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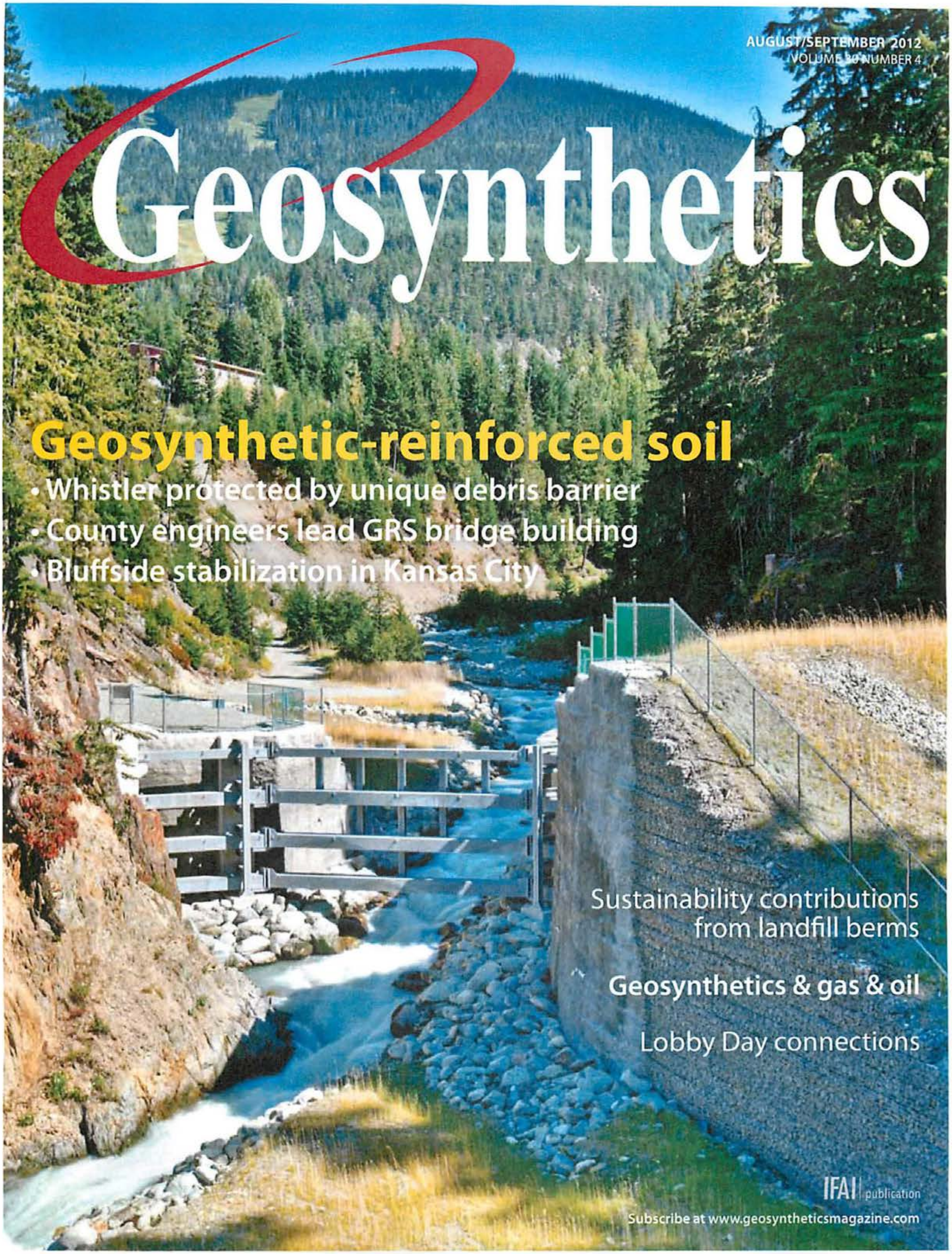

