Use of Native Soil in MSE Structures

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ABSTRACT
Using native soils as the reinforced fill material in Mechanically Stabilized Earth (MSE) structures can be problematic especially if the native soils contain a large percentage of fines (d<0.075mm) and are poorly graded. Several case histories of TerraSteep retaining walls, a welded-wire-form faced MSE structure using such native soils in the Greater Toronto Area (GTA) have been reviewed and discussed in this paper with respect to their design, construction and performance during and after installation of the walls based on monitoring data.

RÉSUMÉ
L'utilisation de sols indigènes comme matériau de remplissage renforcé dans des structures en terre stabiliséee mécaniquement (MSE) pourrait être problématique si les sols naturels contiennent un grand pourcentage de fines particules (d<0,075 mm) et s'ils sont mal classés. Cet article présente et discute de la conception, de la construction et de la performance pendant et après l'installation de plusieurs murs de soutènement du type «TerraSteep» utilisant les sols indigènes de la région de Toronto.

1 INTRODUCTION

MSE structures (retaining walls) commonly utilize granular material as the backfill for the reinforced soil due to its reliability and proven engineering behavior particularly with respect to durability, drainage, soil/reinforcement interaction, and constructability (placement and compaction). Hence its use is highly recommended or required by most of the design codes or guidelines such as the Canadian Foundation Engineering Manual (2006) and the FHWA-NHI (2009).

MSE wall designers/providers, however, are often requested by the owner/contractor to use native soil (on-site soil) available to them as the backfill materials for cost saving purpose or convenience of construction (such as site accessibility for importing required soils or disposing site soils).

If the native soils are non-granular in nature and are poorly graded, particularly with high percentage of fine content, it requires altering common design assumptions and affects the design results (to allow for native soil's unique characteristics). It will almost certainly cause constructability issues during the installation of the wall and may have further impact on the wall performance after its completion.

2 DESCRIPTION OF NATIVE SOILS

In the Greater Toronto Area, on-site or native soils are often non-granular, can range from sandy silt to silty clay containing a percentage of fines (d<0.075mm) generally greater than 50%. Due to the difficulties of disposing the

