A Multi-Geosynthetics Sustainable Solution Case Study- ʔapsčiik ṭašii (Upscheek Tashee)

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ABSTRACT
This paper presents a case study on technical, sustainability, and practical benefits of a multi-geosynthetics approach for ʔapsčiik ṭašii (Ups-cheek Ta-shee), a 25-km long, Multi-Use Pathway on Vancouver Island, BC, Canada. The geosynthetics based solution facilitated a reduced net CO_2 footprint primarily through protection of the sensitive rainforest ecosystem. While geosynthetics were used throughout, this paper focuses on the Wayii Segment where the pathway meanders between Veteran Class trees down a 23-m high foreshore slope with poor foundation soils, equipment access limitations, historical landslide activity and high seismicity. The design was flexible in response to tree root zones and ground conditions. Multiple types of geosynthetics were applied: knitted and polymeric coated, polyester uniaxial geogrids (Pyramid Grid™), high stiffness, polypropylene biaxial geogrids (Titan Earth Grid™), biaxial geogrid composites (Swamp Grid™), nonwoven geotextiles (TE-6) and HDPE geocells. Construction challenges and solutions are discussed.

RÉSUMÉ
Cet article présente une étude de cas sur les avantages techniques, durables et pratiques quant à l'utilisation de géosynthétiques multiples à ʔapsčiik ṭašii (Aps-tchique Ta-chi), un sentier à usage multiple de 25 km, sur l'île de Vancouver, CB, Canada. La solution axée sur les géosynthétiques a aidé à réduire l'empreinte des émissions nettes de CO2, surtout par la protection de l'écosystème sensible de la forêt pluviale. Bien que les géosynthétiques aient été utilisés sur tout le sentier, cet article se concentre sur le segment Wayii, où le sentier serpente entre d'anciens arbres sur une pente de zone de marnage haute de 23 m, avec des sols d'assise de mauvaise condition, un accès limité aux équipements, une activité historique de glissements de terrain, et une séismicité élevée. La conception a respecté la présence de racines d'arbres et conditions de terrains. Plusieurs types de géosynthétiques ont été appliqués: géogrilles uniaxiales en polyester, tissés et enrobés en polymère (Pyramid Grid™), géogrilles biaxiales à rigidité élevée en polypropylene (Titan Earth Grid™)), géogrilles biaxiales composites (Swamp Grid™)), géotextiles non tissés (TE-6) et des géocellules PEHD. Les défis de construction et les solutions sont discutés.

1 INTRODUCTION

This paper presents a case study on the technical, sustainability, and practical benefits of using a multi-geosynthetics approach for the construction of ʔapsčiik ṭašii (Pronounced Ups-cheek Ta-shee), a 25 km long, Multi-Use Pathway through the Parks Canada Pacific Rim National Park Reserve and traditional territories of the Yuułuʔiłʔatḥ and Tla-o-qui-aht First Nation on the west coast of Vancouver Island, BC, Canada. ʔapsčiik ṭašii is a component of a regional trail system that aims to connect the two remote communities of Tofino and Ucluelet (Figure 1).

This paper focuses on the Wayii Segment near Long Beach which consists of an approximately 350 m long section of trail that traverses a 23 m high foreshore slope with poor foundation soils, equipment access limitations, historical landslide activity and high seismicity. Geosynthetics were used extensively and in multiple applications on this section of trail.

Figure 1. Excerpt from Google Earth showing approximate location of the Wayii Section of ʔapsčiik ṭašii

American Society of Civil Engineers Policy Document 418 explains the role of civil engineers in sustainable development and highlights the importance of multidisciplinary team work in addressing the challenges of sustainable development. The significant benefits of using geosynthetics in developing sustainable solutions have been demonstrated by several researchers- Heerten (2012), Dixon et al. (2017), Koerner et al. (2019), Palmeira et al (2021), Touze (2021) and Touze (2022). The advantages of using geosynthetics include reduction in the area of land required for construction, conservation of natural materials like sand and aggregates, use of locally available soils for construction, reduction in the use of materials like cement and steel, reduction in carbon foot print, enhancing the efficiency and resilience of structures.