Geosynthetic-reinforced soil

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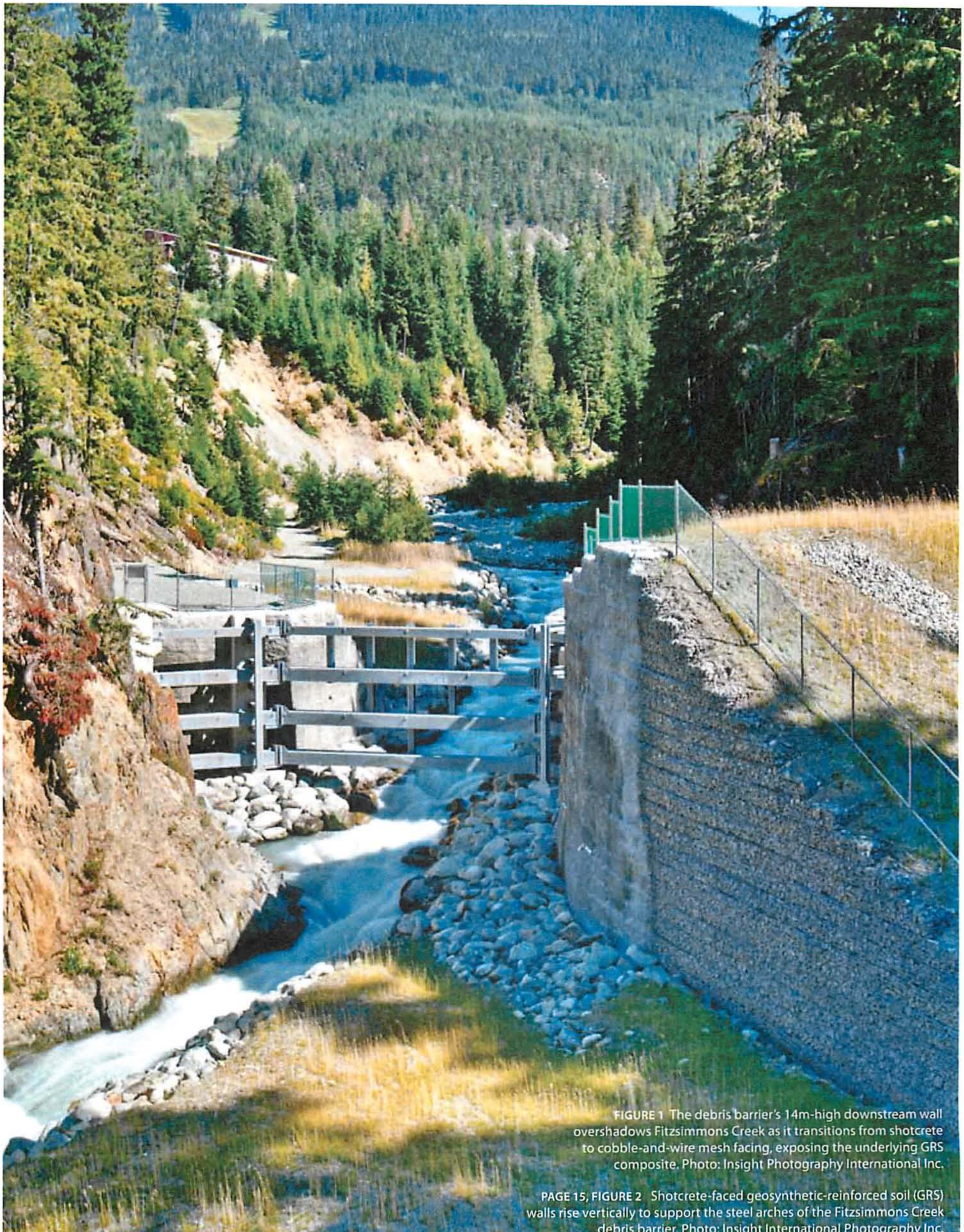

FIGURE 1 The debris barrier's 14m-high downstream wall overshadows Fitzsimmons Creek as it transitions from shotcrete to cobble-and-wire mesh facing, exposing the underlying GRS composite. Photo: Insight Photography International Inc.

PAGE 15, FIGURE 2 Shotcrete-faced geosynthetic-reinforced soil (GRS) walls rise vertically to support the steel arches of the Fitzsimmons Creek debris barrier. Photo: Insight International Photography Inc.

