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Alternative to Soldier Pile Walls – Using Anchored High-Tensile Steel Mesh for Temporary Excavation Support in an Urban Environment

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ABSTRACT

Common practice for near vertical temporary support for building excavations in soil includes soldier pile and lagging, or shotcrete retaining walls. These systems are well proven and have been utilized for decades. Herein, we present a case study using new technology that allows for a system of high–tensile steel wire mesh, specialized anchor plates, and soil nails to be utilized for excavation support. The high-tensile steel mesh and anchor plates are designed to be easily dimensionable and soil nail spacing, and embedment depth are readily determined based on the material properties and geotechnical site conditions. The benefits of utilizing an anchored high-tensile steel mesh solution for excavation support include material cost savings, reduction in installation time, and reduced environmental footprint from recycled materials. Further, we present a cost comparison between using a more traditional soldier pile and lagging support system and the anchored high-tensile steel wire mesh support on a building in an urban environment in Halifax, Nova Scotia. We estimate an approximately 40% reduction in cost with using the anchored high-tensile wire mesh system versus traditional soldier pile and lagging.

RÉSUMÉ

La pratique courante en matière de soutien temporaire presque vertical pour la construction d'excavations dans le sol inclut les murs de soutènement en pile et en soutènement ou en béton projeté. Ces systèmes ont fait leurs preuves et sont utilisés depuis des décennies. Nous présentons ici une étude de cas utilisant une nouvelle technologie qui permet d'utiliser un système de treillis métallique en acier à haute résistance, de plaques d'ancrage spécialisées et de clous pour sol pour soutenir l'excavation. Le treillis en acier à haute résistance et les plaques d'ancrage sont conçus pour être facilement dimensionnables. L'espacement des clous de sol et la profondeur d'encastrement sont facilement déterminés en fonction des propriétés du matériau et des conditions géotechniques du site. L'utilisation d'une solution de treillis en acier à haute résistance et ancrée pour le support d'excavation présente les avantages suivants: réduction des coûts de matériaux, réduction du temps d'installation et réduction de l'empreinte environnementale des matériaux recyclés. En outre, nous présentons une comparaison des coûts entre l'utilisation d'un système de soutien de pile de soldat et de soutien en retard plus traditionnel et le support de treillis métallique ancré à haute résistance dans un bâtiment en milieu urbain à Halifax, en Nouvelle-Écosse. Nous estimons une réduction des coûts d'environ 40% avec l'utilisation du système de treillis métallique ancré à haute résistance à la traction par rapport à la pile de soldat traditionnelle et au calorifugeage.

1 INTRODUCTION

In urban environments with limited space it is often necessary to implement, during construction, some form of temporary excavation support for building excavations in soil and/or weathered bedrock with near vertical slope walls. Historically, these excavation support systems have included soldier pile and lagging or shotcrete retaining walls with tiebacks (Chini and Genauer, 1997). A full review of excavation support systems used in construction can be found in Chini and Genauer (1997). While these systems are well proven and have been in use for decades, they often present problems for construction implementation, scheduling, and budgeting.

Herein, we present a case study using new technology that allows for an excavation support system comprised of high-tensile, steel, wire mesh, specialized anchor plates, and soil nails to stabilize and retain the entire system.

2 SITE GEOLOGY

The case study site is in downtown Halifax, Nova Scotia, north of the intersection between Brenton Street and Brenton Place (Figure 1). The subsurface conditions were investigated by GEMTEC Consulting Engineers and Scientists Ltd. in February 2017. This investigation included two bore holes, one at the north end of the site and one at the south end of the site. The bore holes were advanced through overburden approximately 6 m into bedrock. During borehole advancement, continuous overburden soil samples were collected until the soil bedrock interface was reached. Following soil drilling, the upper 6 m of the bedrock was cored to assess the bedrock geology conditions of the site.

Overburden on the site consisted of urban fill (re-worked till, wood, concrete, and brick debris) that was approximately 600 mm thick which was underlain by in-place and partially re-worked till composed of silty sand with gravel.

The bedrock geology conditions on the site are characterized by thinly bedded siltstone to slate of the Cunard Formation of the Halifax Group (White et al., 2014). Bedding within the site area generally strikes approximately east-west and dips steeply to the south.

