

**HDPE Geogrid on the Low Level Road Project for the City of North Vancouver  
and Port Metro Vancouver**

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## ABSTRACT

This paper will focus on the diversity of retaining walls, steepened slopes, and wall transition sections as utilized on this 2.6 km road realignment project. With retaining heights rising to 14 metres, this project was a significant undertaking for both the City of North Vancouver (CNV) and Port Metro Vancouver (PMV).

For this project, the unique challenges associated with retaining wall design in steeply sloping terrain included:

- Raise and realign the new road section.
- Adding rail lines at the down-slope section of the project by way of a grade separation.
- Improving existing slope stability, and quickly completing the task in 16 months.

This was achieved with 23 000 m<sup>2</sup> of SierraScape® and 4 000 m<sup>2</sup> of Sierra® Retaining System. The versatility of these systems during site installation by the field crew was a unique advantage when selecting a wall system to quickly conform to irregular/steep terrain in a timely construction fashion.

The paper focuses on technical aspects of the design that include:

- A rectangular section and trapezoidal section (where slope stability restraints existed).
- False abutment (pile supported) walls for bridge design at Neptune/Cargill Overpass
- Wall inclinations ranging from vertical to 1H: 10V, and slopes leaning back at 3H: 8V.
- Seismic design analysis for 475-yr and 975-yr return periods.
- Geotechnical conditions, generally comprised of very dense gravelly sand soils of glacial origin.

This project also has the distinction to be the “First Transportation Project to be awarded the Envision Platinum Award for Sustainable Infrastructure”.

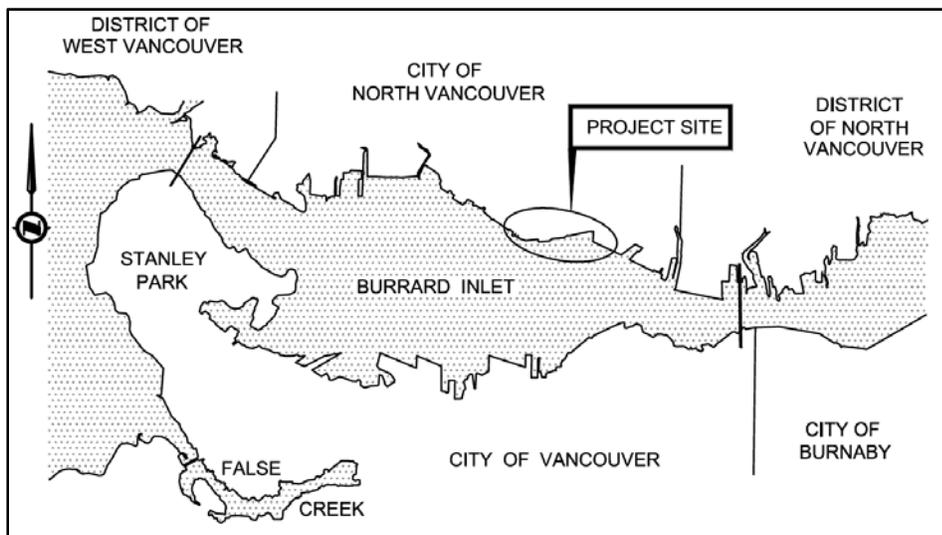
## 1.0 INTRODUCTION

The Low Level Road (LLR), with a project value of \$ 106 million, opened to traffic in November of 2014. The project was designed to improve rail and port traffic, by providing a vertical grade separation, to separate congested municipal roads from port and rail activities.

This involved the realignment and elevation of 2.6 kilometres of the LLR in North Vancouver, B.C., while creating room for two new rail tracks. The project eliminated three existing road and rail crossings while providing a new overpass to access the port terminals. As noted on Map 1, the project is within the City of North Vancouver. The site topography generally rises up steeply when proceeding to the northeast. This added to the challenge of realigning road and rail, along an established port/rail facility, while proximal to foreshore of Burrard Inlet, with diverse geotechnical conditions.

*“Port Metro Vancouver’s Low Level Road project recently received the Institute for Sustainable Infrastructure (ISI) Envision sustainable infrastructure rating system’s Platinum Award. The project is the first transportation project to receive an ISI Envision-verified sustainable infrastructure rating system award.” (1)*

*“The Low Level Road project has increased trade opportunities for Canada while providing safety, traffic flow and recreational benefits to the local community,” said Port Metro Vancouver President and Chief Executive Officer, Robin Silvester. “We are proud of the significant collaboration between funding partners, project staff and the community, and delighted to see recognition of the project’s contributions to sustainability.” (2)*



MAP 1: Project Site Location (Courtesy of Stantec)

## 2.0 GRADE SEPARATIONS and GEOGRID

This paper will focus specifically on the retaining walls and steepened slope structures that utilized high-density polyethylene (HDPE) geogrid as the prime soil reinforcement.

Due to the diversity of retaining structures required, the writer will focus on the following key grade separations:

- Downslope wall (RW-A) which provides the rail to elevated LLR separation.
- Upslope wall (RW-B) which supports road, bike, and pedestrian pathways above the LLR

As noted in Map 2, a diversity of retaining walls (RW) were required to achieve the final realignment and widening of LLR, while safely isolating the lower port and rail activities noted along the southern extent of Map 2. The project involved road realignment, MSE walls, earthworks, sewer, water main, and utility relocations, as well as the Neptune/Cargill overpass.

Geotechnical design challenges were further complicated with steep terrain rising sharply to the northeast predominantly along the eastern half of the project site.



MAP 2: General Retaining Wall Arrangement (Courtesy of Stantec)

Historically speaking as best stated within the *Stantec Geotechnical Engineering Report*,

*Low Level Road was originally constructed prior to 1926, with supposedly near vertical slopes along the north side of the roadway in many areas. Upgrading of the original construction was implemented sometime between 1926 and 1947, resulting in the current roadway alignment. Based on review of ... documentation, sloughing and unraveling of surficial slope material appears to have been an on-going issue for at least the last couple of decades. Some of the sloughing/unraveling that have occurred in the last decade appears to be in areas of the original construction and slope geometry (i.e., very steep soil slopes have existed for perhaps close to 70 years or so). (3)*

The LLR delivered the optimized solution to this historical geotechnical challenge. B&B Heavy Civil Construction commenced construction May of 2013, with completion in November of 2014.

