Sustainable use of alternative, “non-soil” backfills for MSE walls

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ABSTRACT
The majority of MSE walls constructed in the world have used a sand or gravel backfill and this type of backfill has performed extremely well for these structures. As an alternative to sand and gravel fills in MSE walls some “non-soil” fills have been used. Their use should only be allowed after careful consideration of the material properties including their interaction with the soil reinforcement both physically and electrochemically. Consultation with experts experienced in such construction is highly recommended.

RÉSUMÉ
La majorité des murs TSM (Terre Stabilisée Mécaniquement) construits au monde ont utilisé un remblai de sable ou de gravier et ce type de remblai s’est extrêmement bien comporté pour ces structures. Au lieu du sable et gravier, des remblais “non-sol” ont été utilisés comme une alternative dans les murs TSM. Leur utilisation ne devrait être permise qu’après un examen méticuleux des propriétés des matériaux y compris leur interaction avec les armatures dans le sol physiquement ainsi qu’électrochimique mente. Il est fortement recommandé de consulter des experts expérimentés dans ce type de construction.

1 INTRODUCTION

MSE (Mechanically Stabilized Earth) Walls have become the preferred retaining wall type in many civil engineering projects. Their lower material cost and higher speed of erection has saved project owners billions of dollars over the past forty years on a global scale.

MSE walls are composed of three basic components, namely facing, soil reinforcement, and last but certainly not least, soil or backfill. There are many different types of MSE Walls all with different types of facing and soil reinforcement. The facing and soil reinforcement selection are very important for the long-term performance and durability of a MSE wall, but equally important is the backfill. This point can be illustrated by a simple calculation, which shows that backfill accounts for approximately 95% of the volume of material used in the MSE structure.

2 CRITERIA FOR MSE WALL BACKFILL

To provide a high quality structure that will exist with low maintenance for a long life the backfill must meet some important criteria. These criteria includes: 1) adequate frictional resistance with the soil reinforcement, 2) non-aggressive to durability of the soil reinforcement material, 3) suitable drainage properties, 4) non-frost susceptible gradation, 5) limit internal long-term consolidation, 6) constructability, 7) sufficient internal friction angle and 8) controllable deformations of the facing during construction that will avoid wall misalignments.

3 STANDARD MSE WALL BACKFILL

Specifications for MSE wall backfill are extremely varied. The most important criterion is how well the backfill will perform during construction and over the life of the MSE Wall. One of the prime considerations in selection of a backfill specification for MSE walls is whether the wall will be exposed to freezing temperatures or not. For walls exposed to freezing it is necessary for the backfill to be of a type that is free draining and non-frost susceptible at least for the zone of the fill within the depth of frost penetration. For walls in a freezing climate it is possible to have two different types of backfills, one in the frost zone and another beyond the frost zone. However, to simplify construction the free draining, non-frost susceptible fill is usually specified for the entire volume of the MSE wall.

Many MSE wall supply companies have their own specifications for the backfill to be used with their proprietary wall system and these specifications are often used on projects with private owners. An example of a gradation curve is shown in Table 1. For projects with government owners, the government agency generally specifies the backfill by referencing one of their standard aggregate mixtures of clean sand and gravel. These government specifications are usually for a good quality backfill proven to perform well for MSE Walls.

Table 1. Example of a gradation curve

Sieve Size	% Passing
150 mm	100
75 mm	75 – 100
0.075 mm	0 – 15

Although there is a variety of material types used for the soil reinforcement of MSE walls, the vast majority have been constructed with galvanized steel, in strips, bar-mat or ladder configuration. To avoid any aggressive corrosion of the steel, the backfill used generally must meet some electrochemical criteria such as the one that is specified by AASHTO (American Association of State Highways and Transportation Officials) as stated in Table 2.

Table 2. Electrochemical specifications

pH = 5 to 16
Resistivity >= 3000 ohm-cm
Chlorides <= 100 ppm
Sulphates <= 200 ppm

Although inert to corrosion, Geosynthetic reinforcement and its interaction with its backfill must be examined and designed for creep, construction damage, chemical and biological degradation.

