

GEOSYNTHETICS SUSTAINABLE SOLUTIONS IN THE USE OF MARGINAL FILLS IN REINFORCED SOIL STRUCTURES

GEOSINTÉTICOS, SOLUCIONES SUSTENTABLES EN EL USO DE RELLENOS MARGINALES EN ESTRUCTURAS DE SUELO REFORZADO

Patricia Guerra-Escobar, Andrés León & Daniel Zúñiga.

Principal Engineer and Chair of IGS UK Chapter, Geosynthetics Ltd., Hinckley, United Kingdom (UK), patricia@geosyn.co.uk

Senior Consultant, AXIOS ENGINEERING SPA, Santiago, Chile, andres.leon@axiosingenieria.cl

Geotechnical Engineer, AXIOS ENGINEERING SPA, Santiago, Chile, daniel.zuniga@axiosingenieria.cl

ABSTRACT: Marginal fills are fills that do not meet the standards for selected fills in Reinforced Soil Structures (RSS). Geosynthetics can incorporate them into RSS through suitable design, offering sustainable and cost-effective solutions. This paper presents two UK case studies using geosynthetics with marginal fills. The first case involves a 14m high, 160m long Reinforced Soil Wall (RSW) to support construction traffic, a 1000-ton crane, and a 150-ton Tunnel Boring Machine (TBM), using strata geogrid and on-site cohesive material. The second case involves constructing a visual and acoustic bund to screen 700 new homes from a metal recycling plant, using geosynthetics and contaminated fill from multiple sites. The RSW solution, with a maximum height of 13.3m and 43 layers of geogrids, saved 68% in costs and reduced CO2 emissions by 47%. The bund solution, 9.5m high, saved 58% in CO2 emissions and significantly reduced equipment displacement. The study concludes that RSS using marginal fills have been built successfully with good performance in the UK. Also, the use of marginal fills reduces carbon footprint and earthworks costs. Prioritizing testing during both the initial phases and installation stages is crucial for the completion of these projects.

KEYWORDS: marginal fills, reinforced soil structures, carbon footprint.

1 INTRODUCTION

Marginal fills are defined as non-selected fills (cohesive or non-cohesive) that do not meet the codes/standards established for selected fills in reinforced soil structures (RSS). These soils exhibit lower or poor engineering properties compared to selected fills and can be classified into fine soils, coarse soils, or contaminated soils. From an engineering point of view (and legal) there is a need to define the word “marginal” in terms of the specific properties of selected fill that are not satisfied, which are for example fines content, high PI, low resistivity, etc.

Geosynthetics allow the use of marginal fills in RSS with an appropriate design, construction process and testing regime.

Marginal fills are sustainable, environmental, and cost-effective solutions. To use them it requires an understanding of the potential risks on the performance of the RSS.

This paper presents two UK case studies using geosynthetics with marginal fills, showing the experience and lessons learnt during the construction of Reinforced Soil Structures using marginal fine soils. Also, it is presented a testing regime guidance based on these cases. It has to be considered that tests and requirements can change according to specific conditions of each project.

2 MARGINAL FILLS: MAIN CONSIDERATIONS

Marginal fills (fine soils) are very variable and susceptible to environment and weather conditions, and it is important to carefully consider the following soil properties:

- Index properties:
 - o Source of the fill

- o Atterberg limits (consistency), gradation, specific gravity
- o Electrochemical properties, pH
- o Organic content
- o Moisture content, unit weight, density
- o Volume change
- Strength parameters:
 - o Total and effective shear strength parameters determined by appropriate tests.
 - o Long-term and short-term reinforcement pullout tests
 - o Specific Soil/reinforcement interface friction tests: shear box tests
 - o Check and cross-reference measured friction angle against commonly accepted values. To use Triaxial tests (CU, CD) for verification
 - o In the absence of reliable test results, effective friction angle estimated from PI. For design to use the lower quartile value.
 - o Cohesion design value $C = 0$. Apparent cohesion concept. In fine soils there is a drastic reduction in cohesive strength with the increase in moisture content. For design (short and long term) is recommended to use $C=0$
- Drainage
 - o Marginal soils (fine soils) are very susceptible to weather conditions and moisture content.
 - o Internal and external drainage systems, drainage at the base and at the back of the RSS, drainage behind the face when using modular blocks.
 - o Control of water at the surface at all times during construction and also after construction.