Geosynthetic reinforced soil walls for debris barrier in Whistler, B.C.

By Alex Strouth, Mark Pritchard, David Roche, and Calvin VanBuskirk

Introduction

Picturesque Fitzsimmons Creek flows through the heart of Whistler, B.C., Canada—about 80 miles north of Vancouver and one of the host sites for the 2010 Winter Olympics. Few visitors to Whistler realize that Fitzsimmons Creek poses a debris flood risk to the village.

This article describes the role of geosynthetic-reinforced soil (GRS) in the 2009 construction of a debris barrier that now protects Whistler from the damaging effects of a large-debris flood. It also describes the role of GRS as a critical structural component, outlines the GRS design basis and construction procedure, and summarizes performance monitoring results. Lessons learned, unique features, and advantages of the GRS system for the project are also highlighted.

Fitzsimmons Creek debris barrier

The Fitzsimmons Creek debris barrier design incorporates a GRS structure to channel debris and to support a steel arch barrier that spans across the waterway **(Figures 1, 2, 3)**.

The design allows sediment, fish, and kayakers to pass beneath the steel arches during normal flows while trapping surges of boulders, logs, and other debris that could threaten the community during large-debris flood events. The barrier is designed to retain up to 34,000m^3 of debris and withstand overtopping. The GRS abutment walls rise vertically up to 14m above the final ground surface (17m above the foundation).

Angled GRS walls on the upstream side of the structure are positioned to absorb debris flood impact and funnel debris toward the center of the steel arch. The GRS walls are designed to protect vulnerable steel components from debris impact and to resist impact and erosion from boulders and trees careening up to 5m/s.

Downstream, vertical GRS walls form an abutment for the left (looking downstream) steel arch structure foundation. The GRS abutment is designed to retain stored debris and resist horizontal forces transferred from the steel arch legs during debris impact.

The GRS wall system's flexibility allows it to accommodate abrupt changes in face alignment, slope, and footing elevation. This flexibility helped designers minimize encroachment of the abutment structure into the channel while still providing adequate bearing resistance against static and dynamic design loads. GRS flexibility also enabled on-the-fly design modifications to accommodate unexpected site conditions without delaying construction.

GRS design basis

GRS is a term used to describe reinforcement of compacted granular soil with closely-spaced layers of geosynthetic textiles (or grids) to form a composite material of higher strength than soil alone.

PROJECT HIGHLIGHTS

FITZSIMMONS CREEK DEBRIS BARRIER, 2009

LOCATION
Whistler, B.C., Canada

GEOTECHNICAL DESIGN AND REVIEW
Alex Strouth, P.E., and Mark Pritchard, P.Eng., P.Geo., BGC Engineering Inc. (Vancouver, B.C., Canada)

LEAD DESIGN ENGINEER
David Roche, P.Eng., Kerr Wood Leidal Associates Ltd. (Burnaby, B.C., Canada)

GRS DESIGN
Calvin VanBuskirk, P.Eng., P.Geo., Terratech Consulting Ltd. (Salmon Arm, B.C., Canada)

GEOSYNTHETIC MATERIAL
Mirafi HP570 woven polypropylene geotextile

GRS adaptability was most clearly demonstrated at the upstream end of the structure where the GRS wall tied in to a bedrock slope.

When used for walls, a strong connection between the geotextile reinforcement and the wall facing is not required because the GRS facing elements are primarily a construction aid and facade. The wall facing is required only to resist the construction-induced compaction loads and active soil pressure that develops between reinforcing layers (Wu, 2007).

GRS systems are distinct from externally-supported soil retaining systems such as mechanically stabilized earth (MSE) that typically use stronger, but more widely spaced, reinforcement elements connected to a rigid facing. The flexible GRS facing and reduced importance of connection between the facing and reinforcement facilitate construction and allow for a design that can be easily adapted to site conditions. Additionally, the self-stable nature of GRS is compatible with applications like debris barriers where impact and erosion forces could damage the wall facing elements.