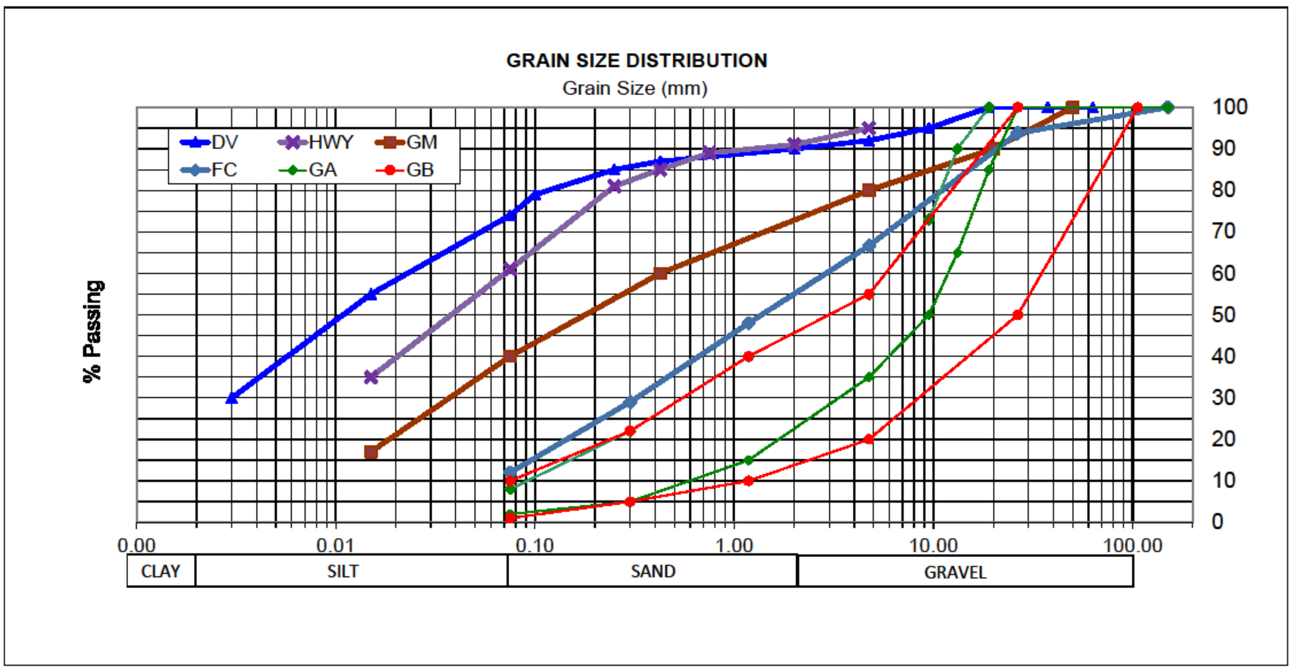

Figure 1. OPS Granular Fill vs. Typical GTA Native Soils

excavated on-site soil and/or availability of native soils for cost savings, the owners of the projects discussed herein requested a variety of native soils be used in the MSE walls. Figure 1 shows the gradations of typical native soils involved in the 4 projects FC, GM, DV and HWY, respectively.

Compared to commonly used Granular "A" (GA) or "B" (GB) (also see Figure 1) specified by Ontario Provincial Standards (OPS), the native soils have the following features:

- High fines content varying from 40% (project GM) to 80% (project DV)
- Broadly (not well) graded,
- Lower shear strength (friction angel generally around 28°/29°) compared to 34°/35° for Granular A and B materials
- Lower permeability hence poor drainage performance

3 DESIGN CONSIDERATIONS

The structures involved in the projects were MSE retaining walls of varying heights and wall batters all with Welded-Wire-Form (WWF) as the facing units, supporting major highway/roads, bus hub or architectural features. Table 1 below shows a general summary of MSE walls in the projects in recent years involved using native or on-site soil as the reinforced soil.

Table 1. Summary of Project Data

Project	Reinforced Soil	Friction Angle (°)	Wall Type	Max. Ht.
FC	Silty Sand	32°	WWF60°/ 90°	5m
GM	Clayey Silt	32°	WWF60°/ 90°	6.4m
DV	Silty Clay	28°	WWF60°	15m
HWY	Sandy Silt	29°	WWF90°	7.8m

3.1 Design Strength

The first key item in the design that needs to be considered is the strength of the native soil. Not only is the internal friction angle generally lower than granular soil, the interaction with geosynthetic reinforcement material (geogrid) is less effective too, which is reflected by the interaction coefficients C_{di} and C_d. Geogrid manufacturers usually provide the interactive coefficients for different soils which can be as low as 0.6 for clayey material and as high as 0.9 for granular material. This would obviously reduce the resistance in terms of direct sliding and pullout of the wall or reinforcement and would generally result in the requirement for a longer or stronger reinforcement. The ratio of design height vs. reinforcement embedment length (H/L) is in general greater than 75% while typically a ratio around 70% would be satisfactory if granular soil were used under the same design conditions.

3.2 Drainage Measures

To address the poor drainage behavior of the silty/clayey fill material, a number of extra sub-drain measures should be considered, in addition to the typical 150mm sub-drain pipe at the base of the wall for most of MSE walls. Depending on the cost, site constraints, constructability, availability of materials and the specific wall requirements, the following systems were designed for the projects shown in Table 1.

- A back drain of granular or geo-composite material placed at the back slope (boundary of reinforced soil and retained soil) leading to the base drain system (a large pipe or base drainage layer). This system can effectively intercept and dissipate potential seepage/groundwater from building up behind the wall and entering into the reinforced zone.
- Blanket drainage layer(s) of granular material or geosynthetic material placed within the native soil fill spaced regularly for draining away pore water/seepage through the wall face and/or back drain
- A chimney drain at the back of the reinforced zone
- Combinations of above

Typical configurations of extra drainage systems are shown in Figure 2 below.

The two extra-sub-drain systems shown above (Figure 2) are considered to be effective as they have been performing properly since the time of the installation with no indication of static water building up behind the walls or any other water related issues observed since the completion of these walls.

4. CONSTRUCTION CONSIDERATIONS

Construction with non-granular soils is more challenging than that with granular soils. It requires special compaction equipment, it is more sensitive to weather and temperature conditions and it requires tighter site control and testing.