3 BACKGROUND

The project site is owned by WM Fares Group and is named the Brenton Building (Figure 1). The Brenton building, currently under construction, will be a 16-story mixed use urban development with three levels of underground parking. The lowest parking level will be 11.5 m below the current ground elevation. The building site is approximately 35 m by 65 m and the depth to bedrock over the area ranged from approximately 2.5 to 3.5 m. To allow for development to take place over the maximum extent of the site, near vertical, temporary soil excavation walls were necessary during construction.

Figure 1. Brenton Building Location (red), Plan View, Halifax, Nova Scotia.

Initially a soil excavation support design that included soldier pile and lagging was recommended. The soldier pile and lagging wall was proposed to be constructed of HP 12" x 74 lb/ft, H-Piling, spaced at 2.5 m, and embedded into rock a minimum of 2.1 m depth (Figure 2a). This design required that the H-Pile be drilled into bedrock with a 600 mm diameter hole and placed a minimum of 600 mm back from the edge of the rock excavation (Figure 2b).

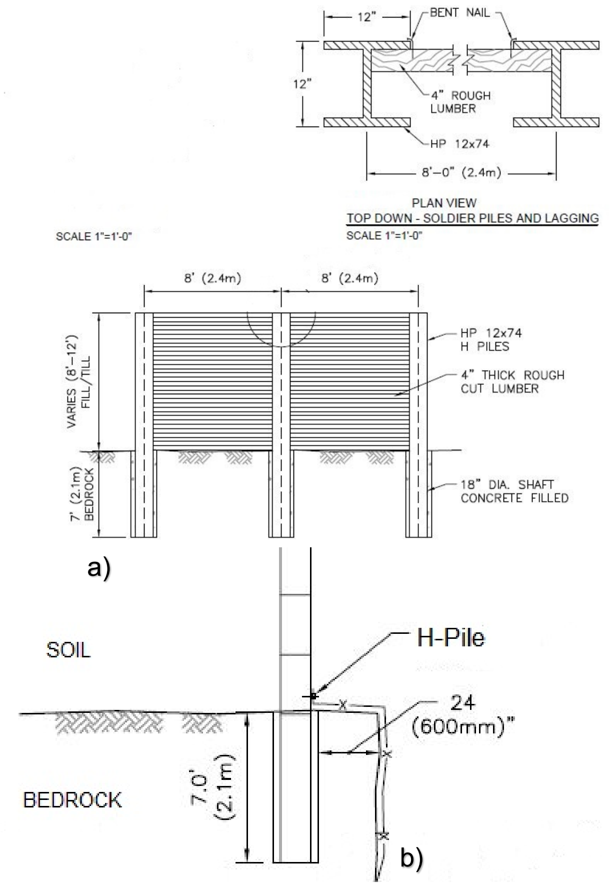


Figure 2. Proposed Soldier Pile and Lagging Design, Brenton Building; a). Elevation and Plan view, b.) Cross-Sectional View.

The initial proposed design resulted in losing 600 mm of space on the north, east and south sides of the excavation (Figure 2b). Additionally, overhead powerlines restricted the height of the drill equipment mast required to drill the 600 mm dimeter H-pile hole. This resulted in making the drilling costly and impractical. While the overhead powerlines could have been moved, the time required to do this greatly affected the project schedule. Further, prior to construction beginning on the Brenton Building, the adjacent property owner located to the north began the excavation and construction of a new 6-story building up against the property line.

The combination of construction restrictions, adjacent property owner development, and the 600 mm set back necessary for the soldier pile and lagging design resulted in building size and schedule restrictions that did not meet the requirements of the owner. As a result, the owner requested an alternative soil excavation support design. A high-tensile steel wire mesh, specialized anchor plates, and soil nails to stabilize the slopes was recommended.

3 TEMPORARY EXCAVATION SUPPORT

Using steel wire mesh slope stabilization systems is common globally and within North America. Mesh systems have been used in a variety of applications from railroads, highways, slope stabilization in urban centres to bridge foundation remediation.

In the past, the mesh used for these projects was produced using steel wire with a relatively low tensile strength of 400 to 500 N/mm^2 (Figure 3). These strengths are not high enough to stabilize an entire soil slope at steep angles (i.e. 60 – 75^o) due to the mesh tearing or punching at the soil nail/mesh interface. As a result, they require a very close soil anchor spacing that is not practical or economical.