Design of the GRS composite at Fitzsimmons Creek was based on the method published by the U.S. Transportation Research Board (TRB) for design of GRS bridge abutments (Wu et al., 2006). That method is an adaptation of the Federal Highway Administration (FHWA) guidelines for MSE walls (Elias, 2001). The revisions provided by Wu et al. (2006) are applicable to structures with closely spaced reinforcement and flexible wall facings, which are defining characteristics of GRS.

The FHWA has recently adopted these revisions, publishing a manual that outlines state-of-the-art and recommended practice for GRS design (Adams, 2011). Although this manual was issued after completion of the project, the GRS design approach developed independently for the Fitzsimmons Creek debris barrier is in general agreement with these recommendations.

Geotextile reinforcement was selected so the design reinforcement load was

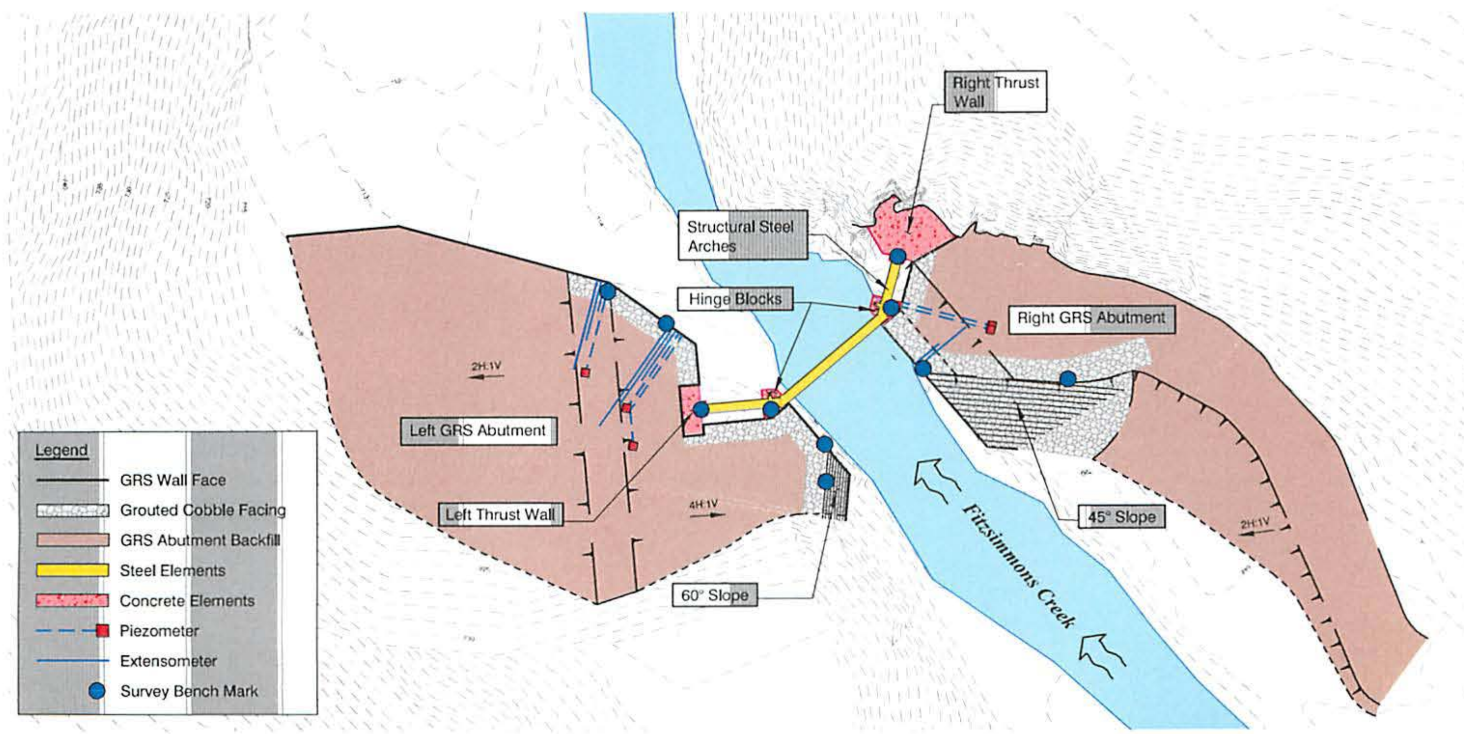

FIGURE 3 Fitzsimmons Creek debris barrier, schematic plan view

exceeded by both the geotextile factored ultimate tensile strength and its tensile resistance mobilized at 2% strain. The factor of safety applied to the ultimate tensile strength accounts for uncertainties such as weathering, construction damage, creep, and degradation. Specification of the resistance at the working strain provides satisfactory performance under in-service conditions by ensuring that the required reinforcement strength can be fully mobilized by the expected reinforcement strain (Wu et al., 2006).

The design reinforcement load was estimated as the theoretical maximum tension applied to a reinforcement layer based on the geotextile spacing and Rankine's active stress condition over the full wall height, as recommended by the FHWA guide for MSE walls (Elias, 2001).

The GRS composite was dimensioned to resist the conventional retaining wall failure modes of sliding and overturning, including the added complication of horizontal forces imposed by the steel arches. Global stability and foundation bearing capacity failure modes were precluded by the near-horizontal bedrock foundation.