4.1 Compaction Equipment

The so called "sheep's foot" roller (Figure 3a and Figure 3b) is considered more appropriate and efficient for plastic materials such as silty to clayey soils. Depending on the configuration of the "foot" on the compaction wheel, it is able to compact from near the bottom of each lift of the fill towards the top as the high contact pressure pushes the feet to penetrate through the soil and compact the soil beneath with the foot tip. While standard flat rollers general compact from the top of the soil downwards.

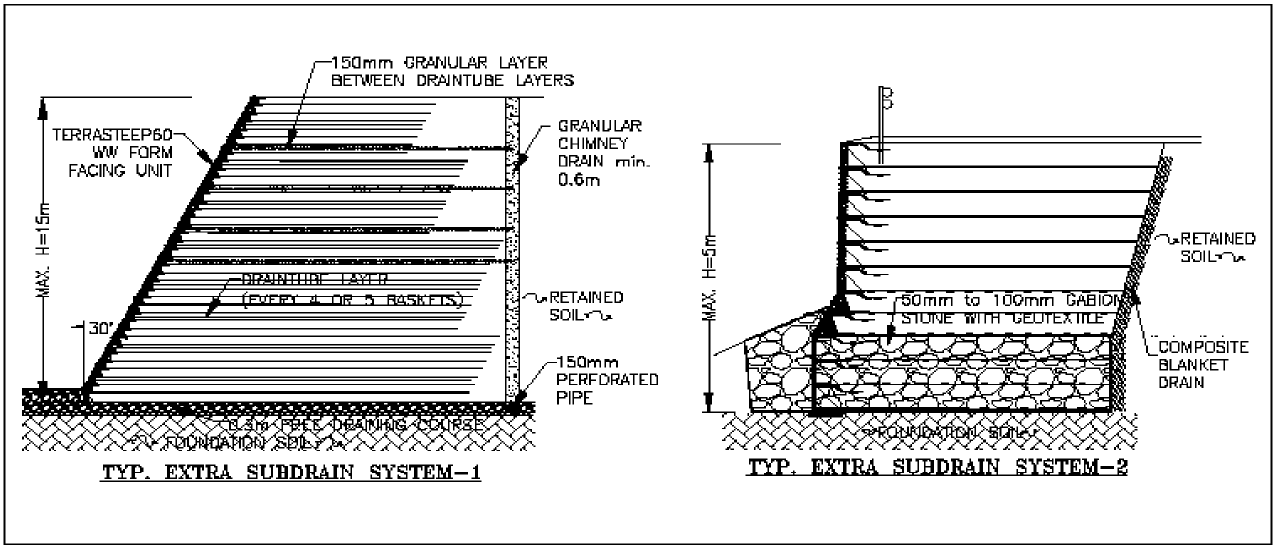

Figure 2. Typical Sub-Drain Systems

Figure 3a. Compaction Activity of Project GM

Figure 3b. Compaction Activity of Project DV

Greater number of passes with the compaction equipment are generally required even with a sheep's foot roller compared to compacting granular soils because of the small area compacted by each foot.

4.2 Weather

Even with appropriate compaction equipment as discussed above, generally more effort is required to compact native soils. Due to the high percentage of fines, it is difficult to reduce or control moisture content in the soil. If the moisture is too high, for example, it would typically cause the soil to become "spongey" where more compaction efforts will not increase the degree of compaction any further. If that happens, placement and compaction of the fill has to be stopped and removing the last layer of the fill is usually required to expose the materials with high moisture contents for air-drying. This could take days or even weeks depending on the weather conditions. If project schedule does not allow for such prolongation, replacement of the fill materials with granular soils may be the only option. This did occur on the projects FC and HWY at some point during construction stage, for each project.

4.3 Temperature

Native soil with high fines content is also more susceptible to freezing temperatures, which may result in an early shutdown of construction as winter approaches, continuation of the construction process risks poor-compaction quality. The final fill (working) surface left from previous winter shutdown usually becomes muddy, soft and sponge in the next spring when thaw starts. Some remedial works are usually required such as removing the top 0.1m to 0.5m poorly compacted till and replacing it with new fill and re-compacting. Projects using native soils with construction periods lasting more than one freezing/thaw cycle will usually experience such extra work.