The LLR project team consisted of the following:

- Port Metro Vancouver
- Stantec
- MMM Group
- City of North Vancouver

### 3.0 DESIGN APPROACH

Nilex Inc. and its engineering partner Tensar® International was pleased to be selected to design 27 000 m<sup>2</sup> of MSE wall and Steepened Slope for B&B Heavy Civil Construction.

The complexity of establishing retaining wall systems up to 14 metres in height, in an existing hillside, all located above critical road/rail infrastructure provided a unique challenge for the geotechnical design team at Stantec.

This challenge was mitigated by utilizing soil reinforcement lengths that varied from a traditional rectangular section, to an optimized trapezoidal section where geotechnical design conditions permitted.

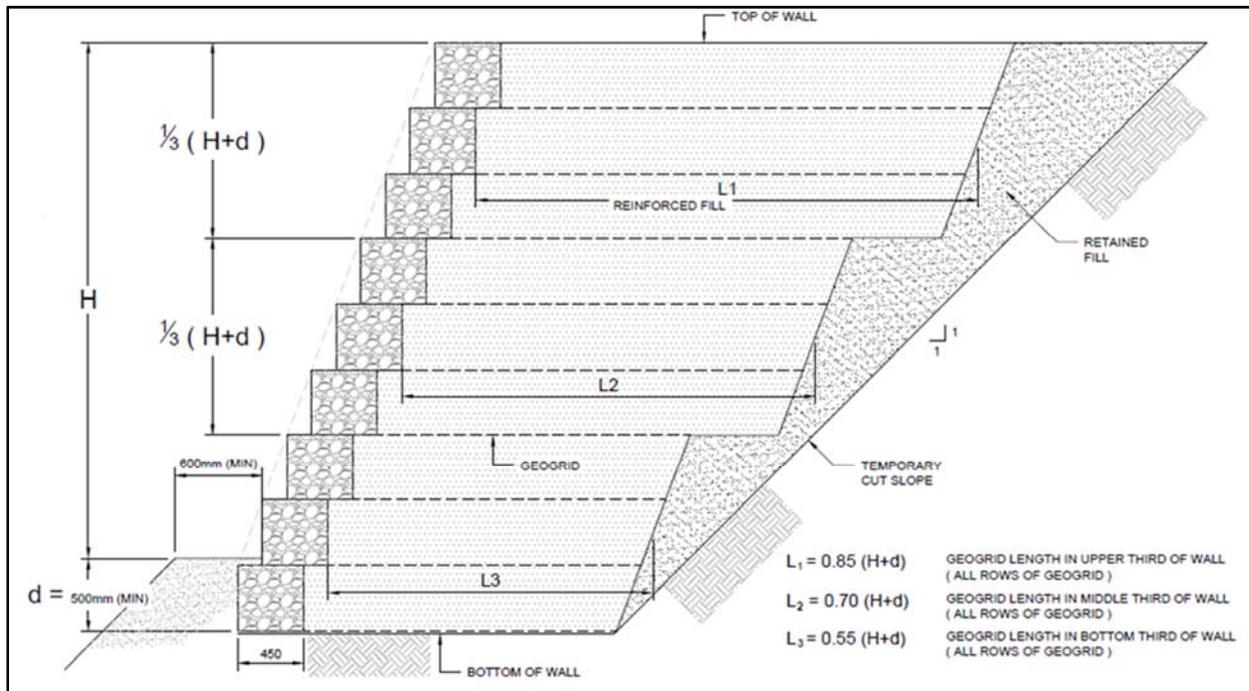


Figure 1: Trapezoidal Geogrid Arrangement (Courtesy of Stantec)

The concept of a trapezoidal section is best illustrated in Figure 1 as issued by the design consultant at time of tender. If the reader focuses on the intermediate soil length  $L_2$ , which is defined in this case as 70% of the total wall height or  $L_2 = 0.70(H+d)$ , this would be the common approach typical of many MSE wall designs.

In circumstances where geotechnical conditions permit, designers may optimize the cut section in an effort to reduce excavation, by employing a shorter geogrid length in the lower third, as illustrated by  $L_3 = 0.55 (H + d)$ . This was especially advantageous in the steep and diverse terrain across this project site. With geometric and geotechnical constraints along the LLR realignment, the designer further prescribed detailed constraints on proprietary wall designs to satisfy global stability criteria.

The prime consultant (Stantec) designed for these challenges as best *summarized and extracted from their Geotechnical Engineering Report (4)*.

*Internal and external stability for MSE walls with trapezoidal geogrid arrangement was analysed under both static and seismic conditions using the simplified design method outlined in the FHWA design guidelines. Internal stability calculations were completed by dividing the wall into three, stepped rectangular sections, each of different length, with the minimum geogrid length for the bottom section being 40% of the total wall height. The difference in length between each of the stepped sections is also required to be less than 15% of the total wall height. (4)*

*External stability calculations were then completed using a rectangular block having the same total height and cross-sectional area as the stepped section. The equivalent block had a minimum geogrid length equal to 70% of the total wall height. The computer programs Slope/W© 2007 and TensarSoil 2.05 were then used to analyse global stability and compound failure planes for the MSE walls with uneven reinforcement lengths. (4)*

*Based on the offset distance between the upslope and downslope MSE walls along Low Level Road, the walls were considered independent (based on FHWA design guidelines) with no interaction between them. (4)*

The following Figure 2 provides an overview of these constraints were addressed in the final drawing package to delineate allowable wall facing inclinations (i.e. Wall Type), and more importantly; specify minimum geogrid lengths required to meet stability requirements.

