A geosynthetic reinforced earth retaining structure to eliminate lateral earth pressure on concrete grade beam walls – a case study

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ABSTRACT
The lateral earth pressure and differential settlement were the major concerns for the construction of a commercial building with anticipated heavy point loads on the slab-on-grade floor. This paper demonstrates a geosynthetic reinforced earth (GRE) retaining structure used to eliminate the lateral earth pressure on the concrete grade beam walls, by leaving a gap in between the grade-beam wall and the GRE structure. The wrap face GRE structure was designed using bi-axial geogrid which reinforced granular material and was fronted by wire-mesh baskets. This approach not only allowed for the grade beam walls to be designed with the assumption of zero lateral earth pressure but minimized differential settlement concerns that could affect the slab-on-grade. This paper presents the design approach of the GRE structure and incurred construction challenges.

RÉSUMÉ
La pression latérale du sol et le tassement différentiel étaient les préoccupations majeures pour la construction d'un bâtiment commercial avec de lourdes charges ponctuelles prévues sur une dalle sur terre-plein. L'étude de cas présentée dans cet article montre une structure de soutènement renforcée de matériaux géosynthétique (GRE) utilisée pour éliminer la pression exercée latéralement par la terre sur les murs de la poutre de fondation de béton, en laissant un vide entre le mur de la poutre de fondation et la structure GRE. La structure GRE à face enveloppante a été conçue à l'aide d'une géogrille biaxiale qui renforçait les matériaux granulaires et était surmontée de paniers grillagés. Cette approche a non seulement permis de concevoir les murs de la poutre de fondation en supposant une pression latérale du sol nulle, mais aussi en minimisant les problèmes de tassement différentiel qui pourraient affecter la dalle sur terre-plein. Ce document présente l'approche de conception de la structure GRE et les défis de construction auxquels elle est confrontée.

1 INTRODUCTION

The use of geosynthetics reinforced earth (GRE) structures has been widely used and studied for all kind of structures such as retaining walls, buttresses to stabilize land slide zones, bridge abutments, foundation slabs, sea walls, dams, containment dykes; subjected to a variety of static, dynamic and seismic loading conditions (Panda and Ray, 2014). Due to their economical, technical, and ecological advantages, GRE walls and slopes have become a very popular and common solutions. Available published literature shows that there are hardly any limitations concerning height, inclination, and shape.

Kachhwal et al. (2019) utilized GRE structure for the foundation of large tank which was susceptible to differential settlement due to soft compressible subgrade conditions. Eight layers of a high-strength geosynthetic material were sandwiched between compacted granular fill to bridge the soft clay layer and minimize differential settlement. Kolay et al. (2013) studied laboratory tests and generated load versus settlement curves to determine that the bearing capacity of silty clay and sandy soils increase with respect to the addition of geogrid reinforcement layers. An increase in bearing capacity over 72% with four layers of geogrid was reported. Soil reinforced with extensible reinforcement, such as geosynthetics has greater extensibility and smaller losses of post-peak strength compared to soil alone or soil reinforced with inextensible reinforcement (Shukla, 2002). Generally, the improved performance of a geosynthetic reinforced earth foundation (REF) can be attributed to an increase in shear strength of the foundation soil from the inclusion of the geosynthetic layer(s) (Crouse and Wu, 1996).

The soil is strong in compression, but virtually has no tensile strength. The inclusion of tensile reinforcing members in soil can significantly increase the strength, load bearing capacity, and lateral deformation. Tsukamoto et al. (1999) studied the influence of geogrid reinforcement on lateral earth pressures and found that geogrid reinforcement significantly reduces the coefficient of active earth pressure. Han and Jiang (2017) showed reduction of lateral earth pressure and deformation within a full-scale GRE structure used for testing. The pullout strength of geosynthetic material is used to resist against the lateral earth pressure of the soil.