Figure 3. Double Twist wire mesh (gabion mesh) with low tensile strength steel (i.e. 400 – 500 N/mm^2) shown protecting a rock slope.

Recent developments in high-tensile steel wire mesh offer increased stabilization capacity that results in more economical and efficient soil and weathered rock slope stabilization systems. Because of the increased tensile strength of the wires in the mesh, and the special rhomboid design of the mesh diamonds a greater spacing between soil anchors is possible. Therefore, reducing the overall time and cost associated with installation. Further, advanced soil nail placement concepts allow for a statistics-based approach to soil nail dimensioning of the high-tensile steel mesh.

At the Brenton building the flexible slope stabilization design consists of a TECCO G65/3 high-tensile steel wire mesh, TECCO engineered spike plates, and 25 mm, grade 75 Dywidag soil nails. The soil slope is at a maximum angle of 1H:2.5V. The mesh is composed of 3 mm high-tensile wire and uses a specialized zinc-aluminum coating for protection against corrosion (Figure 4). For design applications that require more aggressive load requirements the mesh is available in 4mm wires.

Manufacture of the high-tensile steel mesh results in a tensile strength of 1770 N/mm^2. This is approximately 3.5 times stronger than historical low strength mesh. TECCO G65/3 high-tensile steel wires is 12.5 kN per 3mm wire and 22 kN for a 4mm wire, this is approximately 3.5 times stronger bearing capacity than conventional low strength steel wire mesh. The increased strength allows for optimized force transfer of slope loads at the anchor plates to the soil slope.

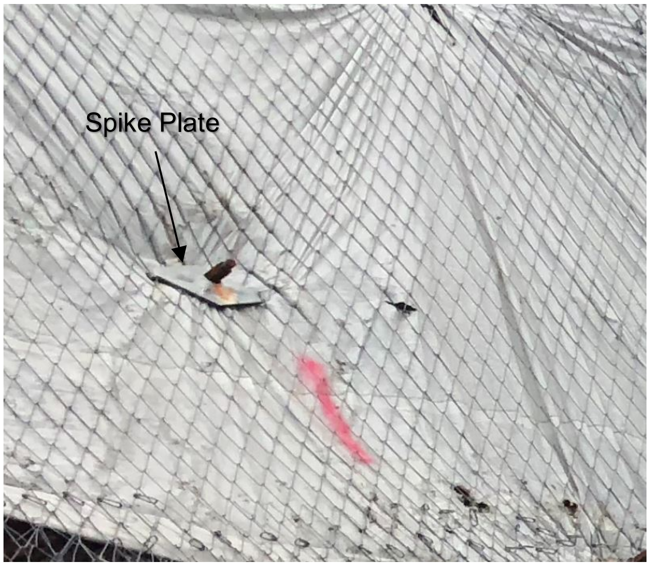


Figure 4. High-tensile G65/3 TECCO wire mesh and TECCO engineered TECCO spike plate used to secure the high-tensile steel wire mesh to the slope. Soil anchors are 25 mm, grade 75 Dywidag.

To insure optimal transfer of forces from the mesh to the anchors, a special diamond-shaped anchor spike plate has been engineered. The spike plate matches the load capacity of the mesh and serves to fix the mesh to soil. The spike plate design is diamond shape for force transmission using a plate designed with ribs (for stiffness), and additional tabs designed to tightly secure the mesh to the plate. Once the nails are tensioned, the spike plates recess into the ground, tensioning the mesh to follow the surface contours (Figure 5).

Figure 5. High-tensile wire mesh and recessed spike plate used to stabilize a soil slope.

TECCO systems utilize connection clips (T3 clips) to allow for full force transmission at the mesh seams. This ensures that the design has no weak links and requires no mesh overlap saving time and material costs (Figure 6). The T3 clip is made from the same high-tensile steel wire and the same corrosion protection as the mesh itself. The T3 clip has a diameter of 4 mm and has two reversed end hooks on one side of the clamp. It is easily and quickly installed by hand without any special equipment tools (Figure 6 a,b). No overlap of the mesh is required saving on materials. Further, the mesh can be connected longitudinally and laterally with only one T3 clip per diamond.