For the Wayii segment of ʔapsčiik ṫašii (Upscheek Tashee), using geosynthetics fostered sustainability (avoidance of the depletion of natural resources to maintain an ecological balance) and, in combination with other compatible strategies, reduced the carbon footprint of the project. Geosynthetic based design minimized the use of concrete, limited the lateral extent of excavation, particularly near the root systems of Veteran Class Trees (i.e. greater than 1 m diameter), allowed for the use of small to medium sized excavation equipment in tight work areas and could accommodate variable ground and other environmental conditions that were encountered during construction. Further discussion about the trail design solution that incorporates geosythetics is presented below.

3 DESIGN AND CONSTRUCTION OF THE TRAIL

3.1 Design

3.1.1 General

The conceptual design for the trail project began in the Spring of 2016 with a team of technical consultants and local First Nations. In addition to a carefully selected trail alignment, micro-routing during construction in response to local environmental, archeological, culturally sensitive and/or geotechnical conditions, was facilitated through use of geosynthetics as described below. This “wandering path” style that was incorporated into the constructed trail resulted in a significant reduction in number of trees being impacted by the project from an estimated 25,000 trees in early path alignment iterations to approximately 1,200 trees in the final alignment.

Notwithstanding the focus of this paper, it is important to note that the use of geosynthetics was only a part of the extensive sustainable aspects of the project. Protection of the adjacent sensitive rainforest ecosystem and cultural resources was introduced as a key project objective at the outset and then emphasized throughout design and construction. During planning and design thorough environmental site characterization was completed and facilitated strategic route selection. Strict contract requirements that focused on protection of the environment were incorporated into the tender and construction documents. The contractor’s Environmental Protection Plan (EPP) was reviewed by registered professional biologists who also provided quality assurance reviews and were present on site throughout construction to make sure the EPP was implemented and adjusted as needed to suit site conditions. The pragmatic and co-operative approach of the environmental consultant retained by Parks Canada and their field team played a significant role in the successful implementation of both the EPP and trail construction.

In addition to the multiple advantages of utilizing geosynthetics, the broader trail project included the following environmentally beneficial elements: three bridges over fish bearing streams, 370 lineal meters of elevated boardwalks over sensitive wetlands, three amphibian highway box culvert crossings, 60 amphibian crossing culverts along the trail, and 11 Fisheries Enhancement sites that resulted in a net increase in spawning habitat. The highway amphibian tunnels reduced the annual mortality rate of Northern Red-legged Tree Frogs, a species at risk.

This demonstrates that while geosynthetics are an important contributor, they should be used in combination with, and in support of, other methodologies and techniques to achieve maximum sustainability benefits.

3.1.2 Multi-Use Trail

One of the technical challenges for construction of the trail in both the Wayii section and broader trail alignment was the presence of soft clay subgrade soil that introduced settlement and bearing concerns. A solution was needed to ensure sound structural stability and longevity of the public trail.

At locations where full depth subexcavation of the soft clay and replacement with compacted granular fill was not practical due to the thickness of low strength subgrade, temporary stability concerns, nearby tree root systems, and/or the presence of other sensitive features, the trail was stabilized with a base layer of composite geogrid (Swamp Grid™) overlain by two layers of granular fill reinforced with high stiffness biaxial geogrid (Titan Earth Grid™). The biaxial geogrid was spaced at 0.3 m vertical intervals. The technical purpose of the geogrid reinforcement was to reduce the potential impacts of differential settlement of the underlying subgrade and increase bearing support for the trail.

At one location along the trail at Wayii where perched groundwater flowing across the trail alignment was encountered, a drainage zone that extended along 5 m of the trail was constructed utilizing angular rock fill wrapped in medium weight, non-woven geotextile (Titan TE-6). Geosynthetics offered a pragmatic solution that could be implemented immediately without the added cost and delay of sizing and procuring a culvert. While technically simple, this timely, practical solution was particularly important since, at the time, this part of the trail served as the primary construction access route for the Wayii work area. This demonstrates that solutions do not need to be complex to

be effective and geosynthetics often can be practically integrated into design and construction to meet both project and sustainability objectives.

Similar reinforced trail structure and drainage zones were constructed at multiple locations along the broader trail project. For the Wayii area, a drainage blanket created through wrapping coarse angular rock in non-woven geotextile was constructed within a toe buttress to manage seepage emanating from the slope.

3.1.3 Global Stability

Site reconnaissance and review of LIDAR imagery showed evidence of historical shallow and deep-seated slope movements in the Wayii area. Subsurface assessment revealed the presence of a thick, soft to firm, lightly over-consolidated clay deposit, that becomes stiffer with depth. Strength and consolidation characteristics for use in modelling analyses were determined through a rigorous field and laboratory testing program. A slope inclinometer that was installed and read at various intervals throughout design showed no obvious signs of movements in the project area.