Lateral earth pressure effect on high concrete foundation walls can be significant when settlement of backfill material underlying a slab-on-grade occurs. Settlement of floor slab and lateral earth pressure on walls can be a driving component in the design. Especially for a structure with significant fill height, this issue can become costly. The conventional approach requires heavier walls to be structurally designed to resist the lateral earth pressure and structural floor slab to resist differential settlement.

This paper presents a design approach where a GRE structure was used behind the grade beam walls to eliminate the lateral earth pressure and minimize fill settlement.

2 PROJECT DETAILS

A two-story commercial retail and office building was to be constructed at the corner of a property in Barrhead, Alberta. The building slab will be used to store heavy loads. The land within the building footprint was sloped at gradient of 15% towards southeast corner. Cast-in-place concrete friction piles with concrete pile caps were used for the foundation of the building. Pile cut-off elevations at the southwest corner were 3.0 m lower than the final slab elevation, thus requiring perimeter grade beam walls ranging in height from 0.3 m to 3.0 m. This also required backfill material inside the grade beam walls ranging from 0.3 m to 3.0 m in thickness. In order to provide a perspective of this project, pre and post construction photos of the building are shown in Figure 1.

Figure 1. Pre and post construction of the proposed building with grade beam wall ranging from 0.3 m to 3.0 m in height

The lateral earth pressure and differential settlement under the slab-on-grade were the major concerns for the construction due to the height of the grade beams and variability in thickness of the backfill material across the slab footprint. To minimize construction costs the client requested a solution that would avoid using a structural floor slab and foundation walls structurally designed to resist lateral earth pressure.

A geotechnical investigation comprised of boreholes up to 10.0 m depths were advanced within the proposed development footprint. The site soil profile in general consisted of a surficial granular road crush which extended to depths ranging from 0.4 m to 1.5 m. The granular material was light brown, damp, dense, and contained trace sand, silt, and clay. Clay till was encountered below the granular roadway base and extended beyond the completion depth in both boreholes. The clay till was brown to grey, stiff, low to medium plastic, damp to moist, and contained trace rusting, and, coal and gravel inclusions throughout. A wet sandy gravel seam was present at the depth of 3.6 m in one borehole. The groundwater levels were measured 24 days following drilling, where the depth of groundwater was 2.2 m below surface in the southwest corner. The field and laboratory measurements of soil characteristics are provided in Table 1.

The native compacted clay till soil was determined to be suitable to provide foundation base for the GRE structure. 100% compaction of the native clay till was recommended to provide a suitable base for the construction of the GRE structure. The factored ultimate limit state (ULS) bearing capacity of the clay till was determined to be 125 kPa for the current design.

3 GRE DESIGN

A wrap face GRE structure was chosen to reinforce the granular backfill material behind the concrete grade beam walls. A wrap face structure consisted of layers of compacted backfill with geosynthetic reinforcement installed at each layer that wraps around the exposed face of the layer and is subsequently embedded within the fill layer horizontal back from the front to form a wrapped face.

A wrap face generates strength when the friction and interlocking between the backfill and geosynthetics material is mobilized. This interface friction enables the layers of geosynthetics to remain embedded within the backfill material. Using this interface friction two design concepts can be used to design the GRE structure (Parrish, 2006).

In the first concept the reinforced backfill mass is visualized as a gravity wall to retain adjacent soil. The geosynthetic reinforcement takes the lateral load of the soil within the reinforcing zone and carries it in tension. The second concept assumes that the failure plane acts at an angle from the horizontal in relation to the angle of internal friction of the backfill soil. The soil behind this line is assumed stable while soil towards the face needs reinforcement. The geotextile reinforcement extends through the failure plane and is anchored within the retained soil by the soil/geosynthetic friction. A properly designed structure should have pullout resistance greater than the lateral load that is transferred to the geosynthetic material through the interface friction.

A 3.36 m high GRE structure was designed using high-strength bi-axial geogrid for wrapping of the granular fill material. Wire-mesh baskets were used to provide a working face of the structure and for ease of construction.

