Sustainable and environmentally friendly reinforced soil slopes and walls constructed with draining geogrids: recent UK experience

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ABSTRACT: Research has shown that geotechnical engineers and the construction industry in general like to think of themselves as working to benefit the environment and providing for future generations in tandem, if not always in harmony, with nature. However, engineers still prefer to work with high quality and expensive imported granular fill, rather than seriously consider using recycled spoil generated as part of construction activities. Engineers can design reinforced soil structures using marginal poorly drained fills without the need to import granular fill, which has both cost and environmental implications. Marginal fills typically have high silt and/or clay contents which, when loaded, have the potential to generate excess pore water pressures in the structural backfill. Poor drainage in the structural fill reduces the available strength of the fill, thus reducing the bond between the fill and the geogrid reinforcement. Therefore, to use marginal fill efficiently, adequate drainage must be provided in the reinforced soil structure. By using a novel geocomposite that combines reinforcement and drainage into a geogrid sustainable and environmentally friendly slopes and walls can be designed and constructed. Between 2015 and 2017 an innovative design methodology and approach for the construction of reinforced slopes and walls, up to 17m in height, with low-permeability fills was successfully used in the UK. The design and construction experience gained in the UK is presented to confirm the effectiveness of the system and given engineers confidence in the use of marginal fills in reinforced soil systems.

Keywords: sustainability, drainage; geogrid; marginal fill

1 INTRODUCTION

The use of marginal fills on site can yield significant cost and environmental savings in a project. In the UK any material leaving a construction site is consisted waste and must be disposed of accordingly. This is expensive as waste is subject to a £86.10/tonne (2017 prices) landfill tax in addition to the cost of excavation and transportation of the soil. Thus, there is significant interest is utilizing material, once considered unsuitable, in site works. Low-permeability marginal fills can be used to construct reinforced slopes and walls, provided adequate drainage is provided within the reinforced fill. Without adequate drainage, excess pore water pressures would typically build up in the fill during construction. Pore water pressure reduces the internal shearing resistance of the fill, and reduces the interface shear strength between the reinforcement and the fill.

Between 2015 and 2017 several reinforced slopes and walls, up to 17m in height, were constructed in the UK using excavated marginal fill from construction activities on site. The reinforced soil structures were constructed using a system consisting of a combined reinforcement and drainage geosynthetics product, with the commercial name Maccaferri Paradrain® , and referred to herein as the draining geogrid, Maccaferri Terramesh® , the facing unit, to form the face, thus eliminating the need for a temporary shutter/formwork during construction and Maccaferri MacDrain® , a geocomposite drain, as a back drain, preventing the flow of water from the retained fill into the reinforced soil block and also removing water from the draining geogrid. A schematic of the system is shown in Figure 1. The draining geogrid was specificity designed for use with low-permeability marginal fills. In presenting the case histories emphases will be placed on the properties of the fill, the design and construction of the structures and the quality control procedures implemented on site.