3D Limit Equilibrium Modelling (3D LEM), as illustrated in Figure 2, was used innovatively to quantitatively account for the beneficial geometric effect and resulted in cost savings relative to more involved Finite Element Modelling (FEM). Analyses indicated that a cumulative 30% increase in Factor of Safety for global stability would be achieved with the post-construction configuration relative to ambient conditions.

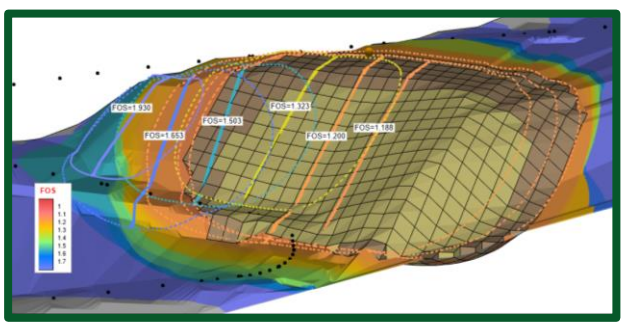

Figure 2. General view of typical 3D LEM Model Output

A switchback alignment that improved slope stability while limiting environmental impacts was identified. The final design involved a cut (unloading) near the upper switchback, a series of Mechanically Stabilized Earth Walls and a geogrid reinforced toe berm. The geogrid reinforcement in the toe berm served two purposes: enhancing slope stability and limiting the lateral extent of berm required. The lower rows of uniaxial geogrid were stronger. The height of the toe berm was controlled by acceptable pressures on the root systems of adjacent trees and pore pressures in the underlying clay.

Geogrid reinforcement in the toe berm was a combination of high strength uniaxial geogrid aligned perpendicular to the strike of the slope and biaxial geogrid installed parallel to the trail centerline. A geotextile separator was installed at the interface of the buttress fill and the fine-grained natural soils. A veneer of granular fill was installed between the geotextile and the first layer of geogrid. The uniaxial geogrid was installed at a vertical spacing of 0.3 m with minimum 0.5 m overlap of adjacent grids and no joints permitted in the longitudinal direction (i.e. perpendicular to the slope). Geogrid was offset on each subsequent layer by approximately a third to a half a grid width to offset joints. Uniaxial geogrid extended from the cut slope to the front edge of the fill slope (Figure 3).


Figure 3. Photo illustrating installation of the uniaxial geogrid in the buttress.

A typical cross-section illustrating the geogrid reinforced buttress, retaining walls and cut into the upper portion of the slope is shown in Figure 4. Further discussion on the biaxial geogrid is provided in Section 3.2 below.

In addition to the toe buttress, trail construction included remediation of a failed section of slope. This involved removal of failed soil and replacement with a geogrid reinforced fill slope. To accommodate the curved shape of the failure zone and slope, biaxial geogrid was installed at 0.3 m intervals. The lateral extent of excavation into the existing slope was restricted as much as possible to limit removal of trees near the crest.

The overall design for stabilization of the Wayii section of trail resulted in a toe berm that was approximately 2 m shorter (vertically) and with a substantially smaller footprint than the initial design concept that had been put forward by another consultant. In addition to the significant amount of vegetation and habitat that no longer had to be removed due to the reduced lateral extent of the toe berm, through careful route selection, the proposed alignment also reduced the total number of impacted larger diameter trees to six (including only two Veteran Class trees). Compare that to the seven Veteran Class trees plus multiple other large diameter (but not quite Veteran Class) trees that were identified for removal from the previous design concept.