Table 1: Field and laboratory measurements of native soil properties

Soil Type	Moisture Content % (Min/Max)	Moisture Content % (Median)		N-SPT (Min / Max)		N-SPT (Median)	Shear Vane (kPa) (Min / Max)	Shear Vane (kPa) Median
Clay Till	17.4 / 35.5	24.8		9 / 28		16	45 / 180	113
Soil Type	Depth	Hydrometer (%)				Atterberg Limits		
		Gravel	Sand	Silt	Clay	LL	PL	PI
Clay Till	2.3	0.3	28.2	40.4	31.1	43.6	15.6	28.1
Clay Till	3.8	1.7	25.7	39.1	33.5	41.0	14.8	26.2
Clay Till	6.8	2.1	28.4	37.2	32.3	38.7	15.5	23.2

Each basket was 0.56 m in height, thus requiring two compacted lifts of granular backfill. The complete GRE structure required six layers of geogrid reinforcement placed and wrapped inside each wire-mesh basket.

Wire-mesh baskets were to be installed with incremental spacing from the grade-beam wall, as you go up from the base layer. The base layer was installed at 25-mm spacing from the grade-beam wall and each subsequent layer was to be setback another 25-mm from the face of the basket layer below. The final layer of the basket was installed at a setback of 0.175 mm from the grade-beam wall. This approach provided a 3° batter for the GRE structure stability and desired separation between the two structures, effectively eliminating any development of lateral pressure on the grade beam walls. Figure 2 shows design details of the GRE structure.