4.4 Site Quality Management

Of importance in construction with native soil is site Quality Control, which can affect the success of the construction. Soil placement thickness, construction speed and site soil testing (moisture content and compaction) are the major issues that require attention. Controlling the thickness of each lift of soil placed not to exceed the specified limit, typically no more than 200mm, can be critical as over placement will significantly reduce the effectiveness of the compaction efforts. Thicker layers of fill will reduce the ability to control the moisture content and often result in requiring the removal of upper layers of soils to expose the soils below for drying. If necessary, observational construction approach, i.e. appropriate monitoring program for movement of the wall under construction should be established to better control the construction activities.

5. WALL PERFORMANCE

5.1 During Construction

One of particular behaviors of walls constructed using native soils is that they are more likely to exhibit lateral movement/distortion. During the construction of the 15m high wall of project DV, which used native soils containing the highest percentage of fines (>70%) of all of the projects discussed herein, noticeable lateral movement was observed when the wall reached about 1/3 of the design height (about 5m). To have better understanding and site quality control on the subsequent construction activities, a monitoring program was then established.

The monitoring results of lateral movement are shown in Figure 4a. It can be noted that as wall height increases, the lateral movement increases at all levels, which means that installation of new lifts tends to “push” the portion already installed below moving outwards, but the impact on the portion below reduces as height increases. The recorded lateral movement reached 62mm at the top portion of the wall upon completion of the installation.

Also noted from Figure 4a is the impact of the construction rate on the walls lateral movement. Installation to 3.5m wall height (about 9 lifts) occurred over 2.5 months (between Sept. and Nov. 2010) and resulted in about 12mm lateral (outwards) movement at the average rate of 5mm/mo, while installing less height (2.5m) of the wall during the last month of the construction (May to June of 2011) generated about 20mm movement (20mm/mo). Lateral movement continued to have progressed 20mm to 30mm for several months after the wall installation completed (although other minor construction activities at the top of the wall continued for several months).

The settlement of the wall exhibited similar behavior as the lateral movement with total average settlement of 43mm, 109mm and 115mm recorded at the end of wall installation for the bottom, middle and top monitoring points, respectively (see Figure 4b).

Note that top and middle portions of soil settled 72mm and 66mm more than that of bottom soil, which suggested