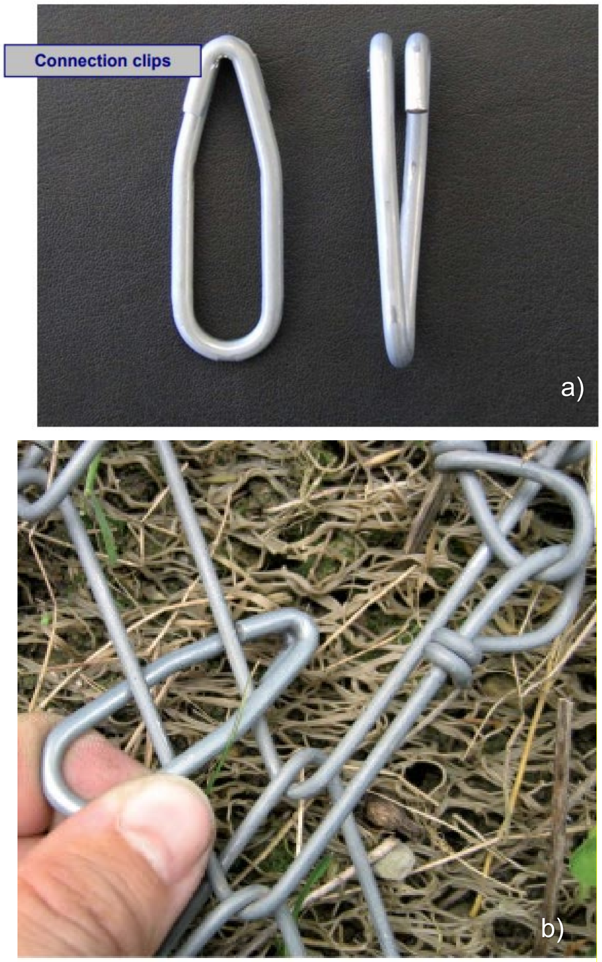


Figure 6. T3 Connection clips (4 mm diameter) used to connect TECCO panels (a and b).

The main anchors of the system are installed in a grid typically ranging from 2.0 to 4.0 m horizontal and vertical dimensions on an off-set pattern. The offset pattern results in the soil anchors being spaced such that each horizontal anchor is offset by half a horizontal nail distance from each other. This limits the maximum possible break out between the individual nails to a width “a” and a length of “2 x b”. Final design spacing depends on the results of site soil characteristics, analysis and modeling. The staggered offset layout is shown in Figure 7, with the general arrangement (Figure 7 a) and the installations at the Brenton Building in Halifax (Figure 7 b).

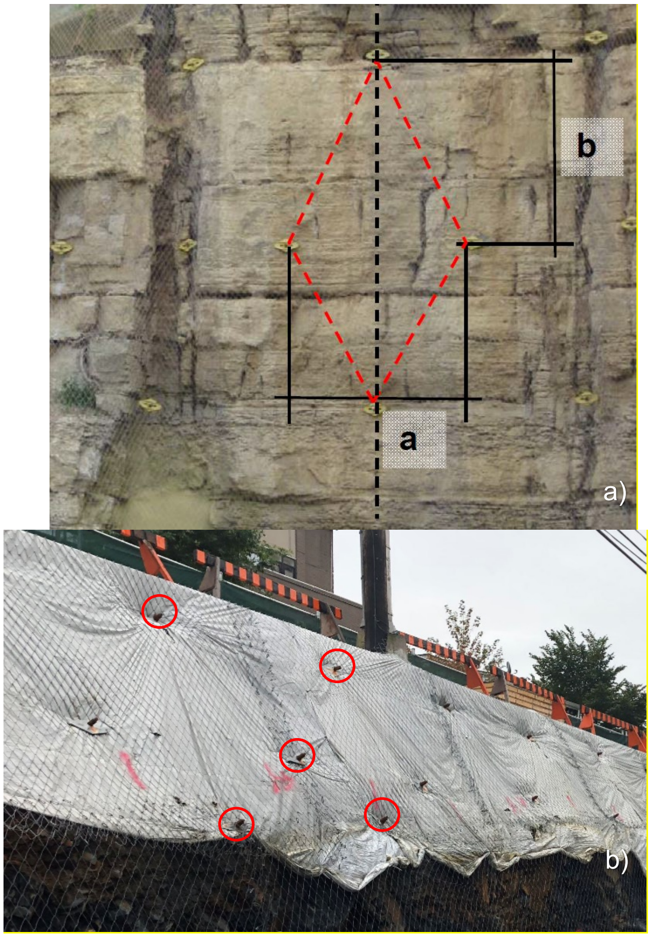


Figure 7. General profile with the nail arrangement showing offset and distance between nails a and b (a) and staggered pattern of nail installations at Brenton Building Excavation (b).