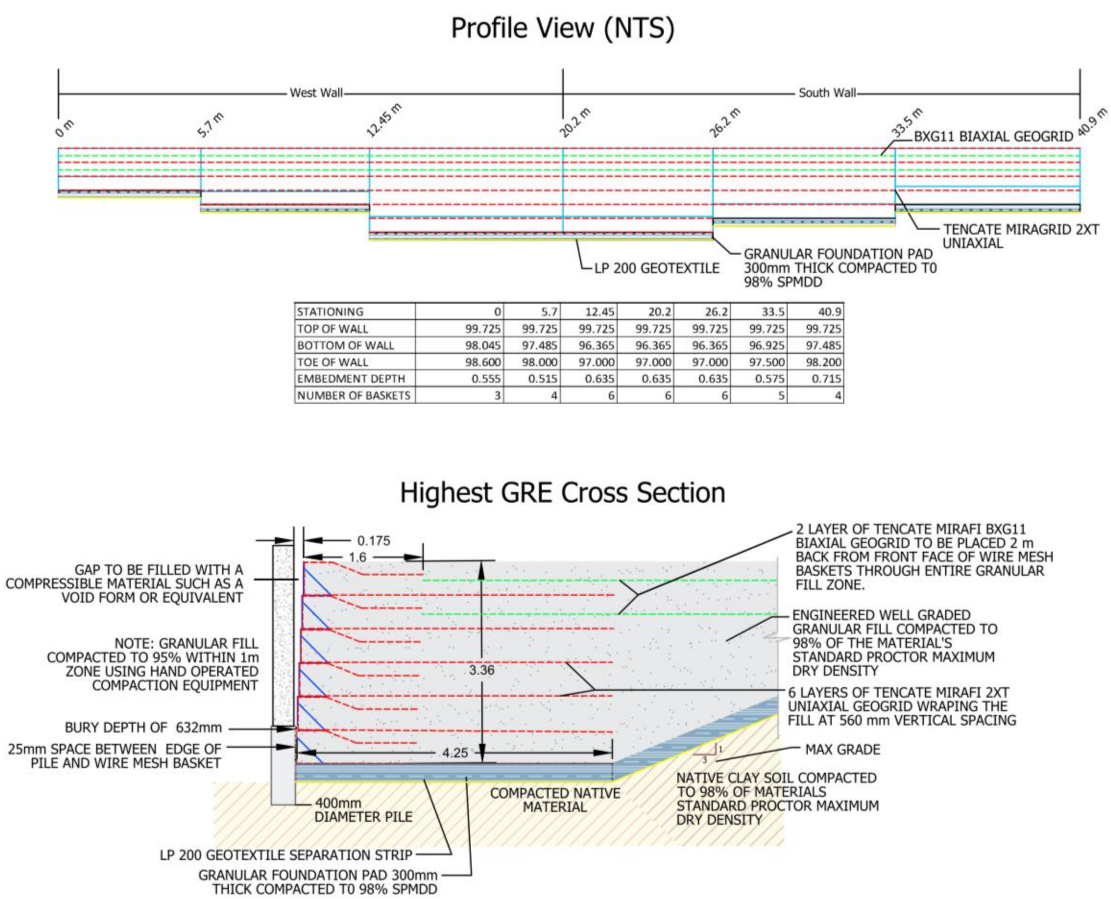

Figure 2. Proposed geosynthetic reinforced earth (GRE) structure design details showing profile and typical cross section

Native clay till soil was medium plastic and was used as foundation and retained soils under and behind the GRE structure. The granular backfill material used for the construction of GRE was Alberta Transportation standard Designation 6 Class 80 Pit-Run material. Soil properties presented in Table 2, below were used in the stability analyses of the GRE design

Table 2**:** Soil properties used for stability analyses of the GRE structure

Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (degrees)
Gravel Fill	22	0	35
Clay Till	19	10	15

Six layers of a Tencate Mirafi 2XT bi-axial high strength geogrid placed at specific vertical spacing within a granular fill was used to construct the GRE. The index properties of the selected reinforcing geosynthetic is provided in Table 3, below.

All Properties provided in Table 3 are the same for both in Machine Direction (MD) and Cross Machine Direction (CD). Long term design strength value was used for the design of the GRE structure. A woven geotextile was used as a separation between granular backfill and clay subgrade interface to eliminate migration of fines within the granular material. Two additional layers of bi-axial geogrid were used under entire footprint of the slab to further minimize the potential of differential settlement under the slab. However, both this additional geogrid and woven geotextile separation layer were not treated as a reinforcing member for the current design and were ignored in the stability analyses.

Table 3: Properties of high strength bi-axial geogrid used in the present study

Property	Test Method	Unit	Design Value
Ultimate Tensile Strength (MARV)	ASTM D6637	kN/m	29.2
Creep Reduced Strength	ASTM D5262	kN/m	20.1
Long Term Design Strength	GRI-GG4	kN/m	17.4

Wire-mesh baskets were used to provide a clean frontage of a wrap-face GRE structure. Wire-mesh baskets not only helped in maintaining design separation between the grade-beam walls and GRE structure but also helped the contractor in installation of geogrid reinforcement. Figure 3 shows an illustration of the Wire-Mesh basket used on the face of the GRE structure.

The basic design approach for the GRE structure is to design against failure and differential settlement of the variable amount of fill required under the building footprint. The three possible modes of failure; (i) global or bearing capacity, (ii) rotational, and (iii) lateral spreading failures, indicate the types of stability analyses required for the design. The bearing capacity of the GRE must be adequate for the induced loads on the slab, and reinforcement must be strong enough to prevent rotational failures. The lateral spreading failures must be prevented by the development of adequate shearing resistance at geosynthetic and granular interfaces within the REF. As such, geosynthetic strength in the longitudinal direction, the traverse seam strength must also be determined (Holtz, 2001.