4 ALTERNATIVE, NON-SOIL BACKFILL TYPES

Alternative backfill refers to a wide variety of backfill not normally used for MSE walls that is neither a soil nor a natural aggregate. The source of this material is usually man-made but also includes materials made by natural process such as Pumice and lean oil sand. If soils can be described as “natural deposits on the earth surface of eroded and/or weathered rock” then Alternative Backfills can be considered as “non-soil” backfills.

Most of the “non-soil backfills” described in this paper have all been used previously in the construction of MSE walls with varying success. This material can be broken into several categories including: 1) re-cycled material, 2) cementitious material, 3) man-made or processed material, 4) industrial by-products, and 5) Natural Non-Soils. Examples of each material are given below:

Re-cycled Material
- Re-cycled concrete
- Re-cycled asphalt

Cementitious Material
- Soil cement
- In-compressible fill
- Lean concrete
- Roller compacted concrete
- Light weight cellular foam concrete

Man-made/Processed Material
- Light weight kiln dried clay (not discussed in this paper)

Industrial By-Products
- Fly ash
- Bottom ash
- Steel slag
- Blast furnace slag
- Mine waste/low grade ore

Natural Non-Soils
- Pumice

5 SELECTION OF ALTERNATIVE BACKFILLS

Alternative Backfill types can and have been used successfully in MSE walls but must be specified and selected carefully. Most Alternative backfills meet some of the criteria listed in the section above called “Criteria for MSE Wall Backfill” but generally fall short of being ideal on at least one or more of the required criteria. See the chart in Table 3.

The motivation for using Alternative Backfill is driven by economic factors despite some risks and tradeoffs on quality. In some cases waste material or re-cycled backfill is available at a small fraction of the cost of imported granular backfill, which sometimes is only obtainable at a great distance from the construction site for the wall.

Although Alternative Backfills are generally used to save cost, this is not always the case. In the case of very poor foundation soils often the use of lightweight backfills in combination with MSE walls can be an economical alternate to foundation improvement techniques or deep foundations. One non-soil material that is extremely light weight and is popular for use in highway embankments on very poor soil is polystyrene, but since it is not used in MSE walls it will not be discussed in this paper.

6 COMPARATIVE QUALITIES OF ALTERNATIVE BACKFILLS FOR MSE WALLS

6.1 Re-cycled Material

6.1.1 Re-cycled Concrete

Re-Cycled concrete is often a readily available alternate backfill on many construction projects. See Figure 1 for photograph of re-cycled concrete. Since concrete is generally relatively inert it has been used successfully in many MSE walls and most recently on a project involving several walls along Esther Shiner Boulevard in Toronto, Ontario. Although the pH value of re-cycled concrete is usually above the electrochemical limits specified above, it is generally considered to be non-aggressive to galvanized steel. However, since no long term corrosion monitoring is available yet for this material in MSE walls, we suggest the installation of corrosion monitoring test samples (discussed at the end of this paper).

One challenge with this material is that it will crush easily during compaction which creates a higher percent of finer material when it is in the compacted state than in its non-compacted condition. Since any grain size analysis performed on this material is generally carried out on the un-compacted material the results of this gradation can be very misleading for considerations such as frictional property and drainage.

6.1.2 Re-cycled Asphalt

Re-cycled Asphalt is a less desirable alternative backfill than re-cycled concrete. There have been reports of large deformations in MSE walls using re-cycled asphalt likely due to the viscous nature of this material. These deformations may be controlled by limiting the percent of re-cycled asphalt to a very low amount in a sand and gravel mixture.

6.2 Cementitious Material

6.2.1 Soil Cement

Soil cement has been used in many MSE walls to improve the frictional characteristics of very fine sand and also to reduce the required soil reinforcement length. In the State of Texas alone, there have been many miles of MSE walls built with soil cement backfill. We are not aware of any problems specifically with this material except for the higher cost and more difficult construction.