Anchors consist of commercially available steel bars ranging from 20 mm to 40 mm. Self-drilling hollow core grout injection anchors are also permitted. Additional anchors may be necessary at boundaries and in low points or hollows.

4 DIMENSIONING

The mesh slope stabilization design was dimensioned against instabilities based on the RUVOLUM concept (Rüegger and Flum, 2006). The RUVOLUM dimensioning software uses the investigation of superficial slope-parallel instabilities (i.e. wedge and planar failures), material friction angle and mesh bearing capacity as shown in Figure 8 to calculate the maximum anchor spacing.

Because of the high bearing capacity of the mesh, significant cost savings can be realized by reducing the number of total anchors required. Using the material properties of the mesh along with the characteristics of a given slope as input, this model determines the optimum anchor spacing to provide stability to the slope (Figure 8). However, global stability analysis is still required for deeper seated failure mechanisms.

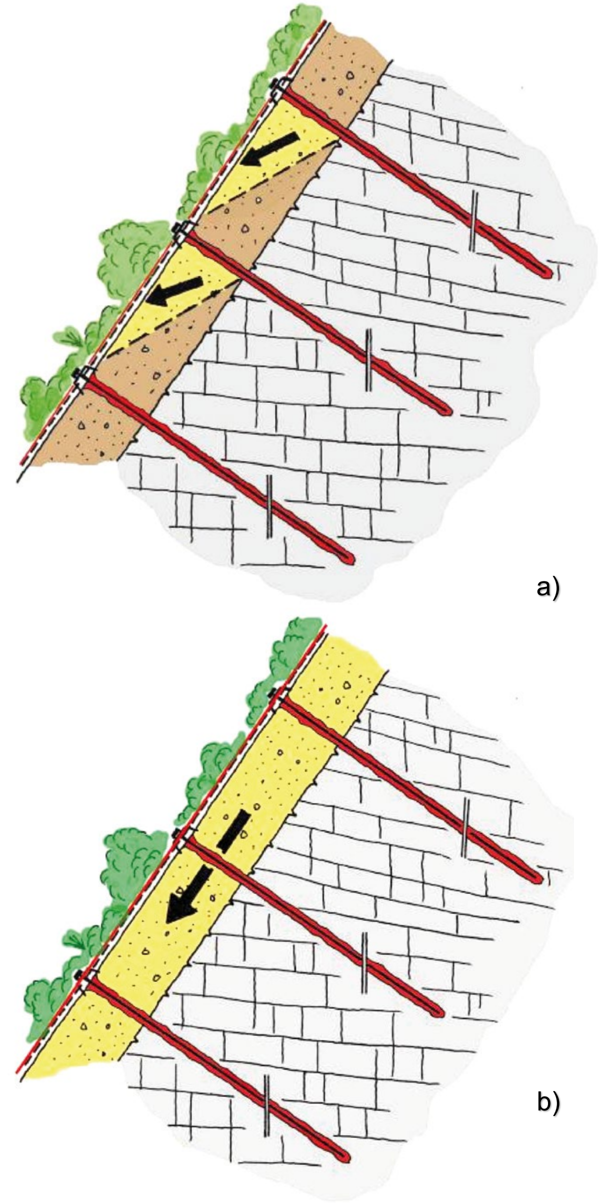


Figure 8. The dimensioning concept is based on the investigation of superficial slope-parallel instabilities (a) and on the investigation of the local instabilities between single nails (b) after Rüegger and Flum, 2006.

5 PROJECT DETAILS

The Brenton building required temporary excavation support along a portion of the north wall and all the east, and south walls of the excavation. As discussed in Section 2, the initial H-pile design was not possible due to a combination of construction restrictions, adjacent property owner development, and the 600 mm set back necessary for the soldier pile and lagging wall. The building site is approximately 35 m by 65 m and the depth to bedrock over the site ranged from approximately 2.5 to 3.5 m (Figure 9). The final design area of stabilization was approximately 330 m^2.