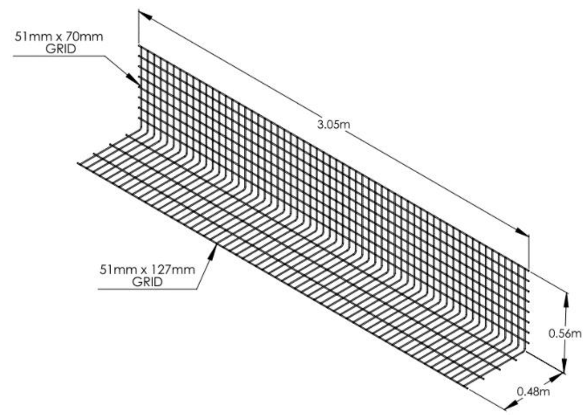

Figure 3. Schematic of a Wire-mesh basket used in current GRE design

The internal and external stability of GRE structure was analyzed using computer slope models for assessment of failure scenarios. To be specific the four scenarios that were modeled and analyzed were base sliding, circular, compound, and global stability of the GRE structure. A surcharge load of 100 kPa were applied on the top of the GRE structure to replicate post-construction loading of the slab. Factor of safety values obtained were 3.24 for base sliding, 1.45 for sliding, 1.93 for compound, and 1.52 for global stability. Stability analyses computer modeled results are shown in Figure 4, below.

4 CONSTRUCTION

GRE construction started in October 2017 following construction of grade-beam walls and installation of rigid extruded polystyrene insulation panels. Selected construction photos are shown in Figure 5.

Overall construction of the GRE structure went as per design, however there were some difficulties related to construction around the protruding perimeter piles, internal pile caps, and unfamiliarity of the earthwork contractor.

Cutting and bending of wire-mesh baskets were required for construction of the first layer of the GRE structure in order to accommodate concrete piles and pile caps that were protruding beyond the interior face of the grade-beam wall.

Re-adjustment of the geo-grid length and orientation was required around an internal concrete pile cap that was within the 5.25 m design length of the geogrid.

One other major challenge was related to communicating the importance of this design to the

