Challenges faced in design & construction of 12 m high geosynthetic reinforced soil slope repair in urban setting

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Philip A. Perzia, P.Eng. FORZA! GeoSolutions, Toronto, Ontario, Canada Michael J. Simons, P.Eng. Maccaferri Canada Ltd., Cambridge, Ontario, Canada

ABSTRACT

The first geogrid reinforced soil structures in North and South America were built in southern Ontario, Canada in the early 1980s. These first structures were steep slopes, typically built at 45°, with a vegetated face. Since then, the design and construction techniques have evolved due to many innovations and refinements. In the City of Mississauga, Ontario, a recently designed and constructed geogrid reinforced soil slope utilized many of these innovations and refinements. The repair of this 12 m high slope failure along 100 m of the Etobicoke Creek presented many geometric and geotechnical challenges that required some unique and powerful solutions. Some of these challenges were due to the urban setting. At the top of the slope sits a residential townhouse development. Underground utilities sit in the rear yards beyond the shoulder of the slope with sanitary sewer pipes running beyond the toe of the slope in the floodplain below. In order to protect the safety and integrity of the townhouses, the underground utilities and the sewers, the slope failure had to be repaired in a timely and economical manner while blending in with the natural ravine environment. This case study will describe how these challenges were addressed during the design and construction of this geogrid reinforced soil slope repair in an urban setting.

PRESENTACIONES TÉCNICAS

Las primeras estructuras de la tierra reforzada con geogrid en America del Norte y del Sur, fueron construidas en el Sur de Ontario, Canada en la decada de 1980. Estas primeras estructuras fueron pronunciadas pendientes construidas a 45°, con un frente de vegetacion. Desde entonces las tecnicas de diseño y construccion se han desarrollado debido a las muchas innovaciones y mejoras. En la ciudad de Mississauga - Ontario, un reciente diseño de geogrid fue construido y utilizado para reforzar un pronunciado declive, utilizando varias de estas tecnicas y diseños. Las reparaciones de este declive de 12 metros de alto a lo largo de 100 metros de Etobicoke Creek, presentaron varias dificultades geotecnicas y geometricas que requirieron unicas y poderosas soluciones. Algunos de los problemas eran debido al entorno urbano. En la parte superior de la ladera se encuentra un complejo de viviendas residenciales. Estaciones subterraneas de servicios publicos en los patios traseros mas alla del hombro de la pendiente y mas utilidades mas alla de la punta de la pendiente. Con el fin de proteger la seguridad e integridad de las residencias, los servicios publicos y otras utilidades, la falta de pendiente tuvo que ser reparada de manera oportuna y economica, mezclando con el medio ambiente natural del barranco. Este estudio describe como estos problemas se abordaron durante el diseño y construccion del geogrid reforzado para la reparacion de una pendiente en el suelo de un establecimiento urbano.

1 INTRODUCTION

The Etobicoke Creek watershed is on the north shore of Lake Ontario in the middle of the most populated area in Canada - the Golden Horseshoe. Part of the border between the City of Toronto and the City of Mississauga is the Etobicoke Creek. On the west bank in the City of Mississauga, sits a large townhouse development. Over the course of a few years, the erosion of the 12 m high steep slope escalated to a rock fall issue and then finally into a full scale slope failure, extending across 100 m of the ravine slope. The top of the failure encroached on the rear vards of the townhouses above threatening the stability and safety of the residential structures. In addition to jeopardizing the integrity and use of the underground utilities and sewer pipes, another major concern was the safety of the residents as the failure created a serious fall hazard.

The City of Mississauga hired engineers Trow Associates Inc. (Trow) to develop a plan to repair the slope failure and supervise its construction. Since the slope failure occurred within an environmentally sensitive ravine area, the design and construction method required the approval of the Toronto Region Conservation Authority (TRCA).

2 SITE DESCRIPTION

The Etobicoke Creek ravine is a natural environment with a large flood plain. The area is home to a variety of plants and animals. The west ravine slope in the vicinity of the slope failure is steeper than 2H:1V and well treed. The flood plain area is park land with a trail running parallel to the creek.

