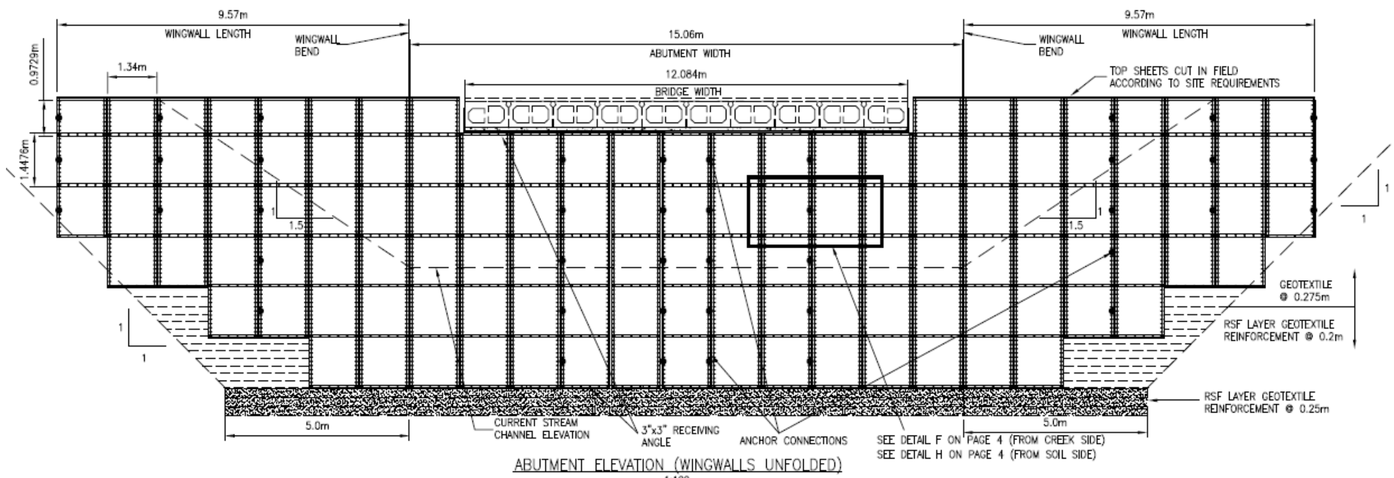

Figure 13: Approved Alternate Corrugated Aluminum Sheeting Wall Design, Section, Wall Layout

II. Construction of GRS, Beam Seats and Girder Erection, and Detour.

GRS was constructed utilizing high strength woven geotextile and a corrugated aluminum sheeting wall. The aluminum sheeting had periodic deadman anchors to help keep the wall plumb but lent no structural support to the GRS soil column; just a facing to prevent scour and erosion. The GRS abutment was constructed in compacted lifts of 200 millimetres to 275 millimetres with high strength geotextile between each lift. The area approximately 1 metre directly below the girders is the beam seat reinforcement zone where the geotextile layer frequency was doubled. The beam seat was approximately 1.30 metres at each abutment measured from the face of the wall. Lifts were compacted to a minimum 99 percent of the standard proctor maximum dry density (SPMDD) 2 metres directly below top of girder, a minimum 98 percent SPMDD the next 1 metre below the beam seat reinforcement zone and a minimum 96 percent SPMDD in all remaining lifts. The beam seats consisted of a row of smooth concrete blocks wrapped in high strength woven fabric on top of high density polystyrene foam also wrapped in high strength woven fabric, these layers were 190 millimetres and 300 millimetres in depth respectively. All backfill within the GRS abutment was crushed 20 millimetre minus aggregate having less than 6 percent fines by mass.

As the Haines Road is the only land route to Haines Alaska closing the highway was not an option and a detour was constructed upstream of the highway with a 70 foot single span detour bridge. The detour bridge was erected close to the new GRS abutments so excavators could unload the girders off the detour bridge. Having the detour bridge in such close proximity to the abutments created challenges with the channel diversion and north abutment excavation.