- o Surface positively sloped such that the water drains away from the reinforced wall.
- o In-plane drainage for dissipation of excess of pore pressure
- o To assess the influence of drainage in the performance of the RSS
- o Drainage systems to be monitored after precipitation events.
- **Compaction**
 - o Relative Compaction: 90 to 95% of maximum dry density (maximum 5% air voids at a dry density equal to 95% of the maximum dry density from 4.5kg hammer compaction test). In some cases, 85% of max dry density is allowed, depending on type of structure and limit of deformation.
 - o Moisture and density carefully controlled during construction in order to obtain strength and interaction values assumed in the design.
 - o Soils with fine percentage > 15% (marginal fills fine soils) constraint drainage within the fill and this may cause excess of pore water pressure, increasing deformations.
 - o Water quality used for compaction can influence the electrochemical properties of the soils and reinforcements. Tests using same source of water to be used during construction.
 - o Compacted soil layers to be protected against increase in moisture content.

3 TESTING REGIME AND GUIDENCE

For the construction of RSS using marginal fills, prior to installation, initial tests are conducted to assess the suitability of the fill material and confirm design parameters. These tests include index tests such as the gradation test (Particle Size Distribution - PSD), as well as measurements of density, moisture content, unit weight, and pH. Additionally, Atterberg limits are evaluated, comprising the Liquid Limit, Plastic Limit, and Plasticity Index. A minimum of three tests are conducted prior to installation, with an additional set of tests performed for every 500m³ of material used or at least three tests per 800m² of planned area at three intermediate heights.

Strength tests involve evaluating various aspects of soil behavior. Soil shear strength parameters, including friction angle and cohesion, are determined through Triaxial tests (CD, CU) and/or Direct shear tests. Additionally, soil-reinforcement interaction is assessed using direct shear box tests. Long-term soil strength parameters are confirmed through Drained Triaxial Tests to establish the effective friction angle. Prior to installation, a minimum of three tests are conducted, with an additional set performed for every 1000m³ of material used.

During construction, tests are conducted in accordance with BS1377:Part 9:1990 standards to ensure quality and compliance:

- Plate Bearing tests, Nuclear density tests, and Dynamic Cone Penetrometer Tests are carried out at intervals of every 50 meters of running length, with a minimum of four tests per layer to determine the California Bearing Ratio (CBR).
- Hand Vane Shear tests are performed with a minimum of three tests per layer to confirm the undrained shear strength of the compacted fill.
- In-situ density tests, including Core Cutter tests and Nuclear Density Gauge tests, are conducted with a minimum of three tests per layer to measure bulk density and dry density for relative compaction, as well as to control moisture content. In-situ moisture content is also determined with a minimum of three tests per layer.
- Sand Replacement density tests are conducted at least twice every three days to compare results of relative compaction and moisture content with laboratory tests.

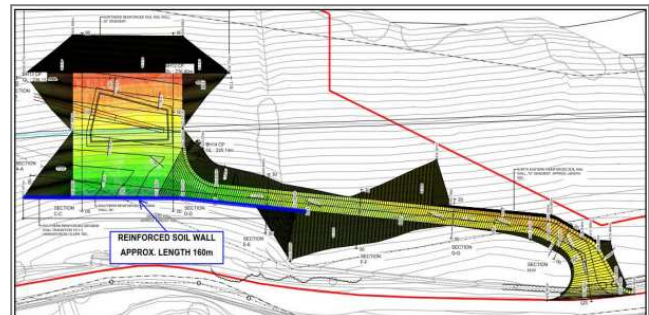
The following main requirements are recommended:

- Minimum CBR: 15%. When there is requirement of very small deformations on top of the RSS, CBR requirement can be higher (CBR = 20% to 30%)
- Relative Compaction: minimum 95% of maximum dry density (Mod. Proctor) (maximum 5% air voids at a dry density equal to 95% of the maximum dry density from 4.5kg hammer compaction test)
- Maximum moisture content: 10% (possible values of 12% but only if CBR values are much higher than 15%). Values to be checked with Optimum Moisture Content of the specific fill material.