GEOGRID ARRANGEMENT FOR MSE RETAINING WALLS				
WALL TYPE	LOCATIONS	BOTTOM ROW GEOGRID LENGTH	TOP ROW GEOGRID LENGTH	GEOGRID LAYOUT
70 °	L100 RIGHT AND LEFT; ALL HEIGHTS	0.55* ( H+d ) MINIMUM 2.5	0.85* ( H+d )	TRAPEZOIDAL
1H : 10V	L100 RIGHT AND LEFT; ALL HEIGHTS L400	0.55* ( H+d ) MINIMUM 2.5	0.85* ( H+d )	TRAPEZOIDAL
90 °	L100 RIGHT AT NEPTUNE / CARGILL OVERPASS ( STA 11+856 TO STA 11+961 )	1.1* ( H+d )	1.1* ( H+d )	RECTANGULAR ( i.e., SAME LENGTH THROUGHOUT )
90 °	L100 RIGHT WHERE WALL HEIGHT EXCEEDS 13.0m	1.1* ( H+d )	1.1* ( H+d )	RECTANGULAR ( i.e., SAME LENGTH THROUGHOUT )
90 °	L100 RIGHT	0.55* ( H+d ) MINIMUM 2.5	0.85* ( H+d )	TRAPEZOIDAL
1H : 10V	L400 (41+500 TO 41+600) L900	0.7* ( H+d ) MINIMUM 2.5	0.7* ( H+d ) MINIMUM 2.5	RECTANGULAR ( i.e., SAME LENGTH THROUGHOUT )
1H : 10V WITH CONC FACE	SPIRIT TRAIL	0.7* ( H+d ) MINIMUM 2.5	0.7* ( H+d ) MINIMUM 2.5	RECTANGULAR ( i.e., SAME LENGTH THROUGHOUT )
1H : 10V	L300	1.2* ( H+d ) MINIMUM 2.5	1.2* ( H+d ) MINIMUM 2.5	RECTANGULAR ( i.e., SAME LENGTH THROUGHOUT )

Figure 2: Geogrid Arrangement for MSE Retaining Walls (*Courtesy of Stantec*)

#### 4.0 RETAINING WALL A

RW-A is the longest continuous wall defining the vertical grade separation between the rail and terminal facilities, along the newly elevated LLR.

In reference to the following Photo A, RW-A is closest to the viewer as seen at the eastern extent of the site. LLR is at its highest elevation at this eastern extent, where it is noted to rise up to accommodate the new overpass structure. The treed area generally consists of the steepest terrain, and the MSE/LLR structure provided enhanced support/safety effectively forming a reinforced berm along this toe slope.

RW-A continues beneath the pile-supported overpass, and then continues along the rail line for a distance of approximately 2.6 km to the far western extent of the project.

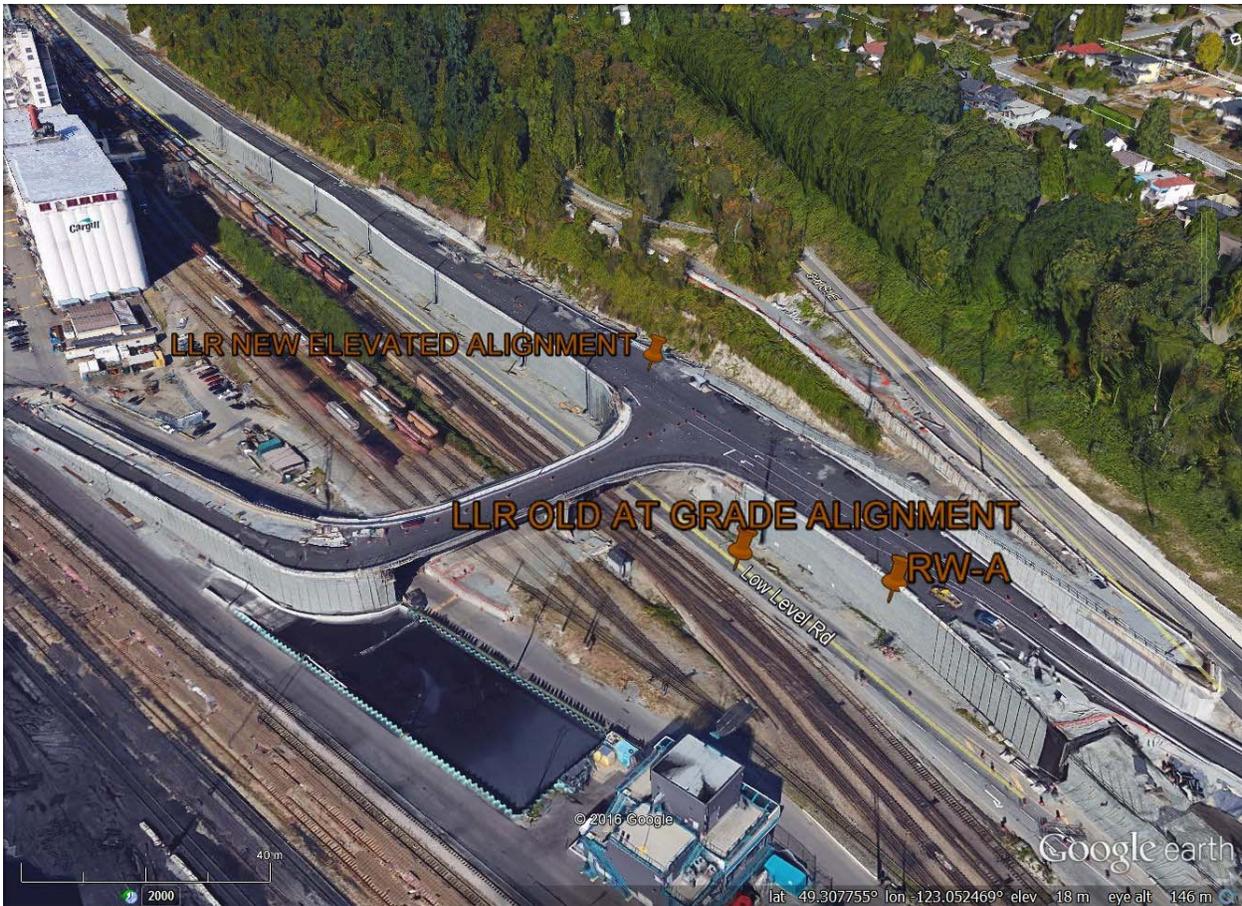


Photo A: RW-A at Eastern Project Extent at Cargill/Neptune Terminals Overpass

RW-A observed at the pushpin location is one example where a trapezoidal section with shorter geogrid in the lower third was employed by the designer at design stage, and later detailed by the successful proprietary wall supplier/designer (Nilex/Tensar).

This proprietary trapezoidal design section is illustrated in Figure 3. The geogrid embedment lengths are noted to increase as a function of increased wall height. In this case for the maximum height of 12.8 m, geogrid lengths for the case of (L1, L2, L3) are (11.05m, 9.10m, 7.15m), in compliance with the governing design requirements at this specific location.

In steep terrain, the benefit of a shorter grid (L3) in the lower third, assisted the project team and stakeholders in an economical design, and assisted the contractor in avoiding an excessively deep excavation cut in hilly terrain.