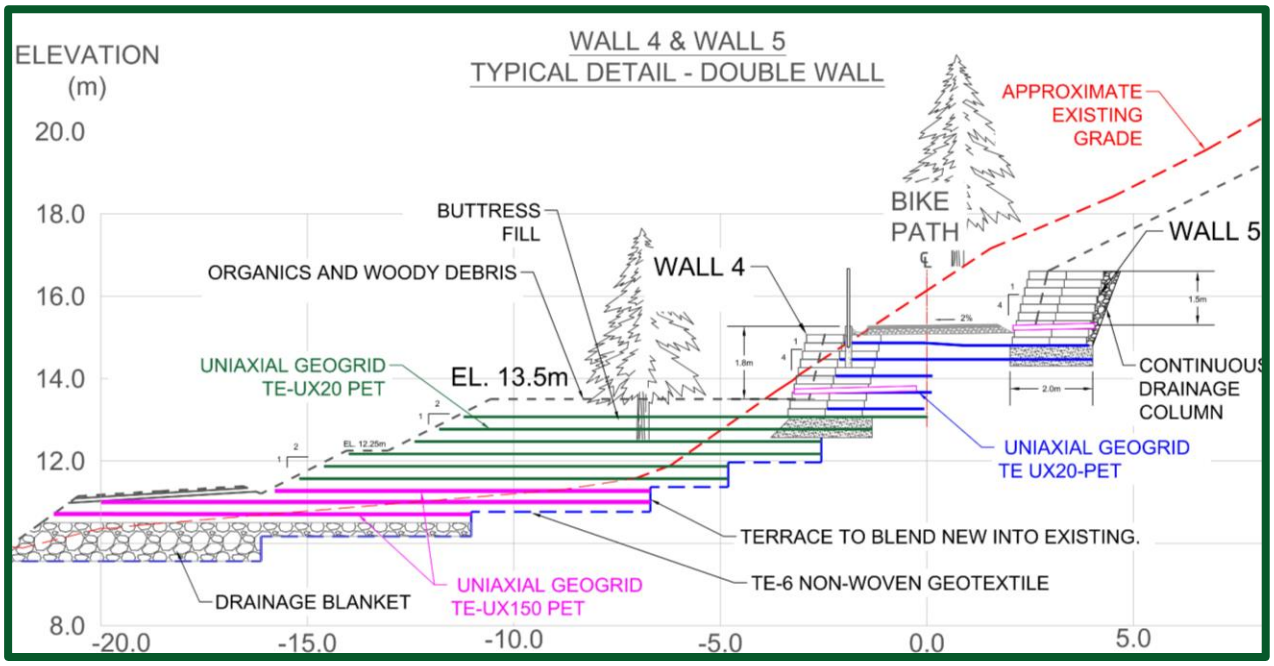

Figure 4. General profile view of geogrid reinforced buttress, retaining walls, and cut into the slope. Note the multiple layers of geogrid with different strengths (different colours) and overall "integrated / connected" aspects of the system.

3.1.4 Retaining Walls

Mechanically Stabilized Earth (MSE) retaining walls were constructed along the toe of the slope to reduce encroachment of the buttress into existing treed areas and across the middle terrace of the trail. Retaining walls ranged in height from approximately 1 m to 4.2 m, with most walls in the Wayii area in the order of 2 m high. Wall design included:

- A foundation pad reinforced with high stiffness biaxial geogrid (Titan Earth Grid™) over a base layer of composite geogrid (Swamp Grid™) to increase the bearing capacity of the subgrade and reduce the potential impacts of differential settlement of the underlying soft clay subgrade.
- An MSE wall constructed over top of the completed soil pad using multiple layers of HDPE geocells and backfill reinforced with uniaxial geogrid (Pyramid Grid™) at 0.4 m vertical spacing (i.e. every second geocell row).
- A maximum facing batter of approximately 1H:4V that was achieved through stepping at each row.
- Drainage was provided behind every wall.
- Backfill was granular fill with less than 5% fines (0.075 mm) placed and compacted in lifts.

Near the base of the slope, a pair of walls was constructed on opposite sides of the trail to allow the trail to meander between trees rather than remove them (Figure 5). Geogrid layers were staggered, and lengths were modified to allow each wall to perform "independent" of the other. The MSE wall system with geocell facing was selected due to its flexibility in adjustment of alignment, ability to be moved and placed manually as needed, and its planting pockets that were created through stepping back each row.

Figure 5. Photo illustrating segment of trail with back to back retaining walls near the toe of the slope where trail meanders between trees. "Mushroom Cap" configuration was used locally on these walls (Refer to Section 4)

3.2 Construction

General wall construction involved preparation of subgrade and construction of the foundation pad described above. Each row of wall construction involved:

- Manual layout of the geocells with spreader bars and shaping to achieve the proper alignment.
- Placement of the geocells into position and zap strapping them to the adjacent constructed section of wall.
- Infilling the geocells with 19 mm minus, crushed sand and gravel and compacting. Slight overfilling allowed for the granular fill to consolidate and achieving a full cell after compaction.
- Placement and stretching of uniaxial geogrid.
- Placement, infilling and compaction of the next row of geocells on the geogrid.
- Placement and compaction of 0.2 m thickness of granular backfill the uniaxial geogrid after it has been pulled hard.