6.2.2 Incompressible Fill

Incompressible fill is a name given to a weak concrete mixture composed mostly of coarse concrete aggregate and cement. The authors are not aware of its use as backfill for the entire MSE volume but have cooperated in its use to repair small voids in MSE backfill that has been washed away during a heavy rain at a later stage of construction of an MSE wall, most recently on the abutment walls supporting Homer Watson Boulevard over Highway 401 near Kitchener, Ontario.

6.2.3 Lean Concrete or Roller Compacted Concrete

Comments for this material are similar to the comments above for soil cement.

6.2.4 Light Weight Cellular Foam Concrete

With typical unit weights of about $5kN/m^3$ this material can be used on poor foundation soils to reduce the weight of an MSE wall to about 25% of its weight with sand and gravel backfills. Despite the more difficult and costly construction we did not rate its cost as an “undesirable” quality since its lightweight properties can make the total installed cost of the structure less expensive when compared to other alternatives involving deep foundation or soil improvement. The most recent use of this material as MSE backfill in Canada is in Surrey, British Columbia on Highway 15 at the South Serpentine River Bridge.

6.3 Man-made/Processed Material

6.3.1 Light Weight Kiln Dried Clay

Not discussed in this paper.

6.4 Industrial By-Products

6.4.1 Fly Ash

Fly ash is the name for the very fine particles or residue from coal burning. It is undesirable for use in MSE walls due to poor frictional qualities, poor drainage, difficult to construct with, and potentially corrosive with the soil reinforcement.

6.4.2 Bottom Ash

Similar to Fly Ash, Bottom Ash is a by-product of coal burning but is much coarser than Fly Ash and because of this its properties as a backfill for MSE walls is much better both physically and electrochemically. We still caution its use due to corrosion potential.

6.4.3 Steel Slag

Steel Slag is a by-product of the steel making process and can have one very undesirable quality as a backfill. Some types of steel slag are expansive and can exert high expansive pressures on retaining walls and in one case many years ago caused cracking of concrete panels in an MSE wall. Because of this we do not recommend the use of this particular type of slag.

6.4.4 Light Weight Processed Blast Furnace Slag

This material is also a by-product of the steel making process, but Light Weight Blast Furnace Slag does not have the expansion problem that the steel making slag has and it has been used successful in several MSE walls. The three applications familiar to the authors are 1) at the intersection of Highway 407 and Highway 400 near Toronto, Ontario, 2) along the Transit Way in Ottawa, Ontario and 3) on Walker Road and CP Rail in Windsor, Ontario. This slag is from a later step in the processing of steel making and undergoes some patented procedure to create the air voids in the grains which result in its light weight. It has a relatively high cost per cubic metre, compared to sand or gravel, but can be economical when combined with MSE walls on poor foundations when compared to other retaining wall solutions. The one challenge is like most light weight backfills the particles will crush under compaction forces. In the projects that the owners were involved in with this backfill a special specification was created to limit the weight of the compactor and also to restrict the use of vibration of the compactor.

6.4.5 Mine Waste/Low Grade Ore

There are many different examples of mine waste or low grade ore which mine owners are often keen to use as an alternate for sand and gravel which sometimes requires long haul distances and/or is scarce at some mine locations. The type of fill which the authors are most familiar with comes from the oil sand mines and is called lean oil sand. The authors have been involved with about one dozen walls constructed with this backfill on oil sand mining sites north of Ft. McMurray, Alberta. This is defined as an oil sand with less than 6% bitumen content which makes it uneconomical for the oil companies to extract the bitumen from it for processing into petroleum products. The first use of this material in an MSE wall began in 1991 after some laboratory testing and a 6m high test structure was constructed. The lean oil sand is a very fine grained material and extremely sensitive to moisture contents above optimum. In the case of water contents above optimum the material develops excess pore pressures which results in "pumping and rolling" of the backfill, loss of friction with soil reinforcement and distortion of the MSE facing. Even when moisture contents are controlled pore pressures during construction still exist and time dependent consolidation is observed. Several measures have been put in place on past projects to ensure its successful use in MSE walls including establishing strict specification for both the material selection and the construction procedure.