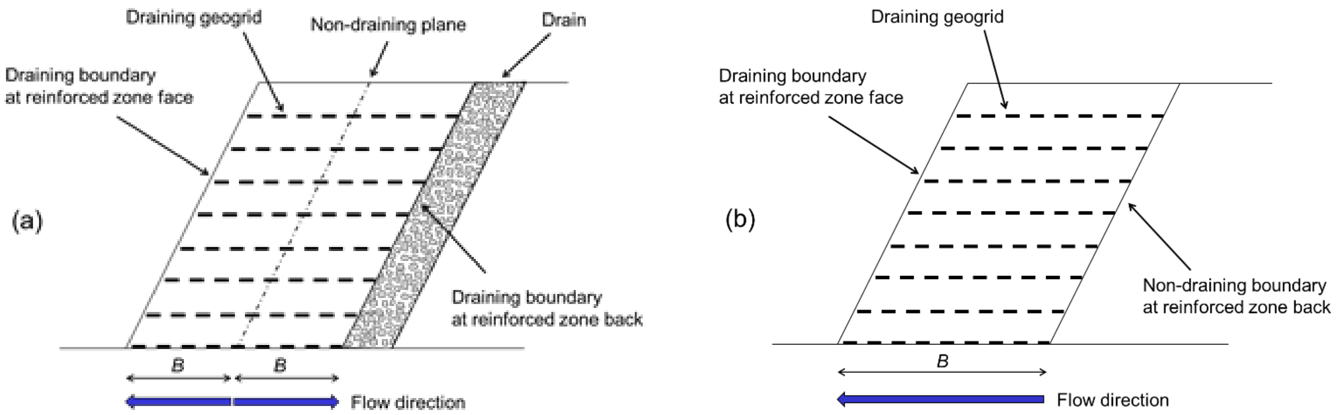

Figure 1. Schematic of reinforced soil system consisting of draining geogrid, facing unit and geocomposite back drain.

2 PROPERTIES OF THE DRAINING GEOGRID

The draining geogrid comprises longitudinal strips and lateral strips. The function of the lateral strips is to maintain the grid geometry, i.e. to ensure that the longitudinal strips remain parallel and equidistant. Each longitudinal strip provides both reinforcement and drainage. A longitudinal strip comprises two components: (i) the reinforcement component consists of high-tenacity polyester yarns encased in a durable polyethylene coating that protects the yarns; and (ii) the drainage component is a channel in the profiled polyethylene coating. The drainage channel is bridged by a thermally bonded nonwoven geotextile filter, which allows water to flow from the fill to the channel while preventing soil particles from intruding into the channel.

Giroud et al. (2014) presented a design methodology for designing reinforced slopes and walls using draining geogrids. The design methodology utilizes the consolidation properties (coefficient of volume compressibility, m_v and the coefficient of consolidation, C_v) of the marginal fill in determining the vertical spacing of the draining geogrid layers and the rate at which the slope can be constructed.

In analyzing the Giroud et al. (2014) design methodology Naughton et al. (2015) showed that constructing one-to-two layers of the slope per day was a realistic target. This is not dissimilar to the rate used for steep reinforced slopes constructed from well-draining material. Naughton et al. (2015) showed that with low-permeability fills consideration needs to be given to the maximum vertical spacing of the draining geogrid. For practical purposes, they suggested than an upper limit of 0.6 m should be employed, primarily to guard against horizontal deformations of the slope. Their analysis also showed that a vertical reinforcement spacing of 0.4 - 0.5 m optimized the time for dissipation of pore pressures while, at the same time, requiring realistic and achievable transmissivities in the draining geogrid. While intuitively lower vertical spacing may appear prudent the required transmissivity in the draining geogrid is significant and it is not realistic to manufacture draining geogrid with these large transmissivities. Furthermore, where global stability must be improved it is preferable to increase the length of the reinforcement than decrease the vertical spacing. Naughton et al. (2015) further showed that reinforced soil structures can be constructed from most low-permeability fills once careful consideration is given to the drainage properties of the fill and the geometry of the reinforcement elements, particularly the vertical spacing of the draining geogrid.

3 DESCRIPTION OF REINFORCED SOIL STRUCTURES CONSTRUCTED IN THE UK USING MARGINAL FILL

Between 2015 and 2016 several reinforced soil structures were constructed in the UK using the draining geogrid and marginal fills. The following sections give an overview of the projects, together with construction photographs. The reinforced soil structures were constructed using the system consisting of facing units, draining geogrid and geocomposite back drain. Discussion of compaction and quality control is discussed in a later section. The primary focus is on the properties of the site won fill and the design and construction of the reinforced soil structures.

Reinforced structures using the draining geogrid and marginal fills were designed using BS 8006-1 (2010) for internal stability, EN 1997 (2004) for global stability and the method presented by Giroud et al. (2014) for dissipation of excess pore pressures in the marginal fill. The time to dissipate excess pore water pressures was generally 24 – 48 hours, however on some project longer dissipation times were required, as dictated by the consolidation parameters of the fill and also earthworks operations on site. In all cases the excess pore water pressure was dissipated to 90% of its initial value after each construction sequence. In design the pore pressure ratio, r_U, was taken as 0.1 in the retained structure.