The near vertical slope failure had an exposed face consisting of glacial till and bedrock as follows:

- 1.7 m high upper layer of clayey silt/sandy till with a thin layer of topsoil on top,

- 1.3 m high middle layer of sandy silt till, and

- a bottom 9 m high zone of weathered shale bedrock. The failed mix of till, rock and vegetation came to rest at the toe of the rock face. Beyond the toe of the slope, the upper zone of the flood plain consists of approximately 2 m of sand and till above the underlying bedrock. The water table was below the toe of the ravine slope.



Figure 1. Failed slope (north is to the right). Layers of shale bedrock are visible. Note townhouses above.

3 DESIGN PARAMETERS AND CONSTRAINTS

The design solution had to meet the performance requirements to stabilize the slope, be economically feasible and be constructible in a timely manner. Various constraints made it very challenging to satisfy the above three requirements.

3.1 Performance Requirements

Due to the urban setting, with the proximity of structures above the slope and people and utilities above and below the slope, the minimum factor of safety for the slope stability was selected as 1.5. In a more remote area, the factor of safety could have been as low as 1.3. It's most likely that the slope wouldn't even have been repaired if it was far away enough from a populated area and did not pose a threat to safety.

The reinstated slope had to have a face angle that would blend in with the adjacent slope face angles at both ends of the failure zone. The finished slope face also had to be vegetated to blend in with the natural ravine environment. Plus, it had to be resistant to potential erosion from precipitation and surface runoff; in particular the bottom section of the slope had to be able to withstand the flow velocities of flood waters.

Proper drainage above, within and beyond the slope repair was also an important performance requirement.

3.2 Soil Parameters

In addition to the above noted native soils, other soils were also used in the stability analysis. To help satisfy the internal drainage requirements, an imported free-draining granular material was selected as the fill to rebuild the slope. Granular B, a Ministry of Transportation of Ontario (MTO) specification, was used. Topsoil was also imported to help establish vegetation on the slope face. See Table 1 for the soil parameters.

Soil type	Unit	Internal angle	Cohesion
	weight	of friction	
	v (kŇ/m³)	Φ	c (kPa)
topsoil	18	20 [°]	5
clayey silt/sandy till	20.5	28 [°]	2
sandy silt till	21	36 [°]	
shale bedrock	24		125
foundation soil	20	30 [°]	
Granular B	21.5	35°	

Table 1. Soil Parameters for Stability Analysis

3.3 Geometrical Constraints

Because the slope failure occurred within the floodplain, the flow volume and path of potential floodwaters had to be maintained. A conventional 2H:1V (26.6°) slope face angle would have extended too far into the floodplain interfering with the water flow and taking up too much volume. It was determined that a minimum slope angle of 1H:1V (45°) slope would be required. This steep slope angle would require geogrid reinforcement to achieve the required minimum factor of safety.

At the top of the slope in the rear yards of the townhouses, the underground utilities consisted of electrical, telephone and cable television wires. Beyond the toe of the original slope in the floodplain, two sanitary sewer pipes ran almost parallel to the slope.

To help minimize the cost and amount of time required for construction, it was preferable to leave the underground utilities and sewers in place. In order to minimize the risk of any potential disturbance, a minimum distance had to be maintained during construction. Any cut at the top of the slope had to remain at least 2 m from the underground utilities. Furthermore, the toe of the repaired slope had to be beyond the zone of influence of the sewers so as to not increase the load on the pipes.

Towards the north end of the slope failure, the sanitary sewers passed close enough to the proposed toe of slope that a 45° slope would encroach upon the zone of influence. For this section, a steeper solution was required.

If possible, it was desirable to create more usable horizontal space at the top of the slope by shifting the shoulder of the slope out a bit from the original slope shoulder. This was to help create more of a buffer zone between the fence along the top of the slope and the actual shoulder of the slope.



Figure 2. Original design cross-section through compound slope near north end. Note proximity of sanitary sewers just beyond the toe of the proposed slope repair.