Placing and filling of geocell facing units are illustrated in Figures 6 and 7.

Figure 6. Photo illustrating typical layout of geocells prior to filling and compaction.

Figure 7. Photo illustrating typical wall construction.

4 CHALLENGES-INNOVATION-LESSONS LEARNED

Several challenges were encountered during construction of the retaining walls, buttress and slope stabilization.

4.1 MSE Walls

The flexibility of the geocells and ability of the geocells to spread out loads and pressures led to innovative use of a “mushroom cap” configuration adjacent to tree root systems to avoid removal of trees or reduce impacts (Figure 8). The concept involved:

- Excavation towards the trees until encountering significant roots that should not be removed.
- Construction of the lower buried portion of the wall with geocells vertically in a couple of lifts to get to just above the roots.
- Placement of bedding sand to allow moisture and oxygen into the roots from ground surface.
- Subsequent lifts of the wall would step out a quarter to half a cell over the roots each lift until the design front face of the wall was achieved. Stepping out in this manner allowed for load transfer back to the main grid bearing on competent ground avoiding significant vertical loads over roots.

Figure 8.

Left Buried portion of mushroom configuration. Red line is approximate future front of wall over the roots.

Right View of MSE wall after stepping out with “mushroom configuration” at same location.

While the geocell wall system was selected for its flexibility and planting cells, these features also inadvertently introduced challenges to construction.

1. The relatively steep facing of the wall was required to accommodate the tight spacing and limit encroachment into the adjacent environment. However, when the front cells were filled completely with organics (for future planting) as was a key objective, subsequent rows of geocells were affected by the reduced support from both the organics and the flexible geocells and it was extremely challenging to maintain proper wall alignment and an aesthetically acceptable facing.

   To overcome this issue, the construction procedure was modified to include complete filling of the cells with crushed sand and gravel, a slightly reduced compaction effort at the front face of the wall followed by removal of crushed gravel by hand and replacement with locally sourced organics. At other locations, a wedge of organics was placed in front of the wall.

   Due to the steep facing angle the width of each planning "bench" was limited (i.e. 50 mm) and it was challenging to remove and replace sufficient organics after wall construction and also leave an allowance for the root system of planted vegetation. If more substantial planting benches are desired, either a reduced facing batter or terraces should be incorporated into the design.

2. The "flexibility" of the geocells allowed for movement of the geocells during infilling and compaction. A high level of quality control was required to achieve an aesthetically pleasing facing, maintain design configuration, and avoid facing cells extending beyond the underlying row of cells. The outside edge of the cells was also prone to collapsing/folding and required straightening with a stiff rod. The multiple ways that the geocells could move out of alignment had a noticeable negative impact on production. It also affected the mood/morale of the crew since they wanted to achieve a quality product and the cumulative impact of multiple small items missed made this challenging.

   A less steep facing would result in all of these elements having less impact on the aesthetics of the finished product and allow contractors to achieve specified configurations with less effort.

3. At locations where the connector "zap-straps" were not fully tightened, the geocells had a tendency to move apart during compaction or as the wall increased in height (i.e. increased pressures). This resulted in some slight misalignment of joints and sections that appeared not "vertical" or angled/crooked.

4. The high level of manual effort involved in placing the geocells, connecting them to the already constructed section of wall and adjustments required to maintain proper configuration was a safety consideration in tight spots such as locations with steep cut slopes behind them. At these locations, additional excavation, shoring and/or other temporary worker protections were implemented. A retaining wall system or updated procedure that requires less manual adjustments after placement would be preferred in such excavation conditions. A less steep wall facing would also reduce impacts of movements of geocell and require less worker access to maintain configuration.

Figure 9. Photo illustrating the result of some of the challenges maintaining facing alignment and batter and providing a planting bench that are described in Points 5 to 7 of Section 4.1. The location is at the tightest curve in the wall where maintaining batter and alignment concurrently was most challenging.

Figure 10. Photo illustrating the general limited overall impact of the localized issues on the visual appearance of the wall noted in Figure 9 due to the effort of the construction crew and consultant working together. The average trail user would not likely notice this. In addition, with time the vegetation that is planted will further mask these aesthetic imperfections.