Since a trapezoidal section has a shorter base grid when considering sliding/overturning of the MSE block, it requires a higher bearing capacity in contrast to a conventional rectangular section.

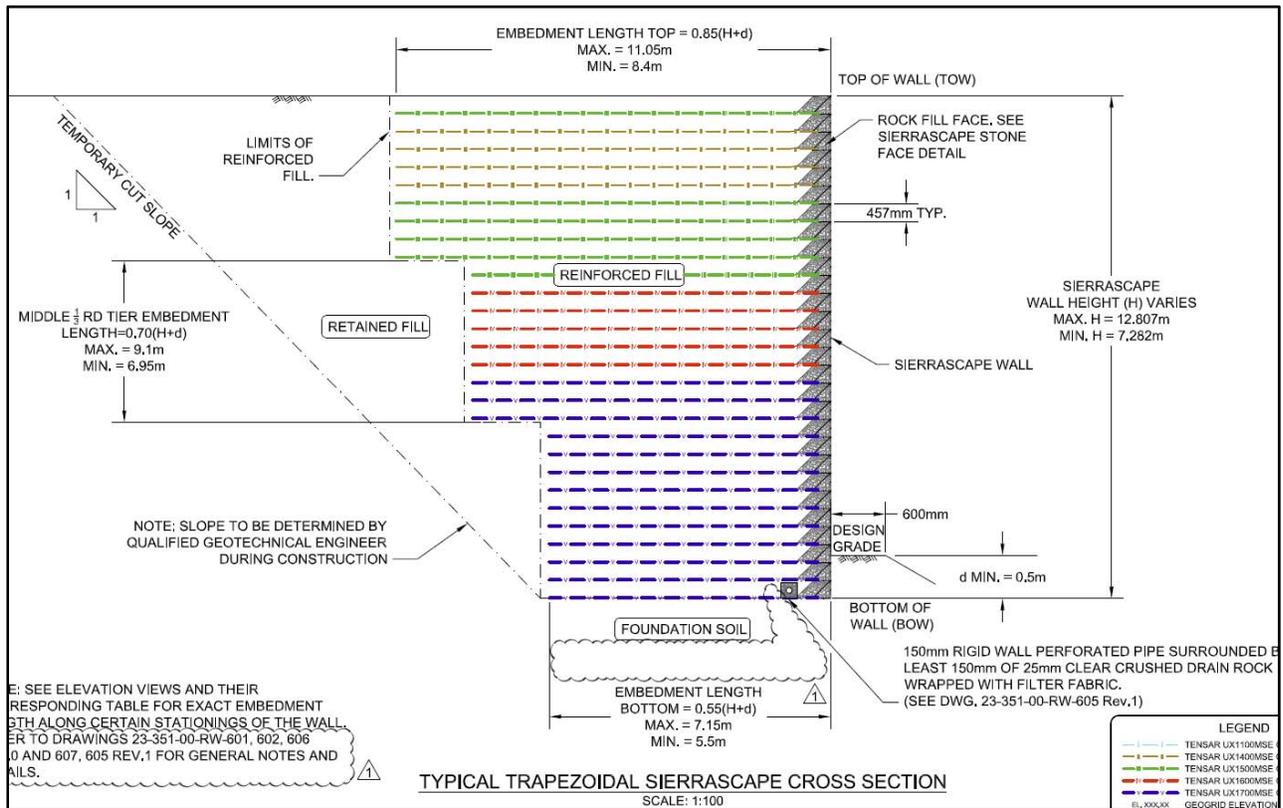


Figure 3: Retaining Wall A, Typical Trapezoidal Section, SierraScape  
(Courtesy of Nilex Inc. and Tensar International)

Bearing capacities specific to figure 3, revealed the following requirements:

1. Static 352 kPa
2. Seismic (1:475 year event) 442 kPa
3. Seismic (1:975 year event) 493 kPa

Approximately 24 000 m<sup>2</sup> of SierraScape® galvanized facing was constructed on this project site forming the majority of wall facing erected. The individual components of this facing system are illustrated in the following Figure 4.

The reader will note that this specific facing is comprised of a connected facing, whereby the soil reinforcement is attached to the lower facing return by use of a connector strut. This assures full load transfer between the prime soil reinforcement (uniaxial grid), and the wire facing element, during its intended 75 year service life.

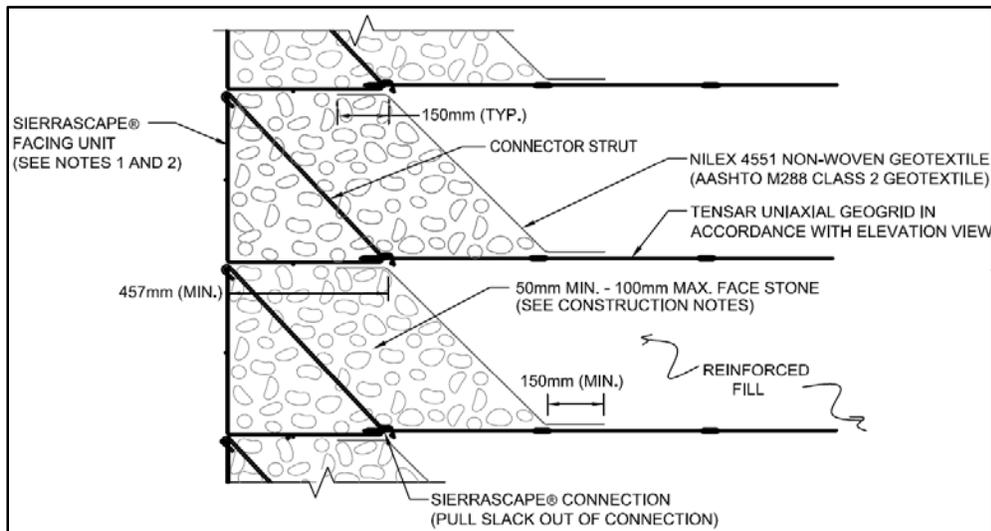


Figure 4: Galvanized SierraScape components c/w HDPE uniaxial geogrid (Courtesy of Nilex Inc. and Tensar® International)

For this permanent application, a facing stone was placed immediately behind the facing cage. The use of stone behind the facing also allows for ease of installation by providing better overall alignment of the final facing system. The facing stone is separated from the structural backfill (reinforced fill) by use of a non-woven geotextile separator (i.e. Nilex 4551 filter fabric).