3.4 Geotechnical Constraints

From a geotechnical standpoint, the near vertical bedrock face was considered stable. Only the 3 m of glacial till overburden above the bedrock required stabilization. However, this was not considered a viable option for safety and aesthetics reasons. Even though the bedrock face was stable, it was considered a potential fall hazard. Plus, pieces of rock from the weathered face could still fall endangering people below. Finally, the exposed bedrock face would not provide a vegetated face to blend in with the natural ravine environment.

Based on a height of 12 m and a 45° slope face angle with horizontal land above and below, the typical geogrid embedment length at the bottom of the slope would be approximately 11 m long, tapering to about 8 m at the top of the slope. The cut required for these embedment lengths would have required the removal of large amounts of the shale bedrock at significant cost. Furthermore, the utilities at the top of the slope would have been within the cut zone. Moving the utilities would have incurred more cost and time requirements.

To improve the financial and scheduling feasibility of the project, it became necessary to come up with a solution that minimized the removal of the bedrock and eliminated the repositioning of the utilities. Since the bedrock was relatively strong, it was also desirable to leave it in place and to utilize its strength to help stabilize the slope repair.

4 DESIGN CHALLENGES

Once it was determined that a geogrid reinforced soil slope offered the best technical and economical solution,

Trow requested the design and site assistance of FORZA! GeoSolutions.

4.1 Final Geometry

For the majority of the 100 m long slope repair, a 45° slope satisfied the geometrical constraints. Where the sanitary sewers encroached on the proposed toe of slope, a steeper slope was required. One option considered was to have an armour stone retaining wall at the base of the 45° slope. This option was not acceptable to the TRCA. A completely vegetated solution was requested.

A compound, vegetated reinforced soil slope was determined to be the most appropriate solution in this area. The final geometry consisted of a 60° angle at the bottom of the slope intersecting with a 45° angle coming down from the proposed shoulder of slope. The toe of the 60° slope started at the edge of the zone of influence of the nearest sanitary sewer.

4.2 Stability Analysis

The first challenge was to make use of the strength of the bedrock while overcoming the fact that the geogrid embedment lengths would be significantly shorter than usual.

The original design concept was to connect the layers of geogrids to the rock face. At the elevation of each layer of geogrid, rock anchors would be installed and connected to horizontal stainless steel bars. The geogrids would then be connected to the horizontal bars. This concept has been used successfully on other projects. Examples include a condominium development in Cambridge, Ontario and an industrial solid waste containment facility in Sarnia, Ontario. However, due to the large scale of the slope repair, this option proved to be cost prohibitive.

The final design built on the technique used to anchor geosynthetics in applications such as soil veneer stability and lining systems. The Rennie Street Landfill in Hamilton, Ontario, as seen in Figure 7, is an example of a project that incorporated anchor trenches to help support the uniaxial soil veneer stability geogrid and the geosynthetic clay liner (GCL) cap lining system.

The innovative solution for the slope repair that helped make the project technically and economically feasible was to create anchor trenches in the bedrock. This would allow for a direct mechanical connection of the geogrid into the bedrock. One anchor trench was located at the bottom of the slope by excavating part of the rock face. The other anchor trench was located in the top of the bedrock at the bottom of the till. The design required a high-strength geogrid to be anchored into the trenches.

The design methodology followed the Federal Highway Administration's guidelines for reinforced soil slopes. For the stability analysis, both Bishop's Modified method and Janbu's Simplified method were used. Circular and non-circular slip surfaces were analyzed. The critical slip surfaces tended to run down the face of the bedrock behind the tail of the geogrids and then shoot out between the layers of geogrid. For this reason, it was critical to provide the mechanical connection between the layers of geogrid and the bedrock.

Typically, the strength of each layer of primary uniaxial geogrid is selected to allow for a maximum vertical spacing of up to 1.2 m. However, the shorter geogrid embedment lengths contributed to the potential slip surface exiting through the face of the reinforced slope between layers of primary geogrid. To help prevent this, the vertical spacing of the primary geogrid reinforcement layers was reduced to 0.3 to 0.6 m for the majority of the slope height (see Figure 2). This allowed for the selection of lighter strength geogrids other than for the anchor trench geogrids.