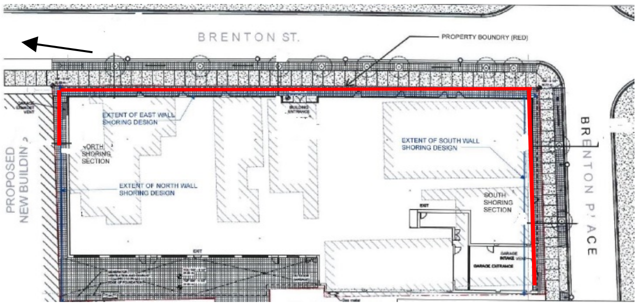
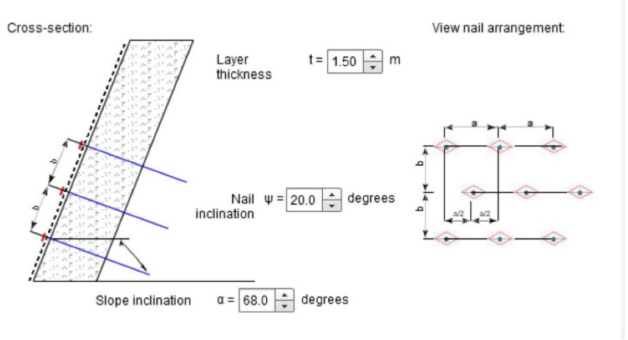


Figure 9. Plan View Brenton building development, area in red shows the location of TECCO G65/m high-tensile steel wire mesh temporary excavation support. The remainder of the building footprint is up against adjacent concrete walls of neighboring buildings.

The area highlighted in red in Figure 9 displays the location that the high-tensile steel wire mesh, specialized anchor plates, and soil nails were used to stabilize the slopes at the Brenton building.

As the excavation support is temporary (expected to be in place less than 6 months) a factor of safety (FOS) of 1.3 was used as the design criteria to model the slope stability. Anchor spacing was analyzed using the RUVOLUM software, version 1.0, available from Geobrugg North America, LLC. The nails were selected to be installed inclined 20° from horizontal (or approximately 90° to the slope face), in an offset with a spacing of 1.5 m vertically and 2.3 m horizontally. For the final design, factored (1.3) pull-out anchor loads were calculated to be 105 kN.

Figure 10 displays the final cross-section output from RUVOLUM and details the anchor dimensioning, slope angle (68°), and assumed layer thickness used in the final design. Friction angle and soil unit weight was obtained form the geotechnical investigation. A friction angle of 32° and a soil unit weight of 19 kN/m^3 were used as inputs to RUVOLUM. Further, for the purposes of this modelling, a maximum layer thickness of 1.5 m was assumed and cohesion was set to 0 kN/m^2.



Layer thickness $t =$ 1.50 m

Nail inclination $\psi =$ 20.0 degrees

Slope inclination $\alpha =$ 68.0 degrees

Figure 10. Cross-sectional view and nail arrangement from RUVOLUM software. The design was completed using soil

a friction angle of 32°, a soil unit weight of 19 kN/m^3, and cohesion was assumed to be 0 kN/m^2.

To meet the requirements to stabilize the soil slope as outlined above (Figure 10) a DYWIDAG 25 mm, grade 75 anchor was selected. This anchor has a bearing resistance to tensile stress of 254 kN and a bearing resistance to shear stress of 147 kN. Further, by assuming a bond stress along the grout (i.e. grout soil interface) of 250 kN/m^2, a drill hole diameter of 76 mm, and a pull-out design load of 105 kN, the minimum anchor bond length was calculated to be 1.75 m. to account for possible adverse soil conditions, a final anchor length of 3.5 m was selected by applying a factor of 2 to the minimum bond length calculation. The anchors were grouted in place using grout capable of compressional strengths of 50 MPa at 28 days.

Figure 11 (a,b) displays the final design arrangement. The mesh was designed to be set back approximately 1 m from the crest of the slope (Figure 11 a) and pinned to the sidewalk.