On a daily basis, the performance of marginal fill will be assessed through In-Situ CBR tests, Hand Shear Vane tests, and in-situ density tests. If test results fall below the minimum requirements, the affected layer must be entirely removed and replaced with on-site won material from a different batch, followed by retesting. If this procedure fails to meet the standards, the layer should be replaced with granular material or cement/lime stabilized soil, and the compacted layer retested.

4 CASE STUDIES

4.1 Reinforced soil wall Ellan Valley, Bleddfa



Located in mid-Wales, the Elan Valley Aqueduct (EVA) was built over a 100 years ago to bring water to Birmingham and surrounding areas. The RSS project involves the construction of a level and horizontal working platform, measuring 14 meters in height and 160 meters in length. This platform will serve to accommodate construction traffic, as well as a 1000-ton crane required for assembling the Tunnel Boring Machine (TBM) and the 150-ton TBM itself. A plan view of the project is shown in the Figure 1. To meet environmental requirements and minimize the project's carbon footprint, on-site won material, including marginal fill, will be utilized as part of the cut-and-fill balance strategy.

Figure 1. Plan View: Downstream EVA Bleddfa – RSW

The fill material for the project consists of marginal fill, characterized as dark brown, very clayey sandy gravel, and slightly gravelly clay, classified as Class 2C – Stoney Cohesive Fill. The design parameters include a friction angle (ϕ') of 28 degrees, a unit weight of 18 kN/m³, and a cohesion (C) value of 0. This material exhibits a low friction angle and contains a significant percentage of fines content. It is highly susceptible to weather conditions and is considered variable in nature.

The chosen solution for the project involves the use of 43 layers of Uniaxial Stratagrids of 120kN/m and 60kN/m as primary reinforcement. The geogrids have a length of 10 meters with wrap-around features and are spaced at intervals of 300 millimeters. To enhance stability and prevent erosion, a

combination of Mesh Face and Erosion Mat is employed. Additionally, at the top of the wall, an integrated granular platform measuring 970 millimeters is installed, reinforced with Biaxial HM Geogrids. A cross section of the solution previously described is shown in Figure 2.

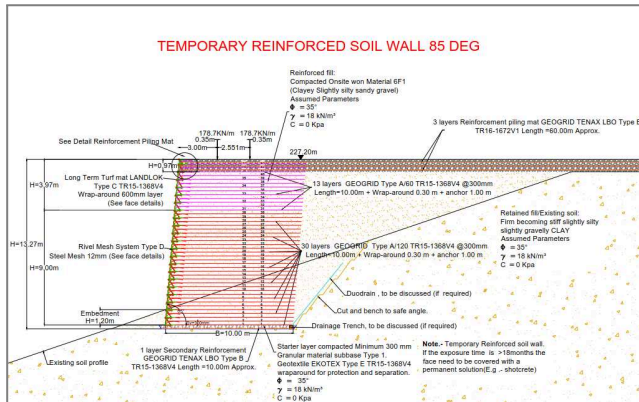


Figure 2. Cross-Section Reinforced Soil Wall Max H = 13.3m

4.1.1 Testing results and changes during construction

During the construction, the testing regime previously described in Chapter 2 was followed for each layer of the Reinforced Soil Wall.

The first layer given results below the requirements was layer number 4. In this layer the CBR value was 10%, with a relative compaction of 85% and moisture content of 18%. The results were below the minimum requirements, but not so far from the target values (CBR 15% and relative compaction 95%). The layer was left exposed for 2 days, during a period of good weather, and then the layer was re-tested adding some additional passages for the compaction of the exposed soil. The new test results achieved the CBR target of 15%, relative compaction of 95% and the moisture content went down to 12%. The same procedure was followed for layers with CBR results between 10% and 15%, relative compaction between 80% and 90% and moisture content up to 18%, when the weather was dry and sunny. This procedure allowed the subcontractor to work in other sections of the RSW, reducing the delays in the construction program.