The primary geogrids used for construction were MacGrids made from PVC coated polyester. In the lower two-thirds of the slope, the long term design strength (LTDS) of the geogrids was 43.0 kN/m. The LTDS in the upper third was 37.4 kN/m.

The special anchor trench geogrids were Paralink 300 with a LTDS of 110 kN/m. ParaLink geogrids are planar structures consisting of a monoaxial array of composite geosynthetic strips. Each single longitudinal strip is an extruded geocomposite with a core of high modulus, low creep polyester yarn tendons encased in a tough, durable polyethylene sheath. The single strips are connected by low strength cross laid polyethylene elements which give a grid like shape to the composite.

To maximize surficial stability in the face area, a layer of light-weight secondary (or intermediate) geogrid reinforcing was added at 0.3 m on vertical centres between layers of primary geogrid. The embedment length of the polypropylene biaxial geogrids used for the secondary reinforcing was up to 2.0 m in from the face.

In Figure 3, the 11 m high, 45° slope shown under construction in 1993 on the Highway 407 Electronic Toll Route (ETR) just north of Toronto, Ontario demonstrates

how secondary reinforcing aids in the surficial stability of the face, allowing for heavy construction equipment to operate right up to the edge of the slope. Such heavy equipment would not be permitted to operate this close to the face of a reinforced soil retaining wall system.



Figure 3. Highway 407 ETR - Secondary geogrid reinforcing in slope face helps support heavy equipment operating along edge of 45° slope during construction.

4.3 Drainage

Since water is usually a major contributing factor in slope failures, drainage was a very important consideration. First of all, it was necessary to prevent as much water as possible from overtopping the slope. This was accomplished in two parts. The first was to install a drainage swale in the rear yards of the townhouses across the entire length of the slope repair and beyond. This swale collects surface runoff and directs it away from the slope. The second was to slope the finished grade above the slope away from the shoulder of the slope and towards the drainage swale. This helps to significantly reduce the potential for any overtopping.

The second drainage consideration was the internal drainage of the reinforced soil slope. Any water that seeped into the reinforced slope from the surface or that entered underground through the back of the slope had to be removed from the system. The use of the free draining Granular B helped satisfy this requirement. Any water entering the system would flow down through the free draining granular to the bottom of the reinforced slope and out to the toe. The less permeable foundation soil under the reinforced slope was graded from the back of the cut towards the toe to direct water out of the system.

The third drainage consideration was beyond the toe of the slope. A drainage swale was installed beyond the toe to help collect any water that flowed down the slope face and/or seeped out through the toe and then transport it away. The finished grade between the toe of the slope and the drainage swale was sloped away from the slope towards the invert of the swale.

4.4 Erosion Protection and Vegetation

The erosion protection of the slope repair consisted of two sections. The elevation of water during the 100 year storm was used to delineate the two sections. Above the 100 year storm level, soft armour was required. Below this level, hard armour was required.

4.4.1 Soft Armour

In order to help vegetate the original 45° geogrid reinforced soil slopes constructed nearly 30 years ago, a thin layer of topsoil, less than 25 mm, was spread on the surface of the slope onto a flat, net-like geosynthetic that was draped down the slope face. In 1983, one of the first geogrid reinforced soil slopes ever constructed in North and South America utilized this technique. Approximately 1 km of MTO's Highway 410 in Brampton, Ontario is supported by a 45° vegetated slope that reaches up to 8 m in height as seen in Figure 4.



Figure 4. MTO Highway 410 - One of the first geogrid reinforced soil structures built in the Americas: an 8 m high, 45° vegetated slope supporting a major highway for nearly 30 years.

The next step in the evolution of the erosion protection of the slope was to drape a turf reinforcement mat (TRM) down the face. This mat had a more three dimensional undulating surface and was thicker (about 25 mm) than net-like material previously the original used. Approximately 25 mm of top soil was spread into the TRM. The slope face was then hydro-seeded. Finally, a biodegradable erosion control blanket was installed to help protect the seeded topsoil and to create a warm and moist growing environment to help accelerate the germination and establishment of vegetation.