## 5.0 DESIGN and LOADING PARAMETERS

Minimum factors of safety for internal and external stability are outlined in the following Table 1.

Stability Analysis		
INTERNAL STABILITY	Static	Seismic
	(475yr/975yr)	
Minimum factor of safety for geogrid pullout	= 1.5	= 1.1 / 1.1
Minimum factor of safety for sliding at lowest geogrid	= 1.5	= 1.1 / 1.1
Minimum factor of safety for geogrid strength	= 1.5	= 1.1 / 1.1
Minimum factor of safety for connection strength	= 1.5	= 1.1 / 1.1
Minimum factor of safety for circular failure (Seismic analyzed at $kh = A/2$ )	= 1.5	= 1.1 / 1.1
EXTERNAL STABILITY		
Minimum factor of safety for sliding at base	= 1.5	= 1.1 / 1.1
Minimum factor of safety for overturning	= 2.0	= 1.5 / 1.5
Maximum eccentricity	= 1/6	= 1/3 / 1/3

Table 1: Minimum factors of safety (Courtesy of Tensar® International)

The proprietary wall designer used TensarSlope Version 1.13 to detail the wall sections. Figure 5 below is one example of the output for the 1:975 seismic event, reveals a factor of safety (FS = 1.291).

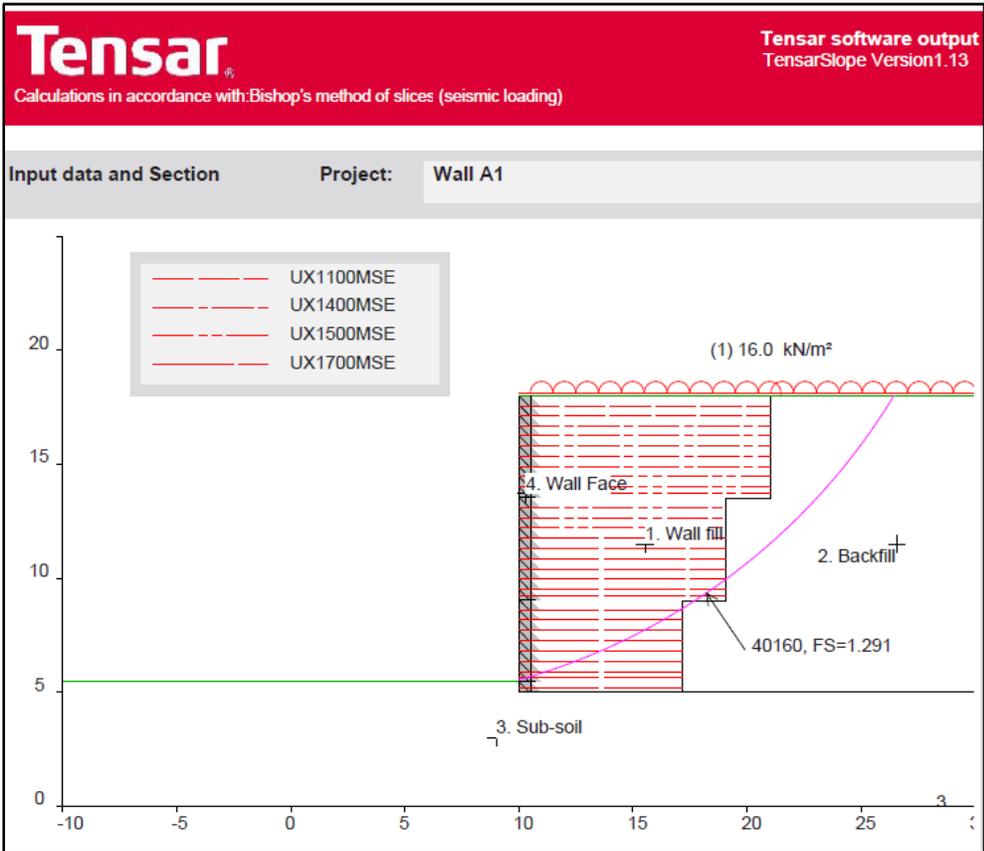


Figure 5: RW-A Compound Stability, 1:975 year seismic (Courtesy of Tensar® International).

Soil parameters utilized in this 13 m high section are provided in Table 2 below.

Soil properties	Soil zone	Drained/ undrained	c	$\phi$	$\gamma_{\text{bulk}}$
			(kN/m <sup>2</sup> )	(°)	(kN/m <sup>3</sup> )
	1, Wall fill	Drained	0.0	36.0	20.0
	2, Backfill	Drained	0.0	36.0	20.0
	3, Sub-soil	Drained	0.0	36.0	20.0
	4, Wall Face	Drained	10.0	34.0	20.0

Table 2: Soil parameters (Courtesy of Tensar® International)

Traffic surcharge and seismic acceleration utilized in this section are noted in Table 3.

Loading		
Traffic surcharge		= 16 kPa
Seismic acceleration coefficient, A -	475-yr return period	= 0.24
	975-yr return period	= 0.32

Table 3: Traffic surcharge and seismic acceleration (Courtesy of Tensar® International)

The allowable long term geogrid design strengths were determined by taking the ultimate HDPE grid strength ( $T_{\text{ultimate}}$ ), and dividing it by appropriate factors of safety, more commonly known as reduction factors (RF). The equation below is the method utilized for determining allowable design strengths when HDPE geogrid is employed in the design of structures.

$$T_{\text{allowable}} = T_{\text{ultimate}} / (\text{RF}_{\text{creep}} \times \text{RF}_{\text{aging/durability}} \times \text{RF}_{\text{installation damage}})$$

- $T_{\text{ult}}$ , Ultimate Tensile Strength
- $\text{RF}_{\text{cr}}$  Reduction Factor for creep of the polymer
- $\text{RF}_{\text{d}}$  Reduction Factor for aging or durability (chemical and biological degradation)
- $\text{RF}_{\text{id}}$  Reduction Factor for installation damage

On this specific project, the proprietary designer used allowable geogrid strengths ranging from 17.9 kN/m to 54.0 kN/m of lineal wall facing. Table 4 below provides the allowable design strengths for the range of uniaxial grid used in this MSE design.