A different procedure was used when there was continuous (and torrential) rain for more than 3 or 4 days and when the tests results were much lower than the minimum requirements: CBR values less than 10%, moisture content above 25% and relative compaction less than 70%. The procedure followed in these cases was:

- Excavate the first two meters from the face of the RSW down to 300mm and replace the on-site won material with a lean mix concrete.
- Replace all the rest of the layer with crush and run material (Granular material Class 6F1).
- Next layer of 300mm to be installed with on-site won material, with layers compacted each 150mm. Additional, to place a drainage geocomposite in strips of 2m, in two meters spacing, between the 150mm layers.

The above procedure was used for layers 10, 11 and 12,

where the first tests results were very low, and the works stopped due to the bad weather conditions. The Reinforced Soil Wall was successfully completed with a total of 43 layers, all layers tested according to the testing regime described in Chapter 2 and following the additional procedures described above. In average the obtained CBR values were between 18% and 20%, with a relative compaction of 97 to 98% and a moisture content between 10% and 13%. The top three layers (41, 42 and 43) were part of the working platform and were constructed with imported granular material. The CBR values of the top layers were given values between 30% and 35%. Figure 3 illustrates different stages of the RSW construction process.



Figure 3. RSW Construction process and breaking through TBM – Elan Valley Bleddfa

4.1.2 Analysis of the RSW solution

The Reinforced Soil Wall (RSW) design utilizes geogrids to incorporate on-site material, specifically marginal fill, resulting in significant cost savings. RSW accounted for approximately 68% in cost savings compared to the initial solution, which involved a Contiguous Pile Wall and Kingpost system with precast concrete units. Additionally, the RSW design substantially reduced the project's carbon footprint by 47%, equivalent to approximately 335 tonnes of CO₂ saved. This reduction is equivalent to the emissions from 58 round trips between London and Paris by plane. To offset this carbon footprint, approximately 524 ash trees would need to be planted.

4.2 Reinforced Bund, Paragon Park, Coventry.

A planning condition to enable Persimmon Homes to develop the site of a former brickworks in Coventry, required the construction of a visual and acoustic bund to screen their new homes from an adjacent metal recycling plant. The project would allow the construction of 700 new homes close to Coventry City Centre. The main requirement was a sustainable solution utilizing contaminated fill.

The basic geometry of the bund was also established by the site's planning conditions, requiring a 9.5m high, 450m long, 80,000m³ bund – with a 2m fence on top – to obscure the adjacent scrap metal merchant from Persimmon's new houses. Figure 4 shows the plan view of the recycling plant along with the

projection of the acoustic bund.



Figure 4. Plan view of Visual and acoustic Bund

The marginal fill used in the project comprised imported hydrocarbon and heavy metal contaminated waste. Despite its contamination, the design parameters for this material included a friction angle (ϕ') of 30 degrees and a unit weight of 18 kN/m³, with no cohesion ($C = 0$). This fill material contained a significant percentage of fines content and exhibited susceptibility to weather conditions. Despite these challenges, it was incorporated into the project's design, likely requiring careful management and mitigation measures during construction to ensure compliance with environmental and safety standards.

The chosen solution involves the use of 19 layers of Uniaxial Geogrid for reinforcement, with varying lengths ranging from 7.10m to 3.70m, including wrap-around features. The geogrids are spaced at intervals of 300mm and 600mm. For the 70-degree slope, the design incorporates Mesh Face and Erosion Mat to enhance stability and prevent erosion. This solution, which can be seen in Figure 5, balances structural integrity with erosion control, ensuring the effectiveness and longevity of the reinforced slope.

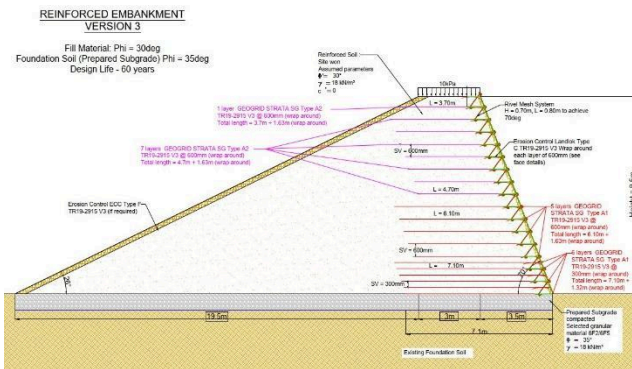


Figure 5. Solution of Reinforced Soil Bund with Geogrids

4.2.1 Testing specific regime for the project

Plate Bearing Tests with a diameter of 600mm are conducted at a frequency of one test per 1,000m³ of fill or per 1m lift. Nuclear Density Tests are performed at a rate of one test per 250m³ of fill.