6.5 Natural Non-soils

6.5.1 Pumice

Also used successfully on several MSE projects our comments on pumice are similar to the comments above on the Light Weight Processed Blast Furnace Slag. One of the most recent uses of pumice backfill was for an MSE wall in Morzine, France.

7 CORROSION MONITORING TEST SAMPLES

As many of the non-soil backfill materials represent relatively new backfill for MSE walls there is no long term data available for the corrosion rate that they will have with galvanized steel. For this reason the authors recommend some caution even when the non-soil backfill meets the specified electrochemical limits. One suggestion is to ensure that corrosion monitoring test samples be installed in the wall that can be easily extracted in the future to measure the corrosion at any point in time without the need to extract functioning soil reinforcement sections. These samples are generally about one metre long and can be placed directly behind the face near finished grade, or buried behind the top of the wall. The location of where these samples are installed depends on where they could be retrieved from most easily in the future when the wall is in service.

CONCLUSION

The concept of using alternative "non-soil" backfills in MSE walls is a worthy idea for improving sustainability and reducing the consumption of sand and gravel resources. However, as all of the alternative backfills discussed in this paper have at least some undesirable qualities as MSE fill, their use should only be allowed after careful consideration of the material properties and their interaction with the soil reinforcement both physically and electrochemically. Consultation with experts experienced in such construction is highly recommended.

REFERENCES

Brockbank, B., Scherger, B. and Kalynchuk, G. 1992. Use of oil sand for construction of a reinforced earth dump wall, *CGS Annual Conference,* Toronto, Ontario, Canada.

Ropret, M. 2009. Innovative backfill for MSE wall, *CSCE Annual Conference,* St. John's, Newfoundland and Labrador, Canada.

Terre Armée Internal Report R18, Confidential. "Translation of the Japanese Publication on the Use of Scoria Broken Slag in Civil Engineering".

Table 3. General qualities of alternative “non-soil” backfills for use in MSE walls

Backfill Type	Cost	Friction with Soil Reinforcement	Crushing Resistance During Compaction	Low Corrosion with Galvanized Steel	Ease to Construct	Long Term Physical Stability Low Creep	Light Unit Weight for use on Poor Foundation	Non-Expansive
Re-Cycled Concrete	Green	Green	Red	Yellow	Green	Green	Yellow	Green
Re-Cycled Asphalt	Green	Yellow	Green	Yellow	Green	Red	Yellow	Green
Soil Cement Incompressible Fill	Red	Green	Green	Green	Red	Green	Yellow	Green
Lean or Roller Compacted Concrete	Red	Green	Green	Green	Red	Green	Yellow	Green
Light Weight Foam Concrete	Yellow	Green	Green	Green	Red	Green	Green	Green
Light Weight Kiln Dried Clay	Yellow	Green	Red	Green	Green	Green	Green	Green
Fly Ash	Green	Yellow	Green	Red	Red	Green	Yellow	Green
Bottom Ash	Green	Green	Green	Yellow	Yellow	Green	Green	Green
Steel Slag	Yellow	Green	Green	Green	Green	Green	Yellow	Red
Light Processed Blast Furnace Slag	Yellow	Green	Red	Green	Green	Green	Green	Green
Mine Waste, e.g., Lean Oil Sand	Green	Yellow	Green	Green	Yellow	Yellow	Yellow	Green
Pumice	Yellow	Green	Red	Green	Green	Green	Green	Green
Sand and Gravel (for comparison)	Yellow	Green	Green	Green	Green	Green	Yellow	Green

Positive	Green	Warning or Neutral	Yellow	Undesirable	Red

Figure 1. Re-cycled concrete backfill behind precast MSE panel