3.1 *Bell Green Retail Park, Sydenham, London, 2015*

Bell Green was a new retail park constructed in South London in 2015. All excavated materials remained on site, thus reducing the vehicle movements to and from the site and the impact on the surrounding area. The materials excavated were used to raise the levels of the site area, which was developed later. The maximum difference in levels between the toe and crest of the slope was in excess of 6m. The fill properties listed in Table 1 were used in the design of the structures.

Table 1. Properties of site won fill, Bell Green Retail Park.

Unit weight (kN/m^3)	% passing 63µm sieve	Apparent cohesion (kPa)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
16.4 – 20.1	5 -18	0	24	0.2*	12*

* assumed values

3.2 *North Gawber Colliery, Barnsley, Yorkshire, 2015*

A soil reinforcement steep slope of approximately 300m length and 4m height was built along the site boundary to create platforms for future development as part of the North Gawber Colliery regeneration. The reinforced soil structure was constructed using the colliery spoil, assumed to be Class 7D material (SHW, 2009), having the properties given in Table 2.

Table 2. Properties of site won fill, North Gawber Colliery.

Plasticity Index (%)	Optimum moisture content (%)	Maximum dry density (Mg/m^3)	% passing 63µm sieve
32	13 - 35	1.33 – 1.74	4 - 82
Unit weight (kN/m^3)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
16.4 – 20.1	25	0.2	8

3.3 *Island Road, Reading, Berkshire, 2016*

As part of a new commercial retail park development over an old waste pit reinforced soil structures were required to form a swale for attenuating and discharging storm water during storm events. The swale was created with a reinforced soil structures that varied in height from 0.8m to 3.0m. The site won fill consisted of competent site won fill material complying with a mix of Class 2A and Class 2C material (SHW, 2009). The properties of the fill are presented in Table 3.

Table 3. Properties of site won fill, Island Road, Reading.

Liquid limit (%)	Plasticity Index (%)	Unit weight (kN/m3)	Apparent cohesion (kPa)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
39 - 53	19 - 32	18.8	0	25	0.2 – 0.4	2.5 - 16

3.4 *Millbrook Park, Barnet, London, 2016*

Millbrook Park is a new housing development in north London. The reinforced soil structure, which varies in height between 3.5m and 4.7m, supports a road and was constructed with site won fill consisting of London Clay having the properties presented in Table 4. A traditional geogrid wrap-around construction technique was used to form the slope face on this project.

Table 4. Properties of site won fill, Millbrook Park, London.

Liquid limit (%)	Plasticity Index (%)	Plasticity	Unit weight (kN/m^3)	pH	% passing 63µm sieve
68 - 78	40 - 58	Clay of high to very high plasticity	18.6 – 19.4	7.9 – 10.1	42 - 56
Optimum moisture content (%)	Maximum dry density (Mg/m^3)	Apparent cohesion (kPa)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
20.5 – 22.4	1.63 – 1.69	0	26	0.2*	7*

* assumed values

3.5 *Palmerston Park, Tiverton, Devon, 2016*

Permanent reinforced soil retaining structures were required to support the access road and to retaining a bank-cutting created for a social housing development on a sloping site in Tiverton, Devon. A number of structures, varying in height from 3.3m to 17m above existing/finished ground level were constructed as part of the scheme. The reinforced soil structures were constructed from site won will consisting of clayey sandy Gravel of low to intermediate plasticity. The properties of the fill are presented in Table 5. Images of the 17m high slope both during construction and approximately 10 months later are shown in Figure 2.

Table 5. Properties of site won fill, Palmerston Park, Devon.

Liquid limit (%)	Plasticity Index (%)	Unit weight (kN/m^3)	% passing 63µm sieve
33 - 38	10 - 15	22	9 - 44
Apparent cohesion (kPa)	Angle of friction (0)	m_v (m^2/year)	C_v (m^2/MN)
0	28	0.1	57 - 73

(a) (b)

Figure 2. (a) 17m high structure during construction in October 2016 and (b) once vegetated in Summer 2017.