Challenges were also encountered in relation to existing culverts and drainage penetrations through the wall.

5. At culvert penetrations through the wall, the facing was a challenge to construct in a manner so as not to allow for loss of soil. Use of non-woven geotextile completely wrapping around the fill seemed to be an effective method of containing the fill. Partial wraps with the geotextile were not as reliable.

6. Where drainage pipes penetrated through the wall, several techniques were attempted with varying degrees of success.

   - Cutting openings in the geocells allowed for connection of the new geocells to adjacent construction allowed for containment of fill but was difficult to cut precisely to maintain proper alignment of the geocells

   - Cutting off the last row of cells and installing the drain pipe facilitated alignment of the geocells but introduced a discontinuity in connectivity and required some additional geotextile to contain the fill at the facing of the wall.

   The preferred solution was a combination of the two methods: cut an opening at the front and back of the front cell (to provide fill containment at the face of the wall) and cut off the cells behind (to facilitate pipe installation and adjustment of the geocell alignment as needed during filling.

4.2 Buttress

To protect several veteran class trees that were left in place a zone of undisturbed soil was left in place below the dripline of the trees. This required adjustments to the trail alignment that affected the retaining wall heights and finished trail grade. To maintain general connectivity of the buttress to function as intended in the design, vertical support for the trail and limit the downslope extent of works, geosythetically confined soil was created through placement of multiple layers of biaxial geogrid at 0.2 to 0.3 m vertical spacing (Figure 11). Where possible the orientation of the geogrid was rotated 90 degrees between layers to reduce the vertical continuity of joints between adjacent sections of geogrid. While geotextile could also have been used, geogrid was recommended (and was readily available on site) to provide further strength to the toe buttress in addition to the stronger uniaxial geogrid that was specified below this elevation.

Figure 11. Photo illustrating the “islands” of soil left adjacent to the root systems of mature trees prior to installation of the GRS geogrid described in Section 4.2

Another challenge for the buttress design was that subgrade sloped up along the strike of the slope which required a “stepped” layout for the geogrid. Since the exact location of these steps was difficult to identify at the time of design, particularly given that the alignment was modified to accommodate Veteran Class trees, geogrid was an ideal solution as it was readily extended laterally to meet actual conditions.

4.3 Slope Stabilization

To facilitate excavation planning for safe work during construction within a previous landslide scar, the thickness of the slide material was confirmed through the innovative use of the PANDA® (Figure 12). This manually operated equipment, owned by WSP, was first calibrated at the edge of the slide zone through soil exposure, then used in the middle of the slide zone in advance of excavation to establish the depth of remolded soil (i.e. the slide surface) that was identifiable by the measurement of a lower tip resistance. At some locations where the slip surface was not visible due to disturbance during excavation and similar colouration, the PANDA® test allowed the field team to proceed without having to attempt further characterization and/or deeper excavation within a marginally stable temporary excavation configuration. The PANDA® testing also confirmed the large-scale failure mechanisms and shapes that were predicted by 3D LEM modelling, providing further confidence in the design.

Figure 12. Photo illustrating the failure interface that was identified with the PANDA testing and then applied in areas where the slip surface was harder to identify visually.

Figure 13 Photo illustrating the finished switchback trail looking down from above. (Photo courtesay of Parsons Inc.)

A photo illustrating the finished switchback trail looking down from above is shown in Figure 13. Note the mature trees in the photo that were able to be protected while simultaneously providing both vertical support to the trail and a slope stabilizing mass (buttress) using geotextiles.

5 CONCLUSIONS

Geosynthetics solutions were extensively employed in this project to address technical challenges associated with low bearing capacity, differential settlement, earth retention, slope stability, global stability and subsurface drainage while simultaneously reducing environmental impacts. An interesting feature of this project was the use of multiple types of geosynthetics including knitted and polymeric coated polyester uniaxial geogrids, polypropylene biaxial geogrids, biaxial geogrid composites, nonwoven geotextiles and geocells. Use of geosynthetics helped to minimize excavations, reduce the footprint of slopes and enabled the construction of retaining structures and slope stabilization by working around existing trees and thereby helped to complete the project with minimum disturbance to the ecologically sensitive landscape. The project also demonstrated that simple, innovative and sustainable solutions using geosynthetics are possible with detailed planning and close and continuous interaction between geosynthetics specialists, geotechnical designers, biologists and the contractors.

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