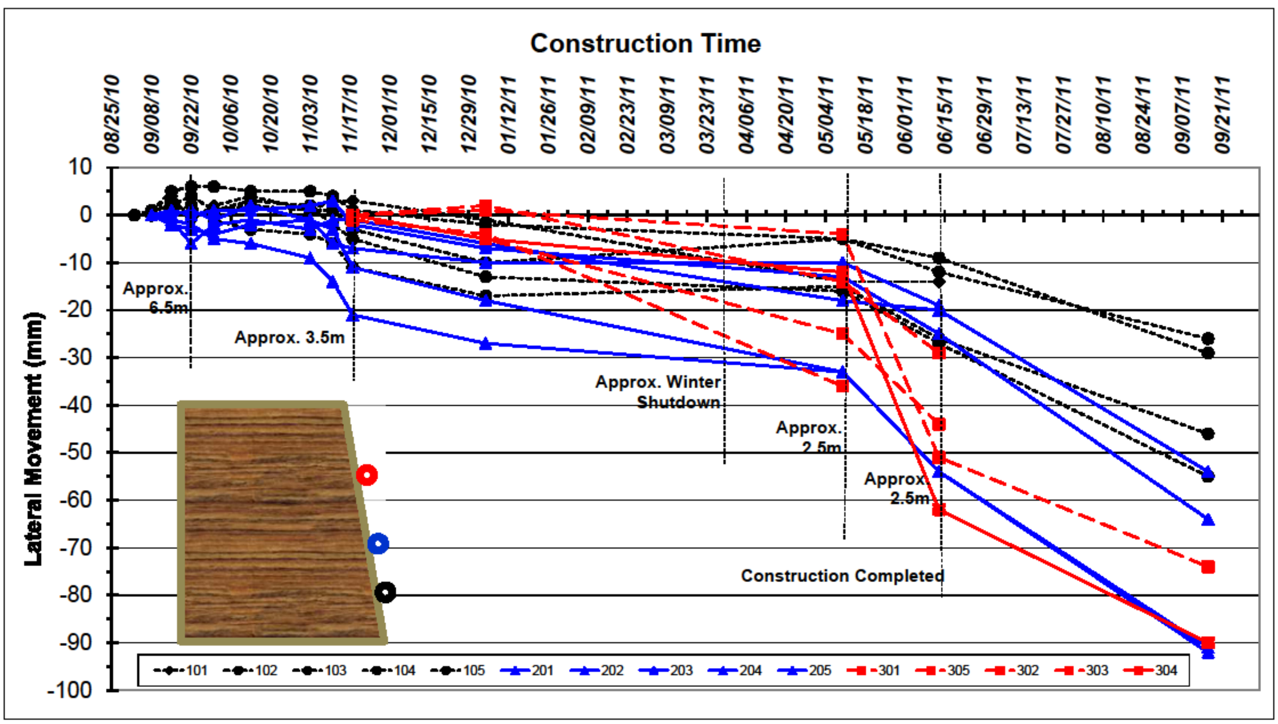

Figure 4a. Lateral Movement of The Wall

Monitoring target sets of 100 series (black), 200 series (blue) and 300 series (red) were installed at the face of the wall in sequence as the construction progresses in elevations with set 300 series established last.

that even with compaction, the clayey fill could still experience consolidation process.

Excessive compaction efforts, in order to achieve the required density, lower sliding resistance and creeping/secondary consolidation of the clayey soil (as evident by the large settlement observed at middle and