3.6 *M40 Noise Bund, Banbury, Oxfordshire, 2016 and 2017*

A noise bund, varying in height between 2m and 7m above existing ground level, was constructed along the M40 motorway in Oxfordshire. The bund, which was 1,300m in length, shielded a new housing development from the visual and noise generated by the motorway. The bund consisted of a 70^0 reinforced soil steep slope on the motorway side and an unreinforced 1V:3H slope on the housing side. The bund was constructed entirely from site won fill consisting of Dyrham Formation and Charmouth Mudstone (classified as Class 2A and 2B (SHW, 2009)) with the properties listed in Table 6. Figure 3 shows the placement and compaction of the fill during construction.

The M40 Noise Bund was shortlisted in the sustainability category at the Ground Engineering Awards 2017.

Table 6. Properties of site won fill, Banbury Noise Bund, Oxfordshire.

Unit weight (kN/m^3)	Optimum moisture content (%)	Maximum dry density (Mg/m^3)	Apparent cohesion (kPa)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
19.5	22.3	1.62	0	24	0.3 – 0.5	5 - 40


(a)


(b)

Figure 3. (a) Placing and (b) compacting site won fill material over the draining geogrid.

3.7 *Jenkins Lane, Barking, London, 2017*

Reinforced soil structures, varying in height between 6m and 7.6m were required as part of a commercial development as Jenkins Lane in London. The site won fill consisted of Made Ground which was generally described as a black or brown and grey clayey, silty, sandy fine to coarse angular to sub-rounded brick gravel with occasional glass, wood, ash, clinker, ceramics, plastic, waste metal, rebar, organic material, and occasional concrete and brick cobbles. Localized areas of finer grained cohesive Made Ground were also encountered. Given the varied nature of the site won fill a decision was made to only utilize fill that meet the requirement of Class 2 fill in the Specification of Highway Works (SHW, 2009), thus removing all non-soil waste from the fill. Table 7 presents the properties of the site won fill.

Table 7. Properties of site won fill, Jenkins Lane, Barking.

Liquid limit (%)	Plasticity Index (%)	Plasticity	Unit weight (kN/m^3)	pH	% passing 63μm sieve
59	27	CL	18.6	6.9 – 7.6	0 - 87
Optimum moisture content (%)	Maximum dry density (Mg/m^3)	Apparent cohesion (kPa)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
15 - 20	1.46 – 1.77	0	24	0.5*	12*

* assumed values

3.8 *North Bexhill Access Road, Phase 1 and Phase 2, East Sussex, 2016 & 2017*

The North Bexhill Access Road project is a 2.4 km single carriageway road designed to accommodate future employment land to the North of Bexhill. Reinforced soil structures were constructed from site won Tunbridge Weels Sand / Ashdown formation, which was specified as Class 2A (SHW, 2009) material of intermediate plasticity along the extremities of the road embankment. The properties of the site won fill are presented in Table 8. The embankment was partially over peat and in those location, was supported on Controlled Modulus Column; the majority of the embankment was over soft clay and directly placed on a reinforced foundation with unidirectionally high tenacity polyester based geosynthetics, Figure 4 (a).

The North Bexhill Access Road scheme received the Institution of Civil Engineers South East England Engineering Excellence Awards in 2017.

Table 8. Properties of site won fill, North Bexhill Access Road, East Sussex.

Liquid limit (%)	Plasticity Index (%)	Plasticity	Optimum moisture content (%)	Maximum dry density (Mg/m^3)
44	23	Intermediate plasticity	18	1.74
pH	Apparent cohesion (kPa)	Angle of friction (^{0})	m_v (m^2/year)	C_v (m^2/MN)
5.2	0	25.5	0.5*	12*

* assumed values

3.9 *Queensway Gateway Link, Hastings, East Sussex, 2017*

The Queensway Gateway project consists of a single lane road embankment, 300m in length and 9m high, connecting the A2690 and the A21 with an underpass tunnel pedestrian walkway and an attenuation pond. The site is underlain by the Ashdown Formation (sandstone, siltstone and mudstone). The

Wadhurst Clay Formation overlies the Ashdown Formation. Alluvial deposits are present. The draining geogrid was used as reinforcement for the embankment shallow slope with 1V:2H inclination. The engineered fill was described as stiff slightly sandy clayey Silt and had the properties listed in Table 9. Figure 4(b) shows the construction of a shallow slope at Queensway Gateway. Construction occurred during the dry Summer months and a line of damp soil, resulting from dissipation of pore water pressures in the body of the slope, was observed where each layer of the draining geogrid intersected the face of the slope.