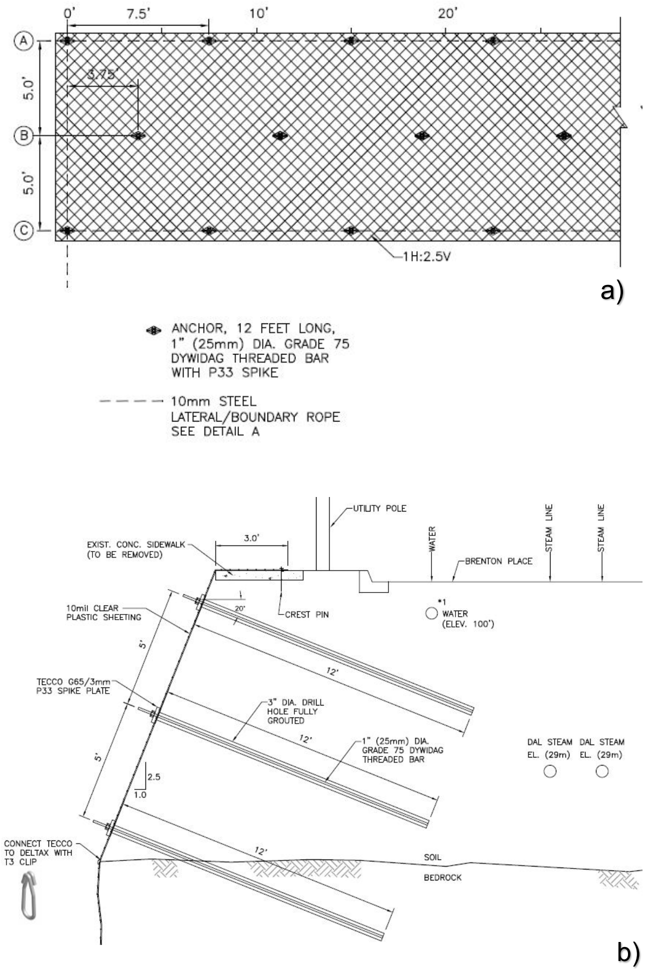


Figure 11. (a) display's an elevation view of the final TECCO G65/3 high-tensile wire with offset anchor dimensioning; (b) displays a cross-sectional view of the final design

6 CONTRACTORS COMMENTS ON CONSTRUCTION, SCHEDULE AND BUDGET

Dexter Construction Company Ltd. (Dexter) was the prime earthworks contractor on the Brenton building project. A subsidiary of Dexter, Innovative Drilling (Innovative), installed the TECCO G65/3 mesh and soil anchors. Innovative used a Furukawa 900 top hammer drill to drill the holes and install the anchors. The nature of the till subsurface material allowed Innovative to drill the holes and install anchors without casing, thus saving on time. The project scope and implementation were ahead of schedule and generally adhered to design specifications. Two of the anchor installs on the east side of the excavation required adjusting the drill hole azimuth to avoid city utilities. In these cases, the anchors were extended an additional 1.5 m to ensure the bond stress between the soil and the grout was achieved.

Dexter completed a budgetary assessment of installing a traditional H-pile, soldier pile and timber lagging wall versus the Brenton building design of a TECCO G65/3 high-tensile wire mesh. Based on their experience installing soldier pile and lagging walls at similar sites in Halifax, they estimated that an H-pile wall costs approximately \$830/m^2 to install. The cost of the TECCO G65/3 high-tensile wire mesh system at the Brenton building was estimated by Dexter to cost \$505/m^2. This is a cost difference of approximately 40% and represented a cost savings of \$107,250 to the building owner (based on 330 m^2). Further work under different slope configurations, with different soil material properties would be required to fully quantify the cost savings versus traditional methods.

7 CONCLUSIONS

A TECCO G65/3 high-tensile wire mesh slope stabilization system was installed as temporary excavation support in a restricted urban setting. The high-tensile steel mesh and anchor plates are designed to be easily dimensionable. Also, soil nail spacing, and embedment depth are readily determined based on the material properties and geotechnical site conditions. This design was implemented to replace an H-pile soldier pile and lagging wall design that was not possible due to construction restrictions, adjacent property owner development, and space limitations. We estimate an approximately 40% reduction in cost with using the anchored high-tensile wire mesh system versus traditional soldier pile and lagging. Additionally, the installation of the mesh system offered schedule savings over a traditional soldier pile and lagging.

7 REFERENCES

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