Static conditions with a water table at one-third wall height and seismic loading were both considered. Drains through the impermeable wall facing were included to maintain the water table below one-third of the wall height in case a design event causes increased water infiltration into the fill.

Fitzsimmons Creek GRS design and construction

The GRS facing elements, reinforcement spacing, and construction sequence used at Fitzsimmons Creek have been used for numerous retaining wall, soil arch, and bridge abutment applications across Western Canada in roadway and railway applications (Strouth et al., 2009).

Welded wire mesh forms were used as facing elements, with cobbles placed in the forms within 1m of the face, to retain the GRS fill during construction. The open facing forms allowed simple integration of elements that pass through the face such as drains, extensometers, and tieback anchors for adjacent concrete works.

Each facing form is #4 gauge galvanized weldmesh that is 56cm tall, 46cm wide, 3m long, and bent at 90°. A high-strength woven polypropylene geotextile was placed as reinforcement at the bottom and middle of each form, resulting in vertical reinforcement spacing of 28cm.

The ultimate strength of the geotextile is 70 kN/m in both machine (MD) and cross (CD) directions, and the resistance at 2% strain ranges from 14 kN/m (MD) to 19.3 kN/m (CD). The geotextile's tensile resistance at 2% strain exceeded the design load in both MD and CD, which allowed placement of the geotextile in either orientation relative to the wall face.

The required reinforcement width was equal to about two-thirds of the maximum wall height to meet the overturning and sliding criteria. Identical geotextile type, vertical spacing, and extent were specified for the entire wall because the risk of placement errors during construction was considered greater than the relatively minor cost savings associated with

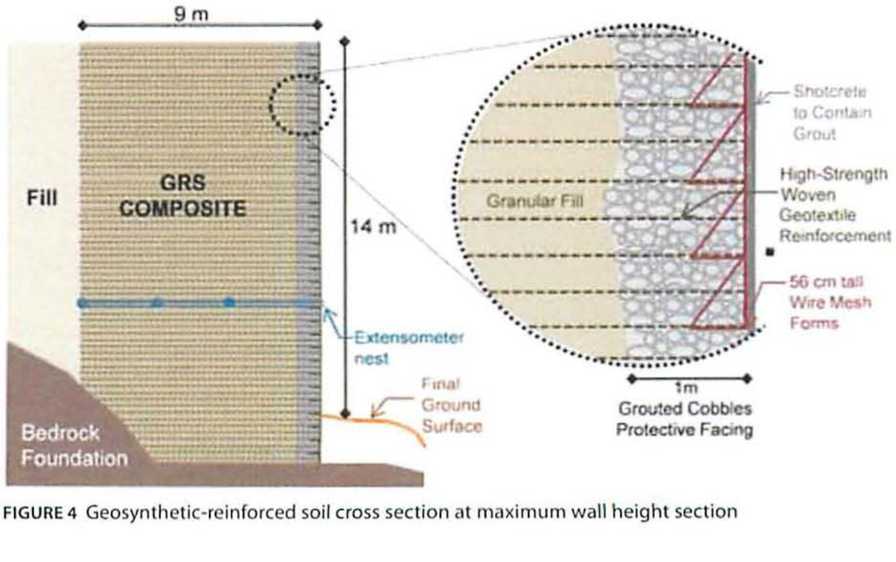

FIGURE 4 Geosynthetic-reinforced soil cross section at maximum wall height section