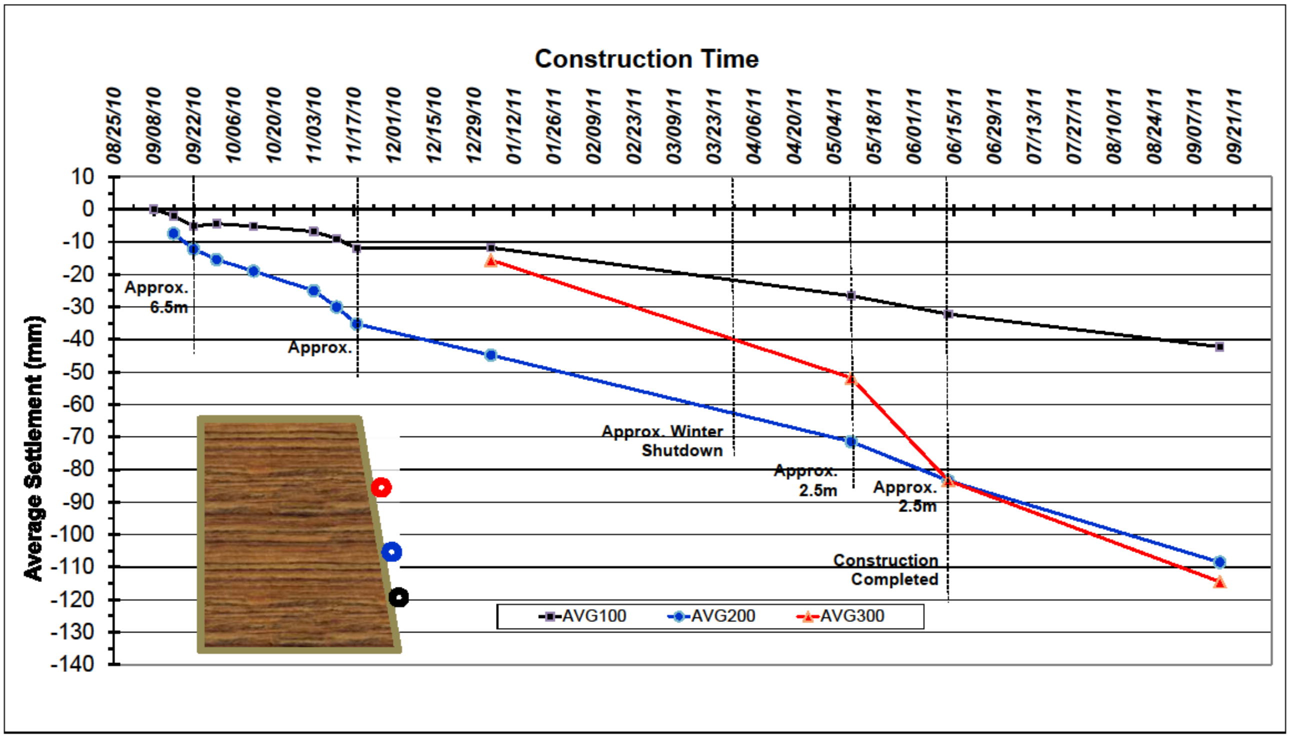

Figure 4b Average Settlement of the Wall

top of the wall) appear to be the main factors causing these movements.

5.2 Post Construction

The retaining wall applied for Project GM is a 6.4m high 90° wire form MSE wall. The monitoring program started about one month after the completion of the wall and continued for about 2.5 years. Six (6) lateral movement points and 9 vertical movement points all along the wall alignment were installed at or near the top of the wall as shown in Figure 5a.

The monitoring results are shown in Figure 5b. As it can be noted, during the first 7 months after completion of the wall, significant lateral movement had occurred. Particularly at Points C and E (both are approximately at the middle-point of a section of the wall changing alignment orientation), the lateral movement reached 100mm and 260mm respectively. Thereafter, lateral movement clearly exhibited a trend of approaching stabilization. At the end of the monitoring, most of the lateral movements were about or within 30mm, or ±0.5%H, which is in the order of typical MSE wall lateral movement of 1%H. At the two locations mentioned previously, the lateral movement reached maximum 290mm, or 4.5%H.

In addition to the similar reasons that discussed for Project DV, some placement and compaction of the fill material were occurred during sub-zero weather conditions hence the compaction quality could have been compromised and potentially as one of the factors causing the excessive lateral movement.

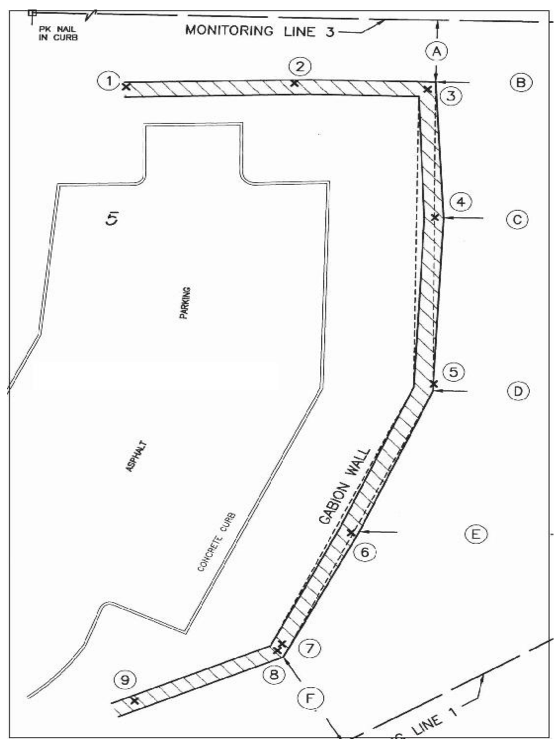

Figure 5a Location of Monitoring Points

The total settlement measured during the entire monitoring period, however, was in the range of 15mm to 30mm along the alignment of the wall, of which 95%