In 1994, six 45° slopes were constructed using this technique during the widening of MTO's Highway 401 near the Rouge River in Toronto, Ontario (see Figure 5).

Finally, to help maximize the viability of vegetation at such a steep angle, it was determined that significantly more than 25 mm of topsoil is required. The challenge was to develop a cost effective technique that would allow for the stable placement of a much thicker zone of topsoil (a structurally weak soil) on the face of these steep reinforced slopes that is relatively easy to install.

The technique that was developed was to wrap the face of the slope and physically contain the topsoil. The original geogrid wrapped face slopes used relatively high strength uniaxial geogrids to construct the wrap. By the late 1990's, this evolved into a more cost-effective solution by making use of the secondary geogrid reinforcing (lighter weight and less expensive biaxial

geogrids) and a permanent, non-biodegradable erosion control blanket to construct the wrap.



Figure 5. MTO Highway 401 onramp - Biodegradable straw erosion control blanket being installed over topsoil filled and hydro-seeded TRM on 8 m high 45° slope.

One of the first major projects to incorporate this technique was during the reconstruction of the Highway 427 and Highway 409 interchange in 2001 in Toronto, Ontario for MTO. A 45° slope was required to support an on ramp that circled a storm water management facility (see Figure 6).



Figure 6. MTO Highway 409 onramp - Construction of 45° slope with geogrid wrapped face to contain and support 300 mm of topsoil in face of slope.

A 0.6 m high wrap was created with a biaxial geogrid. Inside the face of the wrap, a non-biodegradable permanent erosion control blanket was installed. In the middle of the wrap, a horizontal layer of secondary biaxial geogrid was installed unless a layer of the primary uniaxial geogrid was to be installed at that elevation. This resulted in a vertical spacing of geogrid in the face zone of 0.3 m for the entire height of the slope. This helped increase the stability of the face, in particular during construction.

In 2002, this same wrapped face technique was used to help stabilize a 1.2 m thick soil veneer directly on the uniaxial veneer support geogrid and allow for vegetation to grow on the 1.5H:1V slope on the aforementioned Rennie Street Landfill project (see Figure 7).



Figure 7. Rennie Street Landfill - On right bank, geogrid wrapped face is used to help stabilize soil veneer on GCL cap lining system. Anchor trenches were used to support the uniaxial soil veneer geogrid and GCL cap liner.

For the slope repair, a layer of topsoil 300 mm thick was installed in the face of the wrap. This very thick layer of topsoil offers an excellent medium for the establishment and sustainability of vegetation. By comparison, most lawns and garden beds have much less topsoil in them.

4.4.2 Hard Armour

The need for hard armour below the 100 year storm level was contradictory to the requirement of a completely vegetated slope face. The challenge was creating a solution that allowed for both hard armour and vegetation to coexist.

The innovative solution was to install "vegetated" hard armour. Fortunately, this solution had already been developed and used successfully on previous projects.

In 1993, a 9 m high, 45° geogrid reinforced soil slope was constructed along the Humber River in Vaughan, Ontario to help support a residential subdivision. This project also required the approval of the TRCA. The bottom 3 m of the slope was covered in riprap as the hard armour. The riprap was then filled with topsoil (see Figure 8) and hydro-seeded with a native wildflower seed mix. Once the vegetation was established, the hard armour was barely visible (see Figure 9). As far as the authors are aware, this was the first use of vegetated hard armour.

To improve upon the above technique, the rip rap/topsoil mix was installed inside of the geogrid wrapped face. A layer of nonwoven geotextile was installed in the wrapped face as a separation layer between the reinforced fill (the Granular B) and the rip rap/topsoil mix. For the 60° section of slope, a stay-inplace double twisted woven wire mesh formwork as shown in Figure 10 was used to help construct the slope at such a steep angle.

To help protect the toe of the slope from being undermined by erosion, a layer of rip rap was installed from the invert of the swale to 1 m up the face of the slope. This rip rap was also filled with topsoil and seeded.