Table 9. Properties of site won fill, Queensway Gateway, Hastings.

Liquid limit (%)	Plasticity Index (%)	Plasticity	Unit weight (kN/m^3)	Apparent cohesion (kPa)	Angle of friction (^{0})
42	20	Low	19	0	26

(a) (b)

Figure 4. (a) Uniaxial high strength geogrid placed at the bottom embankment constructed from site won fill at North Bexhill and (b) Shallow slope during construction at the Queensway Gateway Link project where the drainage geogrids are placed in layers at equidistance vertical centers; the facing element of the slope will be created using hydro seeding over an erosion geosynthetic mat.

3.10 *Control of ground water*

A geocomposite drain was place at the back of the reinforced soil block in most case studies presented here. The geocomposite had two functions. Firstly, it provides a drainage channel for water leaving the draining geogrid, thus reducing the dissipation time (Giroud et al., 2014). Secondly, the drain prevented ground water entering the reinforced block from both under and behind the structure. The use of a geocomposite drain also guards against potential long-term changes in ground water and prevents the buildup of pore pressures behind the reinforced soil block, thus improving stability over the life time of the structure.

3.11 *Compaction and quality control testing*

Marginal fills have higher fines contents, higher optimum moisture contents and lower maximum dry densities than traditional predominately granular materials. This can make compaction of marginal fills more challenging. BS 6031 (2009) states that the engineering properties of fill will differ depending on their percentage fines (passing 63μm sieve). Fill with greater than 35% fines behave as a fine-grained soil, while fills with less than 15% will behave as course-grained soil. Intermediate fills between 15% and 35% fines content, when used in shallow slopes are generally considered to behave as course-gained fills. However, when intermediate fills are used with a draining geogrid in steep slopes (where the face is between 45^0 to 70^0 from the horizontal) it is assumed that the fill will behave as a fine-grained soil.

Projects in the UK have mainly utilized well-graded granular wet, dry or stoney cohesive fill, which are classified as Class 2A, 2B and 2C under the UK Department of Transport, Specification for Highway Works (SHW, 2009). Class 2A and 2B have a grading with 100% passing 125mm, 80 - 100% passing 2mm and 15 – 100% passing 63μm and 2C fills has 100% passing 125mm, 15- 80% passing both 2mm and 63μm. These materials are normally compacted using a method specification where the layer thickness and number of passes of a particular type of compaction plant are specified (SHW, 2009). The method of compaction is such that the layer thickness and compaction plant vary from project to project.

Quality control testing of the compacted marginal fill is critically important when using marginal fill, as the archived dry density of very dependent on the moisture content. Given the varied nature of the fill and the method approach used during compaction it is important to conduct compliance testing to ensure that the minimum dry density is greater than 90% of maximum dry density. Compaction quality control testing in fine grained fills is problematic as most tests require determination of the fill moisture content, which can delay reporting of results by 1 – 2 days. Experience in the UK indicates that the nuclear density testing is a suitable proxy to moisture content related testing and this is used widely on projects constructed from marginal fill. The number of tests is taken as 1 – 2 tests per 1,000m^3 of material up to a maximum of 5 per day. This requirement is in line with recommendations by Trenter and Charles (1996) and HA 44 (1995).

4 DISCUSSION OF CASE HISTORIES

Several case histories were presented which demonstrated the effectiveness of using a draining geogrid and marginal fill in the construction of steep slopes.