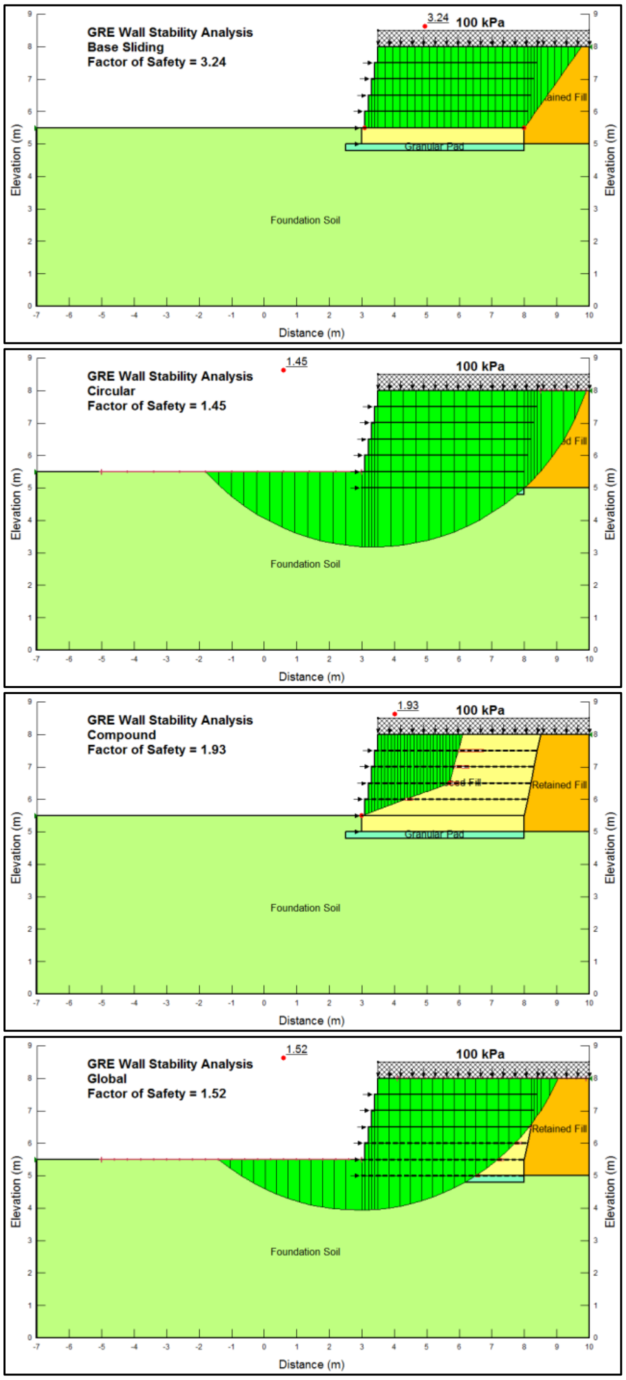

Figure 4. Stability analyses results of the proposed GRE structure showing factor of safety values for base sliding, circular, compound, and global stability scenarios, top to bottom, respectively

earthwork contractor. The earthwork contractor was a local contractor not familiar with geosynthetics design and did not have full understanding of engineering aspects of this design. Continuous monitoring was required to ensure proper construction and that a gap between the two structures is maintained as per design, since the grade beam walls were not designed for any lateral loads.

Figure 5. Construction photos of GRE construction, starting from top, showing prepared subgrade, first row of wire-mesh baskets, geogrid installation, and desired gap between grade beam and GRE structure

5 CONCLUSIONS

Overall the GRE structure worked satisfactorily in eliminating the lateral loads and minimizing differential settlement under the slab-on-grade floor of the building. As inspected in May 2019, there are no signs of any stresses on both the exterior face of the grade beam walls and on the concrete floor of the building.

This approach not only allowed for the grade beam walls to be designed with the assumption of zero lateral earth pressure but minimized differential settlement concerns that could affect the slab-on-grade. The result was cost and time savings to the project that would have been associated with design of grade-beam walls to resist lateral earth pressures and a structural floor slab.

6 REFERENCES

Crouse, P.E., Wu, J.T.H. (1996). Long-Term Field Performance of Geosynthetic-Reinforced Soil Retaining Walls, U.S. Department of Transportation Federal Highway Administration, Final Report, May 1996, Report No. CDOT-DTD-97-12.

Han, J. and Jiang, Y. 2018. Recent Advances in Geosynthetic-Reinforced Retaining Walls for Highway Applications, Frontiers of Structural and Civil Engineering, 12(2): 239-247.

Holtz, R.D. (2001). Geosynthetics for Soil Reinforcement, The Ninth Spencer J. Buchanan Lecture, College Station, TX, Nov 9, 2001

Kachhwal, L.K., Dean, M., Santino, S.P., Nesbit, B., Lefrancois, J. (2019). A Case Study of Predicted and Field Measured Settlement of a Large Diameter Tank Constructed on the Geotextile Reinforced Earth Foundation with Challenging Soil Conditions, Geosynthetics Conference, IFAI, Houston, Texas, USA, 1: 703-711.

Kolay, P.K., Kumar, S. and Tiwari, D. (2013). Improvement of Bearing Capacity of Shallow Foundation on Geogrid Reinforced Silty Clay and Sand, Journal of Construction Engineering, 2013: 293809. https://doi.org/10.1155/2013/293809

Panda, S., and Ray N.H.S. (2014). An Investigation on Behavior of Centrally Loaded Shallow Foundation on Sand Bed Reinforced with Geogrid, International Journal of Engineering Research and General Science, 2: 128-146.

Parrish, B.R. (2006). Geotextile Wrap-Face Wall Using Marginal Backfill, Master’s Thesis, University of Missouri, Columbia.

Shukla, S.K. (2002). Geosynthetics and Their Applications, Thomas Telford Publishing, London, UK

Tsukamoto, Y., Ishihara, K., Higuchi, T., and Aoki, H. (1999). Influence of Geogrid Reinforcement on Lateral Earth Pressures Against Model Retaining Walls, Geosynthetics International, 6(3): 195-218.