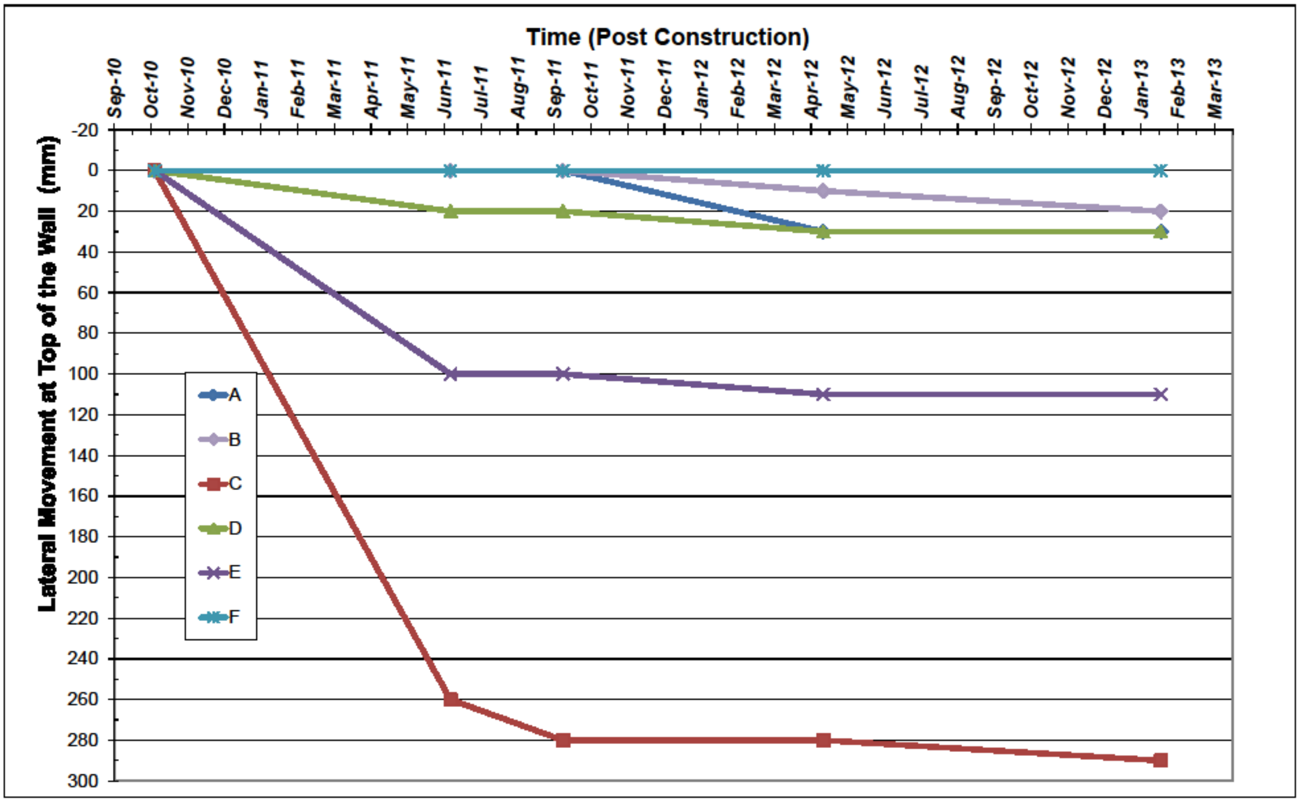

Figure 5b Post Construction Lateral Movement

occurred during the first year and approached stabilization after the 2nd year.

6. DISCUSSIONS AND CONCLUSIONS

Based on above discussion and observations, the following conclusions may be drawn in using of native soil in the GTA area for the MSE walls:

- Even though granular soils are preferable, non-granular soils with fines content more than 50% may be considered as the backfill materials for the reinforced fill and to be successful. Figures 6a and 6b show the completed walls in service.
- The native soil design strength should be carefully reviewed and examined by a Geotechnical Engineer and soil specific strength testing should be performed prior to wall designer so that the reinforcement configuration can be optimized in the design.
- Special drainage systems should be considered and designed to provide sufficient sub-drainage capability preventing pore water pressure or static water from building up within and behind the wall.
- Construction difficulties should be anticipated and possible schedule prolongation should be allowed, particularly when moisture content of the fill governs the compaction.
- Tight site quality inspection and control can never be overstressed which includes placement of the fill compaction method, rate of construction and adequate site testing. Missing or loosely arranged site control will almost surely course the installation of the wall to be problematic, during or after the completion.
- Large settlement can occur due to the consolidation of the clayey fill particularly for very high walls.
- Lateral movement and distortion of the wall during and post construction should also be expected, and sometimes can be significant. Acceptability of such potential lateral movement to any structure associated or supported by the MSE wall should be reviewed in advance.
- These potential impacts should be communicated to the Owner before the final decision to utilize native soils for the reinforced back fill.

Figure 6a – Project GM 1 year after wall completion

Figure 6b – Project DV 1 year after wall completion

REFERENCES

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