FIGURE 5 Irregular GRS wall alignment around left thrust block showing welded wire forms, backfill, geosynthetic reinforcement, and cobble facing zone. Photo: KWL

optimizing the fabric type and extent over the wall height.

The maximum wall height is 17m above the foundation and 14m above the riprap-armored finished grade. Geotextile reinforcement was specified to extend 9m back from the abutment wall face because this meets the external stability requirements and is exactly twice the standard geotextile roll width (4.5m). The use of an even multiple of the roll width simplifies construction by allowing the geotextile to be rolled out parallel to the wall face while minimizing the need to trim the geotextile layers **(Figure 8).**

No connections were specified between adjacent sections of geotextile reinforcement or the wall face, but a 3-cm overlap between adjacent geotextile sections was used to ensure continuous coverage **(Figure 8).** The location of the reinforcement overlap was staggered in successive lifts to avoid a continuous vertical seam between layers. The reinforcement width was truncated to a minimum base width of 2m wherever the GRS encountered the sloping bedrock canyon wall within 9m of the wall face **(Figure 4).**

The GRS structure contains many irregular corners, variable face-slope angles, and varying foundation elevations along the walls **(Figures 5, 6).** The flexibility and adaptability of the GRS composite system to site conditions was fully realized during construction by bending and cutting the facing elements at corners, altering the setback distance of facing elements at each level to create different slope angles, and clipping the tops of facing elements to create a horizontal lift regardless of irregular or varying foundation elevations.

A crew of three, after only a few hours of instruction, was able to assemble the facing and place the fabric reinforcement. GRS facing elements were placed, trimmed, bent and connected using hand tools, and geotextile reinforcement was rolled out, trimmed, and placed in the orientation most convenient for construction.

This was possible because the geotextile reinforcement has similar strength and stiffness characteristics in both the machine direction and cross direction, and the GRS design does not require mechanical connections between adjacent sections of geotextile or between the geotextile and the facing.

Fill was placed with an excavator and compacted with a 10-ton, vibratory, smooth-drum roller or a 900-lb, vibratory, plate tamper near the wall face.

GRS adaptability was most clearly demonstrated at the upstream end of the structure where the GRS wall tied in to a bedrock slope. The tie-in point between the GRS and bedrock was field-fit to minimize bedrock excavation and vulnerability of the tie-in point to erosion. Wire mesh facing elements were trimmed with hand tools to match the profile of the exposed bedrock, and the grouted GRS facing was anchored to the bedrock using rebar dowels **(Figure 7).**

Where the face of the GRS composite is exposed to erosion and debris impact, it is protected by grouting of the 1m-thick, cobble-filled zone. The grouted zone was constructed by sealing the welded wire facing with a minimum 8cm thickness of shotcrete, and then injecting grout into the cobbles. Grout injection was done after every 1.5m of vertical GRS construction.

Strips of geotextile reinforcement were removed within the 1m-wide cobble zone to facilitate grout permeation while retaining adequate connection between the grouted face and GRS composite **(Figures 5, 6).** Grout was injected to the base of each grout lift through 50mm diameter PVC tubing installed with the cobbles at about 1.5m spacing.

Full grout encapsulation was confirmed by measuring the rise of grout in adjacent PVC tubes and the appearance of grout at the surface. Grouting proved challenging but ultimately successful due to the combination of closely-spaced, large-diameter tubing for grout injection, well-sorted cobbles, and grout mix additives to maximize flowability of the sanded grout.