<b>Geogrid Type</b>	<b>Ultimate Tensile Strength (kN/m)</b>	<b>RFcr</b>	<b>RFid</b>	<b>RFd</b>	<b>Design Strength (kN/m)</b>	<b>Geogrid Percent Coverage (%)</b>
UX1100MSE	58.0	2.56	1.15	1.10	17.9	94
UX1400MSE	70.0	2.56	1.15	1.10	21.6	94
UX1500MSE	114.0	2.56	1.15	1.10	35.2	94
UX1600MSE	144.0	2.56	1.15	1.10	44.5	94
UX1700MSE	175.0	2.56	1.15	1.10	54.0	94
Soil-geogrid interaction coefficient Structure design life					= 0.8 = 75 years	

Table 4: Ultimate tensile strength of uniaxial geogrid and factored allowable design strengths

The coefficient of interaction  $C_i$ , is dependent on the type of backfill utilized, and provides a measure of how effectively the geogrid strength is mobilized relative to the strength properties of the backfill. In this instance, a  $C_i$  of 0.8 was utilized, consistent with the compacted granular backfill used on this project.

## 6.0 RETAINING WALL A at CARGILL/NEPTUNE TERMINAL OVERPASS

A priority for the stakeholders was to establish a new overpass above the existing rail, improving the safety and efficiency of industrial truck traffic accessing the port side, as well as the local travelling public.

The SierraScape® wall system identical to that previously described was utilized for this pile-supported abutment as designed by Stantec.

In Figure 6, the reader will now note the rectangular section of geogrid within the pile supported abutment wall. Behind the abutment seat, a 50mm to 100mm gap between the retaining wall and abutment seat is noted. This is referred to as a “*pressure relief wall*” which assisted the design team in reducing fill loads off the back of the abutment seat.

Due to the loading requirements on this specific structure the uniaxial geogrid on this specific portion of RW-A is comprised of one grid type (UX 1700) with a factored allowable design strength of 54 kN/m.

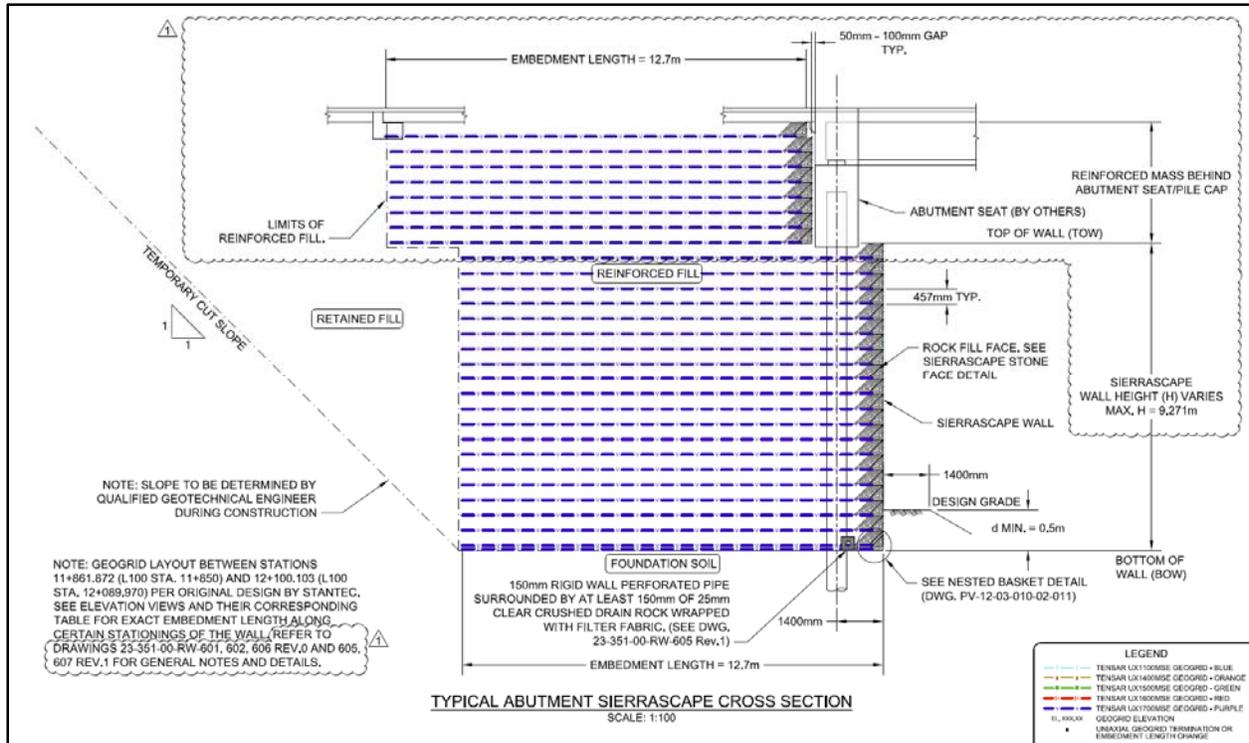


Figure 6: RW-A at Cargill/Neptune O/P (Courtesy of Nilex Inc. / Tensar® International)

As indicated within the Stantec Geotechnical Engineering Report, this structure required comprehensive full scale field tests in order to finalize the design of Neptune/Cargill,

*Full-scale field tests<sup>1</sup> have recently been completed for pile foundations installed behind and near MSE abutment wall facings. The field tests yielded results for reduced lateral pile resistance that has been incorporated in the design of pile foundations discussed later in this report. The conclusions based on these full-scale field test results are valid only when the length of geogrid reinforcement behind the MSE abutment wall facings is at least 110% of the total wall height for all rows (i.e., rectangular geogrid arrangement). Therefore, MSE abutment walls for the Neptune/Cargill Overpass and Spirit Trail Overpass at E. 3rd Street were designed using a rectangular geogrid arrangement with a minimum geogrid length equal to 110% of the total wall height. (5)*

Final finished grades were set at a burial depth of 0.5m(d MIN.), with a horizontal bench width of 1400 mm immediately in front of the wall face at lower elevation.

The embedment/geogrid lengths are substantially longer at 12.7 metres, in contrast to the overall wall structure height of 9.27 metres. It is not uncommon for soil reinforcement lengths in bridge supporting applications such as this one to exceed the wall height. Longer grid lengths allow for a larger reinforced soil block to develop higher factors of safety with respect to external stability forces such as the potential for sliding on the base.

Piles were 610 mm diameter closed ended steel pipe piles, spaced at 3000 mm along this abutment section.