Figure 14: Construction of South Abutment

Figure 15: Construction of South Abutment

Figure 16: Construction of North Abutment

Figure 17: Construction of North Abutment

Figure 18: Placing foam board for beam seat zone

Figure 19: Girder Erection

Construction of the south abutment took approximately 9 days plus excavation and construction of the north abutment took approximately 7 days plus excavation. Total construction days including installing the detour, installing the detour bridge, removing the existing structure, completing all dewatering and diversions, installing the abutments, erecting the girders, grouting the keyways, installing temporary guiderail for the winter as well as restoring the guidebanks was approximately 45 construction days (See Table 3). Final costs for construction of the detour, installation and removal of the detour bridge, removal of the existing structure and installing the geosynthetic reinforced soil integrated bridge system was approximately 1 million dollars. This does not include engineering costs or approach guiderail installation costs.

Table 3: Construction Schedule

Milestone	**Approximate Time To Complete (Days)**
Detour Construction	5
Detour Bridge Installation	1.5
Excavation & Diversion	3
Remove Existing Structures	1
Diversion	1
South Abutment Excavation	2

South Abutment Dewatering & Re-establish Excavation	1.5
South Abutment GRS Construction	9
North Abutment Excavation	2
North Abutment GRS Construction	7
Beam Seat Construction (North & South Abutments)	2
Girder Erection	1
Hoarding & Grouting of Keyways and Parapet Bolt Holes	3
Time to cure	3
Install Temporary Guiderails	1
Remove Detour Bridge	1
Place Rip Rap and Restore Guidebanks	1
Total Days:	**45**

Figure 20: Bridge Open to Traffic

Figure 21: Completed GRS-IBS with Temporary Guiderails (view from upstream)

Figure 22: Completed GRS-IBS with Temporary Guiderails (view from downstream)

III. **Construction Challenges:**

Due to a short span bridge design and the contractor's selected location of the detour bridge, excavating to bottom of foundation depth proved to be difficult. The clean glacial till also provided challenges in keeping excavations dry as water seeped through the excavations and pumps were ran around the clock at the beginning stages of both excavations. Keeping the walls plumb during construction also became a challenge as there was no vertical bracing or way to bring the wall back into plumb after backfilling above the deadman anchors of each horizontal section. This was the first time this aluminum sheeting wall proposed by the contractor had been used and it was a first time for the workers onsite to be constructing a GRS abutment.

5. <u>Lessons Learned:</u>

Inadequate excavation layout as well as close proximity of the detour bridge to the abutments resulted in delays and issues with the abutment excavation. Project delays also resulted from an insufficient initial channel diversion plan to meet water levels experienced, and from the seepage of water through the excavation walls. Because there was no experience installing the aluminum sheeting wall installation times were slow and the wall was erected out of plumb in areas. Erecting a wall of corrugated aluminum sheeting that is assembled in a corrugated pattern also made it difficult to monitor plumbness of the wall and place the geotextile fabric crease free. Although the wall facing lends no structural strength to the wall, having continuous vertical sheeting or bracing up the wall may be beneficial in building a more plumb and aesthetically pleasing structure. In the future, ensuring that the excavation limits and depths are properly considered as well as utilizing a facing wall material that has been installed on previous jobs should reduce the installation time and improve project costs. Ensuring the GRS is constructed by a crew that has previous experience with this type of construction may also lend to shortening installation times. Another consideration may be to use a wall like the original steel sheeting wall that only requires installation at the beginning of wall construction and does not need to be constructed in horizontal panels. The ability to erect the wall all at once would reduce wall assembly time.

Benefits of utilizing a GRS-IBS structure were the minimal materials required, long service life, ease of installation, joint-less approaches and unlikelihood of settlement. In the future geosynthetic reinforced soil integrated bridge systems should be considered for sites with minimal anticipated scour as well as a nearby rip rap and aggregate source. In remote locations bringing all materials with the exceptions of the girders on one truck load has major cost saving implications.