The GRS fill behind the facing area was well-graded, clean, 50mm minus, crushed granular material from a local borrow pit compacted to a minimum 95% of Modified Proctor Maximum Dry Density (ASTM D1557). Reference laboratory Modified Proctor tests were used in conjunction with a test fill and a nuclear density gauge to calibrate a method specification for the compaction equipment. Construction quality control used the method specification combined with periodic measurements with a nuclear density gauge.

Performance monitoring

The GRS was instrumented with different lengths of rod extensometers, vibrating wire piezometers, and surface survey monuments along the wall crest.

The left abutment extensometer nest includes 3m, 6m, and 9m rod extensometers. The purpose of the extensometers was to monitor horizontal strain of the GRS wall face during and following wall construction. The extensometers are vertically located near one-third of the wall height, and are horizontally positioned in the area of maximum wall height. This location was chosen because it is expected to be near the zone of maximum outward deformation of the wall face (Allen and Bathurst, 2001) and it is accessible with a standard ladder from the ground.

FIGURE 6 GRS construction around the left thrust block area (Note: no connection between reinforcement sections and reinforcement strips near face). Photo: BGC

FIGURE 7 GRS tie-in to bedrock slope at upstream left abutment (note shotcrete facing). Photo: KWL

Since completion in the fall of 2009, annual inspections and instrument readings have been carried out. Performance of the GRS walls has been excellent. All piezometers remain dry, and the maximum wall displacements are near the threshold of measurement precision for the rod extensometers.

Survey monuments installed along the crest at the end of construction show no measurable movement. A **diagram** that illustrates the wall deformation recorded with time during and after construction for the 9m extensometer in the left abutment, which showed more displacement than any other extensometer. (See this diagram at: geosyntheticsmagazine.com/0812_f1_debris_barrier.html).

Maximum outward wall displacement at the extensometer location is less than 0.1% of the final wall height. Displacement published for other instrumented reinforced soil walls is on the order of 0.2% to 0.8% (Allen and Bathurst, 2001). The stiff, grouted cobble facing and relatively stiff fabric used may be factors that minimize the wall displacement.

FIGURE 8 Geosynthetic fabric reinforcement rolled out parallel to wall face. Photo: KWL

FIGURE 9 Fact Box: Fitzsimmons Creek debris barrier

Special features of Fitzsimmons Creek debris barrier GRS
Shaped and dimensioned to channel debris, absorb impact
Shotcrete, grouted cobble face for erosion and impact protection
GRS wall resists steel arch horizontal thrust during debris impact
Truncated base: reinforcement width trimmed to bedrock slope
Reinforcement and facing elements assembled with hand tools
Field fit to tie-in with irregular bedrock foundation and canyon wall
Geotextile reinforcement placed parallel or perpendicular to the wall face
No connections between adjacent reinforcement sections
Discontinuous fabric reinforcement perpendicular to wall face

Project summary

The innovative use of GRS for the Fitzsimmons Creek debris barrier allowed the construction of a barrier at reduced cost, in a shorter time, with minimal environmental impact, and using considerably less concrete than conventional designs. The work highlights a number of advantages of GRS, including:

Design flexibility: GRS can be designed to create almost any shape, corner, or slope angle, and allowed grouted cobble facing erosion and impact protection.

Construction adaptability: GRS can be easily "field fit" to adapt to site conditions such as unexpected and irregular foundation elevations.

Ease of construction: Other than soil, the GRS system uses three components (facing forms, facing ties, and geotextile reinforcement) that can be hand assembled by a small crew of laborers with only a few hours of instruction.

Minimal construction footprint: Minimal laydown area and use of heavy equipment reduces environmental impact.

Cost savings: GRS was less expensive than other concrete and steel design options that were evaluated, and construction was completed on time and within budget.

The Fitzsimmons Creek debris barrier was designed and constructed on behalf of, and is currently owned and maintained by, the Resort Municipality of Whistler.

Acknowledgements

The design team included Kerr Wood Leidal Associates, BGC Engineering Inc., Terratech Consulting Ltd., Gygax Engineering Associates, and Cascade Environmental Resource Group. The general contractor for site works was Creekside Resources Inc., a business corporation of the Lil'Wat First Nation from Mount Currie, B.C., Canada.

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