These tests are essential to assess the stability and density of the fill material.

The project specifications mandate a minimum California Bearing Ratio (CBR) of 15% to ensure adequate load-bearing capacity. Additionally, a minimum compaction of 95% of the standard Proctor density is required to achieve the desired structural integrity. These requirements aim to guarantee the stability and performance of the fill material under varying conditions.

Furthermore, the maximum allowable moisture content is set at 10% to prevent excessive saturation, which could compromise the strength and stability of the fill. Adhering to these specifications is crucial to ensure the durability and reliability of the constructed infrastructure.

4.2.2 Analysis of the RSS solution

The Reinforced Soil Bund (RSB) designed specifically to incorporate contaminated waste material (marginal fill) using geogrids, achieved a remarkable reduction in the project's carbon footprint. Compared to a traditional bund solution, the RSB reduced the carbon footprint by 58%, resulting in approximately 3,316 tonnes of CO₂ saved.

This reduction in CO₂ emissions is equivalent to the emissions from approximately 780 round trips between London and Paris by plane. To offset this carbon footprint, approximately 7,070 ash trees would need to be planted.

In addition to the environmental benefits, the RSB solution significantly reduced the number of vehicle movements required during construction, with approximately 10,990 fewer movements. This reduction in transportation activities further highlights the sustainability and efficiency of the RSB approach, emphasizing its positive impact on both the environment and project logistics. Figure 6 shows a comparison of the number of loads required for the construction of the bund using marginal fills with geosynthetics and granular material without reinforcement.

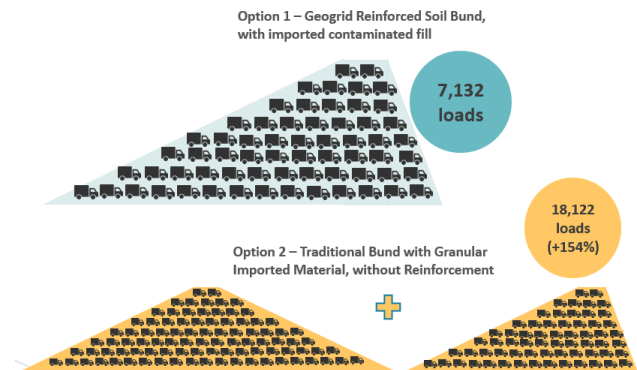


Figure 6. Comparison of alternatives using 1) Geogrid reinforced soil bund with contaminated fill and 2) Traditional bund with granular imported material without reinforcement.

5 CONCLUSIONS

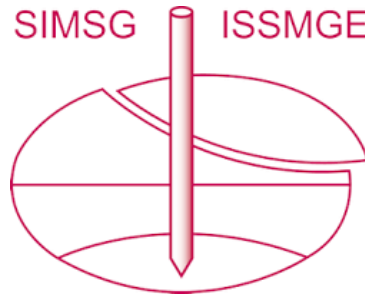
The main conclusions of the use of marginal fills are the following:

- They offer a dual benefit of reducing both the carbon footprint and project costs, making it an attractive option for sustainable and cost-effective construction projects.
- Employing a specific design approach, incorporating geogrids, enables the effective utilization of marginal fills, tailored to the unique conditions of each project.
- Initial testing is crucial to grasp the fundamental properties of the fill material, with ongoing testing during installation essential to maintain control over compaction, moisture content, and other factors.
- Project and site-specific laboratory and in-situ testing criteria should be established to address the specific requirements and challenges of each site.
- A well-planned construction program, considering the specific location and timing, is vital to optimize construction efficiency and minimize risks associated with marginal fills.
- Adequate drainage measures are imperative when using marginal fills to prevent issues related to water infiltration and drainage.
- It's essential to identify and mitigate risks associated with the use of marginal fills, ensuring that all stakeholders comprehend the limitations and associated risks.
- Reinforced Soil Structures incorporating marginal fills have demonstrated successful performance in various projects in the UK and worldwide, attesting to their reliability and effectiveness as a sustainable construction solution.

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