Figure 8. Humber River - 45° slope supporting residential subdivision under construction. Riprap filled with topsoil to create vegetated hard armour.



Figure 9. Humber River - 9 m high, fully vegetated, engineered structure blends in with natural ravine environment.



Figure 10. 60° face created with stay-in-place woven wire mesh supported by welded wire mesh with permanent erosion control blanket sandwiched in between.

4.4.3 Vegetation

With the assistance of the TRCA, a site-specific seed mix of native plants and flowers was developed. This seed mix was added to the topsoil in the finished slope face.

5 CONSTRUCTION CHALLENGES

In the summer of 2008, the contractor Cambridge Landscaping Inc. commenced construction of the geogrid reinforced soil slope repair. The geosynthetics were supplied by Maccaferri Canada Ltd.

Numerous challenges had to be overcome. Some were known prior to the commencement of construction. Some arose during construction.

The limited site access was known ahead of time. There was some access at the top of the slope through the backyards of the townhouses. The majority of work was performed from the bottom. Vehicular access was permitted along the existing trail. The work area itself was limited in order to keep the trail open to the public and operating during the entire construction process.

Due to the height of the slope, it was not possible to reach all the way to the bottom from the top; nor was it possible to reach all the way to the top from the bottom. This required construction to occur from both the bottom and the top. Furthermore, to assist with vehicular access, a temporary ramp was built up the face of the slope. Once construction of the reinforced slope was high enough to allow access from the top, the temporary ramp was removed and that section of reinforced slope face was finished.

One of the unforeseen construction challenges was encountered during the installation of the anchor trenches for the two high-strength layers of primary geogrid reinforcing. For part of the bottom anchor trench, the shale bedrock was breaking apart too much and not allowing for an actual trench to be formed. As shown in Figure 11, the anchoring of the geogrid to the bedrock in this area was enhanced by using concrete as the backfill material for the trench and by installing vertical rebars through the concrete and geogrid into the bedrock. Concrete ended up being used as the backfill for all of the lower and upper anchor trenches to maximize the bond between the geogrid and the bedrock.



Figure 11. High-strength primary geogrid being installed in anchor trench. Concrete was used to fill anchor trench with Granular B used to cover rest of geogrid. The layer of geogrid at 0.3 m vertical spacing at the face of a 45° slope significantly helps with constructability because it helps support construction equipment near the face. However, placing the 0.3 m layer thick of topsoil is a challenge. A useful technique contractors have employed, including on this project, is to create a series of movable wooden forms as demonstrated in Figure 12. The face of the formwork is set at 45° at the location of the finished face. The reinforced fill is placed to within 0.3 m of the finished face. The topsoil is then placed between the reinforced fill and the temporary formwork and lightly compacted.

Because of the height of the slope, the contractor chose to hand spread the custom seed mix into the topsoil as each lift of topsoil was placed instead of hydroseeding the whole slope after completion of the construction.



Figure 12. Temporary wood formwork used to help create 45° angle face in geogrid wrap.

6 CONCLUSIONS

Construction was successfully completed on schedule and within budget in the autumn of 2008 (see Figure 13). Since then, the geogrid reinforced soil slope appears stable and the slope face is well vegetated.

The design and construction of the 12 m high geogrid reinforced soil slope repair in an urban setting along the ravine of the Etobicoke Creek satisfied the required performance, cost and time criteria while overcoming the various geometrical and geotechnical challenges.

The use of geosynthetics in the design and construction of this slope failure repair made the project technically and economically feasible. In addition to allowing for the construction of a stable slope, geosynthetics helped this fully engineered structure blend into the natural ravine environment as shown in Figure 14.

Over the course of the past three decades, the design and construction of geogrid reinforced soil slopes has evolved with many innovations and refinements. Thousands of successful projects have been constructed around the globe. This project demonstrates that this evolution has helped make geogrid reinforced soil slopes a powerful solution for many earthworks challenges.



Figure 13. Geogrid reinforced soil slope after completion of construction. At north end, note 60° face with 45° above.



Figure 14. Two years later, fully engineered structure beginning to blend in with natural ravine environment.

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