The engineering characteristics of the marginal fills was found to vary significantly between projects. Angles of friction for the marginal fills were in the range 24^0 – 26^0, lower than the 30^0 conservatively used with granular fills. The consolidation characteristic of the fills also varied but the values used correspond to soils with a permeability of the order 10^{-10} m/s, corresponding to very poor draining materials. The optimum moisture content of the fills was in the range 15 – 23%. The fills were general clay of low to intermediate plasticity. Compaction was generally performed using a method specification with ongoing monitoring to ensure the design dry density was achieved. Nuclear density measurements were found to be an efficient method to confirm adequate compaction.

The length of the draining geogrid at the base of structures was found to be vary between 0.7 – 1.0 times the overall height of the structure, which is higher than that required for steep slopes constructed with good quality imported granular fill. Marginal fills with high fines content require reinforcement lengths at the base of the structure which were approximately the same as the slope height. It should be noted that the soil – reinforcement interaction values for the draining geogrid are significantly higher than those normally found between a conventional non-draining geogrid and marginal fill (O'Kelly & Naughton, 2008). Furthermore, the lower angles of friction of the marginal fill, in some cases, resulted in slightly longer reinforcement lengths to satisfy the global stability limit state. However, the advantage of using a draining geogrid is that the fill can be taken as drained, resulting in shorter reinforcement length than those expected with a conventional non-draining geogrid used to reinforce a marginal fill designed under undrained conditions.

Excess pore water pressures were designed to be dissipated to 90% of their initial value inside 24 – 48 hours, depending on the quality of the marginal full. This facilitated the construction of between 1 and 4 layers of reinforcement every 1 – 2 days. This rate of construction did not affect the construction time for any of the structures presented in this paper. No movement of deformation of the structures were observed either during construction or post-construction. This was attributed to allowing 90% dissipation of pore water pressures during each construction sequence (layers constructed in one go). The rate of construction is an important design consideration when using marginal fills and can be adjusted to optimize earthworks on site.

Quality control testing of the compacted marginal fill is of primary importance in structures of this type; as these fills generally have optimum moistures > 15% and are compacted wet of optimum. The UK Specification for Highway Works (SHW, 2009) requires that Class 2 materials, of which most marginal fill fall, are compacted using a method specification. Nuclear density testing was found to be a fast and effective method of checking compliance with the compaction specification. The frequency of testing at 1 - 2 tests per 1,000m^3 complies with UK recommended frequencies given in HA44 (1995).

5 CONCLUSIONS

Significant monetary and environmental savings can be achieved on construction projects by utilizing excavated marginal soils in earthworks, especially as the structural fill in reinforced soil structures. Concerns around the buildup of excess pore pressures in marginal fills during construction are often cited as reason not to use these soils in this application. The case histories presented in this paper have shown that a wide range of marginal fills, going from colliery spoil to made ground to high plasticity clays, when combined with a draining geogrid have been successfully used in constructing reinforced soil structures up to 17m in height.

Using a draining geogrid, where both drainage and reinforcement functions are combined into a single product, are ideally suited to these applications. Having a drainage element at each reinforcement layer immediately improves the soil – geosynthetic interaction and allows the marginal fill to be considered drained in terms of the selection of strength characteristic for use in design. The case studies presented in this paper have shown:

1. A wide range of marginal fills, with varying engineering properties, can be used as structural backfill in reinforced soil structures.
2. The engineering characteristic of marginal fills can vary significantly and are inferior to those of expensive imported granular fills. This does not however negate there use as structural backfill.
3. An adequate quality control programme must be put in place during construction. In the UK most marginal fills are Class 2 fills (SHW, 2009) and are compacted using a method statement. Marginal fills have high optimum moisture contents and are generally compacted slightly wet of optimum. Onsite quality control must ensure that the design dry density is achieved.
4. The dissipation of excess pore water pressure is time dependent. However, by careful selection of the vertical spacing of the draining geogrid the rate of construction of the reinforced soil structure can be adjusted to meet the earthworks programme on site, ensuring that a structure with marginal fill can be constructed at a similar rate to that constructed using granular fill.

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