## **7.0 RETAINING WALL B**

The grade separation along this section consisted of a combination of retaining wall and sustainable steepened slope system on the upslope side of the new LLR realignment. This is best illustrated when viewing the left hand side of photo B.

Commencing on the left hand side of photo B, the reader will note the galvanized SierraScape facing immediately atop the Sierra Steepened Slope. The construction crew is observed working on the elevated LLR construction grade. Retaining wall A is observed in the centre of this photo forming the transition from LLR to original pavement and rail/terminal to the far right.

Note the original road alignment and pavement structure at similar grade as the existing rail at the time of construction, along with the tight curvature at this location prior to road realignment.

A key safety benefit of this project was the ability to safely separate the industrial rail from the local municipal traffic by the grade separations (RW-A/B) as currently under construction in Photo B.



Photo B: LLR elevated construction in progress looking southeast at Cargill Terminal

A typical section of RW-B is noted in the following figure 7 which illustrates the SierraScape system atop the Sierra slope. Along this section of grade separation the combined wall/slope system ranged from 6 to 10 m in height.

The Sierra slope system is a unique feature which allowed the stakeholders to incorporate sustainability into the overall design as encouraged by our professional and engineering organizations.

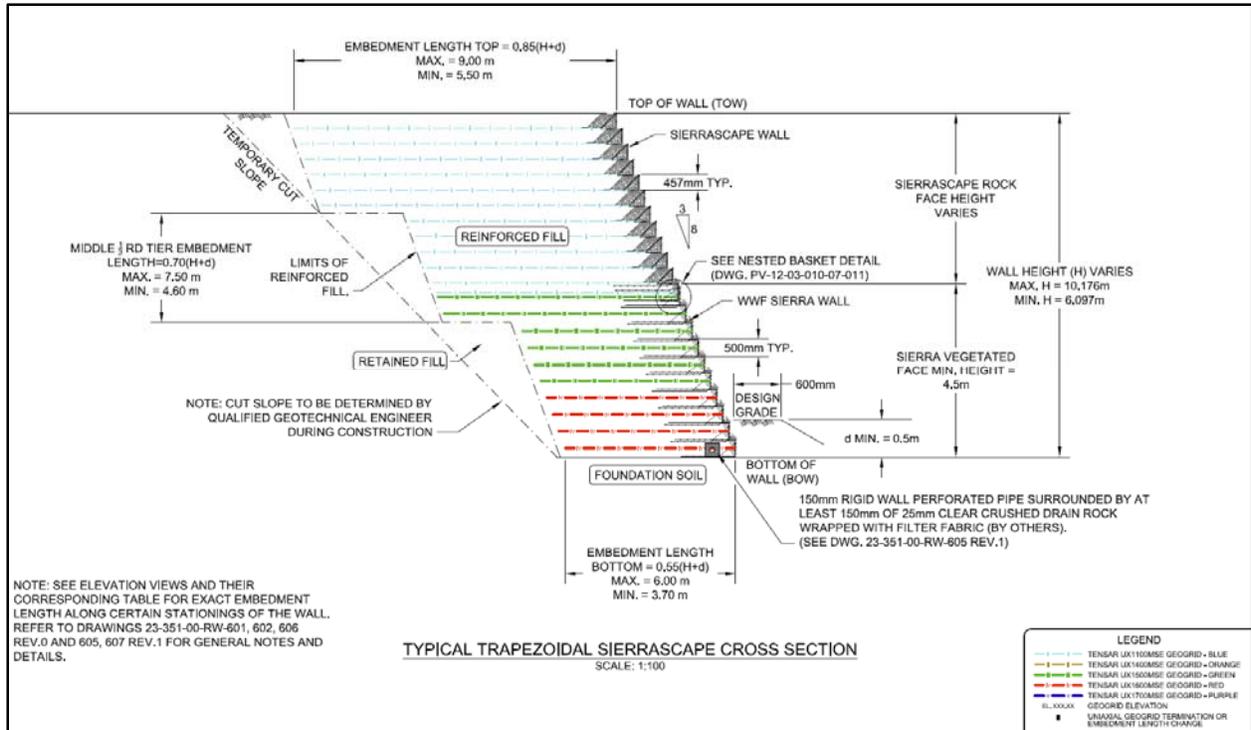


Figure 7: Trapezoidal Section and Combination of SierraScape atop Sierra Slope

Components unique to the Sierra slope design are illustrated in figure 8 with the following differences noted when compared to the SierraScape design.

- Welded wire facing (WWF) is utilized at the slope face.
- UV stabilized biaxial grid wrap structurally forms each vertical 500 mm increment.
- Erosion control mat is placed immediately behind the WWF to promote germination.
- Top soil pocket is located behind the erosion mat to allow for vegetation growth.

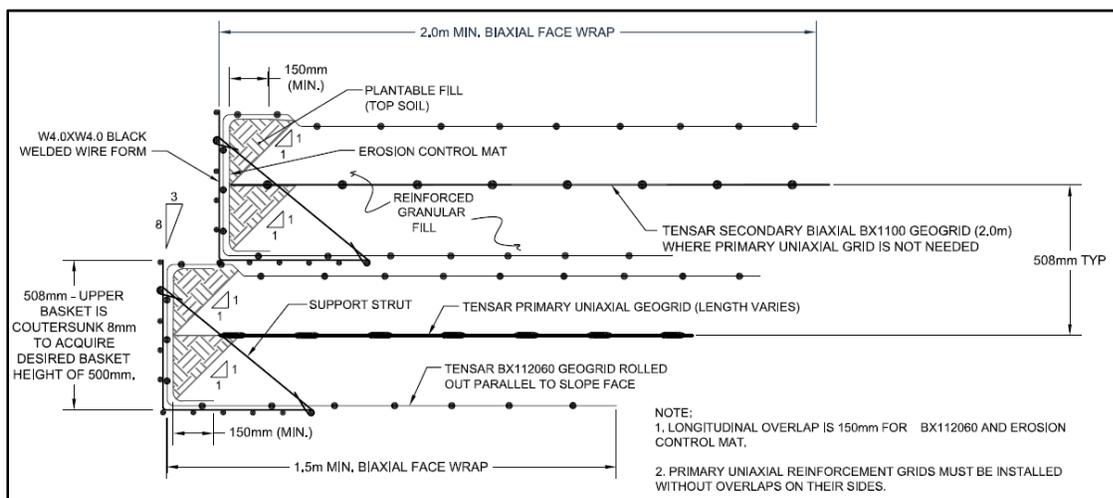


Figure 8: Sierra Slope components c/w WWF, Biaxial Grid Wrap, and Erosion Blanket

Photo C below illustrates the completed combination wall atop slope, along the left hand side of the LLR realignment. To the far right hand side of this photo (just through traffic barrier/railing) the rail cars/terminal are now noted at a lower elevation, by way of this new grade separation.

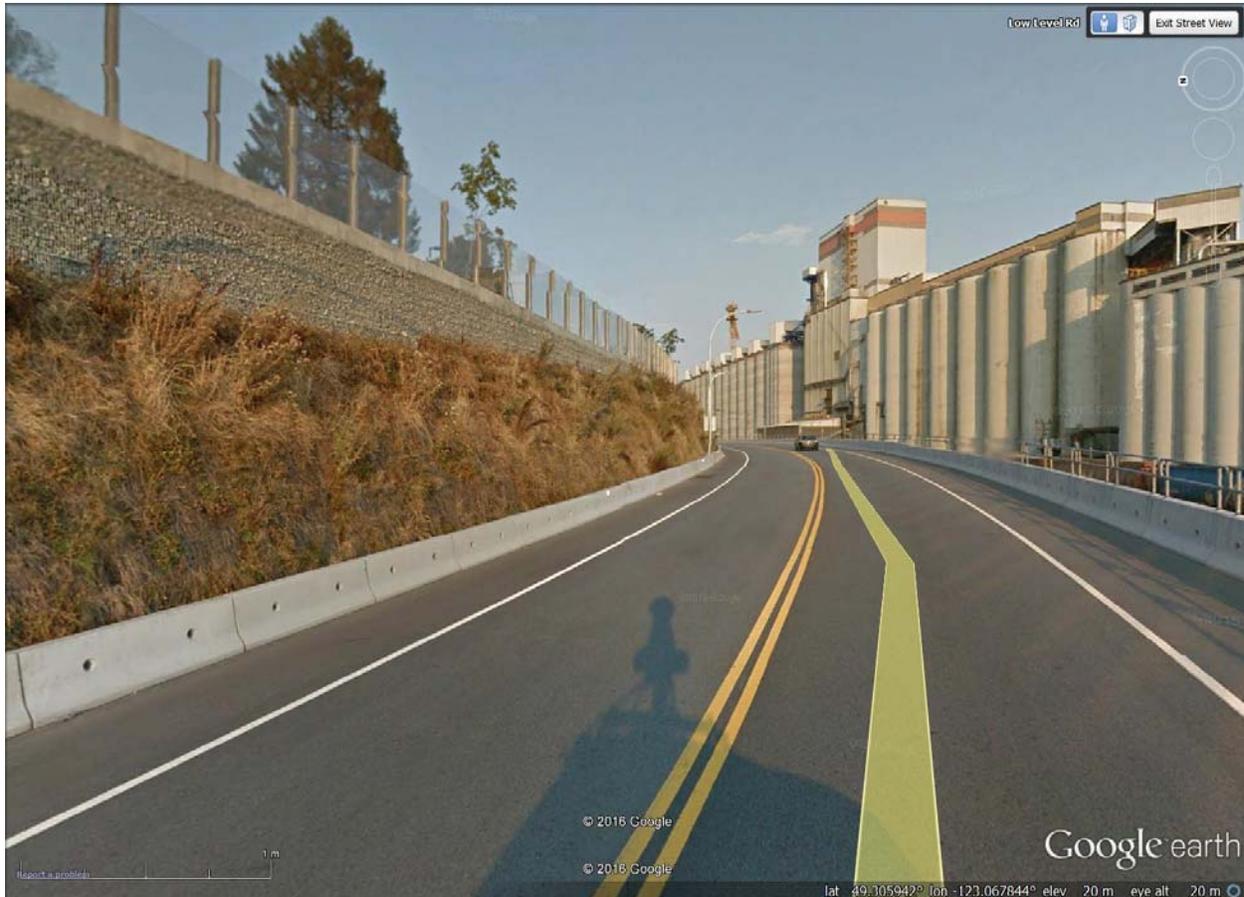


Photo C: RW-B illustrating the SierraScape atop the Sierra Steepened Slope System.

## 8.0 GOODS MOVEMENT

Stakeholders cite the LLR as a significant improvement for goods movement, safety, sustainability, and a significant engineering feat by the project team.

*"Our government is proud to deliver on another Asia-Pacific Gateway success story. The Low Level Road Project will contribute to Canada's trade competitiveness in the Asia-Pacific region, while providing environmental and economic benefits to local communities and industry right here on the North Shore... (6)*

*"The Low Level Road Project is a fantastic example of Port Metro Vancouver working to achieve our mandate by increasing trade opportunities for Canada while balancing the needs of the environment and local communities. This project and the joint effort of all funding partners will contribute significantly to increasing trade opportunities in the Pacific Gateway, while also increasing safety and quality of life for local residents in North Vancouver." (7)*

*"Projects of this nature are made possible through a shared vision and cooperation. Improving the Low Level Road, which is part of the major road network, is key to the safe and efficient movement of people and goods across the region. This project will also help ease traffic congestion and enhance road safety for pedestrians, cyclists, drivers and transit users traveling in or through the North Shore community." (8)*

*"The improvements made to the Low Level Road will deliver significant benefits to our community. This signature new road is now a landmark that will greatly improve congestion, and its redesign addresses safety, noise and pollution. The extension of the Sprit Trail and addition of dedicated bicycle paths will provide lasting health benefits to the community. Many thanks to all for your patience during this major engineering feat." (9)*

*"Stantec is very proud of our work on the Low Level Road, and we are thrilled it is the first Envision-verified transportation project in North America," said Managing Principal, Transportation, B.C., Neal Cormack. "On this multifaceted project our team realigned the roadways to accommodate rail expansion and increase safety, while securing the road's slopes and bridge structures to enhance resiliency, protecting against sea level rise and seismic threats." (10)*

## **15.0 ACKNOWLEDGEMENTS**

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The writer would like to primarily thank all the stakeholders and the project team, for their collaboration, and engineering ingenuity to solve this complex engineering challenge, whilst bringing forth sustainability, and designing with community-in-mind.

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