Performance of geotextile reinforced soil wall in unsaturated poorly draining backfill soil conditions

F. H. M. Portelinha & B. S. Bueno
University of Sao Paulo, Sao Carlos, Sao Paulo, Brazil
J. G. Zornberg
University of Texas, Austin, Texas, United States

Portelinha, F.H.M., Bueno, B.S., and Zornberg, J.G. (2012). "Performance of Geotextile-Reinforced Soil Wall in Unsaturated Poorly Draining Backfill Soil Conditions." *Fifth European Geosynthetics Conference*, EuroGeo5, 16-19 September, Valencia, Spain, pp. 455-465.

ABSTRACT: The use of marginal backfills in geosynthetic stabilized earth (GSE) walls has not been recommended by different standards specifications. Restrictions are motivated by the improperly hydraulic conductivity of fine soils that are capable of developing of water pressures. However, the use of granular materials can expend the cost of the construction. As a result, local soils, granular or not, have been increasingly used. Unsaturated conditions of fine soils may result in convenient performance even using extensible reinforcements. This paper evaluates the performance of a full scale model of a nonwoven geotextile reinforced wall constructed with fine backfill. The unsaturated condition was maintained and matric suctions, displacements and reinforcement strains were monitored during the test. Results have shown that the unsaturation of the backfill allowed maximum reinforcement peak strain of 0.4 %. A convenient performance and a good agreement between measured strains and factors of safety from limit equilibrium analyses have shown the maintenance of unsaturated conditions as an economical alternative.

1 INTRODUCTION

Since reinforced soil technique began to be used in retaining walls, embankments and slopes, standard organizations have been concerned about the improperly hydraulic behavior of poorly draining backfill soils (NCMA 1997, FHWA 2010; AASHTO 2002;). The major problems are the development of positive water pressures inside the reinforced zone and reinforcement degradation in the presence of water.

In fact, the low draining capacity of fine soils can affect the reinforced soil walls performance under rainfall infiltration as reported by Yoo and Jung (2006). On the other hand, an excellent performance can be expected from these structures under unsaturated conditions due to the positive effect of matric suction on soil and interface behavior. Khoury et al. (2010) report that pullout strength of geotextiles embedded in unsaturated soils are so influenced by matric suction as shear strength of soils. Additionally, some real cases reported in the literature could confirm the strong influence of unsaturated conditions of backfill on the performance of geosynthetic reinforced soil walls (Ehrlich et al. 1997). However, the maintenance of unsaturated conditions of backfill soils is a difficult task regarding field conditions. Koerner & Soong (2001) recommend avoiding any possible water in the front, behind and beneath the reinforced zone collecting, transmitting and discharging the water. Furthermore, the top of the zone should be waterproofed, e.g., by a geomembrane or a geosynthetic clay liner, to prevent water from entering the backfill zone from the surface.

Matric suction can improve the walls performance in two aspects: increasing the soil stiffness and improving the interface shear strength behavior. Therefore, two design implications can be drawn from these aspects: a stiffer soil favors the selection of lower stiffness reinforcements, resulting in reductions of costs; and, convenient interface behavior provides a good transmission and mobilization of forces by the reinforcement. Eventually, the costs related to the maintenance of unsaturated conditions of soil may be lower than the use of high stiffness reinforcements or granular soil.

This paper describes the performance of an instrumented full scale model of a nonwoven geotextile reinforced soil wall under unsaturated conditions of backfill, in order to quantify the influence of matric suction on displacements, reinforcement strains and design predictions.

2 EXPERIMENTAL PROGRAM

2.1 *Materials*

Full scale models were constructed using clayey sand with hydraulic conductivity of $5\text{x}10^{-6}$ cm/s, with 40% passing the No. 200 sieve, and low plasticity (PI = 18%). Compaction parameters from standard Proctor tests are maximum dry unit weight of 17.8 kN/m^3 and optimum water content of 14.6%.

With the relative low hydraulic conductivity and significant percentages of fine particles, this material would be restricted by AASHTO (2002) and FHWA (1998), being classified as a poorly draining soil. Triaxial tests in unsaturated soil samples indicated cohesion of 0 kPa and friction angle of 38^o for CD conditions and, cohesion of 60 kPa and friction angle of 25^o for CU conditions, in terms of total stresses.

The reinforcement is a polyester needle-punched nonwoven geotextile made of polyester with mass per unit area of 293 g/m^2, thickness of 2.69 mm, tensile strength of 10 kN/m and strain at failure of 83% (ASTM D4595). A relatively weak and extensible geotextile was specifically selected to generate detectable strain levels.

2.2 *Full scale model construction*

Full scale walls have been constructed in the Laboratory of Geosynthetics located within the Sao Carlos School of Engineering at the University of Sao Paulo.

A metallic box allows reinforced soil wall structures to be constructed with 1.8 m height by 1.55 m width, with backfill soil extending to a distance of 1.8 m from the front edge of the metallic box. The soil was compacted at 98% of relative density and the maximum dry unit weight and optimum water content from standard Proctor tests. In order to assure the required relative density, compaction was performed manually in layers of 5 cm height. Compaction control was assured by the drive-cylinder method (ASTM D2937), spiked every compacted layer reaching 30 cm height. The backfill soil was seated on a rigid concrete foundation.

Geotextile reinforcements were placed at 30 cm vertical spacing with declivity of 1% to the face. Each layer of reinforcement had a total length of 1.80 m measured from the face. The wall was constructed with no facing batter and using the wrapped-around technique. Protective shotcrete coating varying from 5 to 8 cm was used. Drainage geocomposites were used as face drainage elements into the second and forth reinforced layers located at 30 cm from the face forward into the wall. Figure 1 presents photographs and the cross section view of the model.

2.3 *Instrumentation*

Instrumentation was deployed to record pore water pressures including negatives values (soil suction), internal horizontal displacements, reinforcement strains, and horizontal face displacements. Instruments locations are presented in Figure 2.

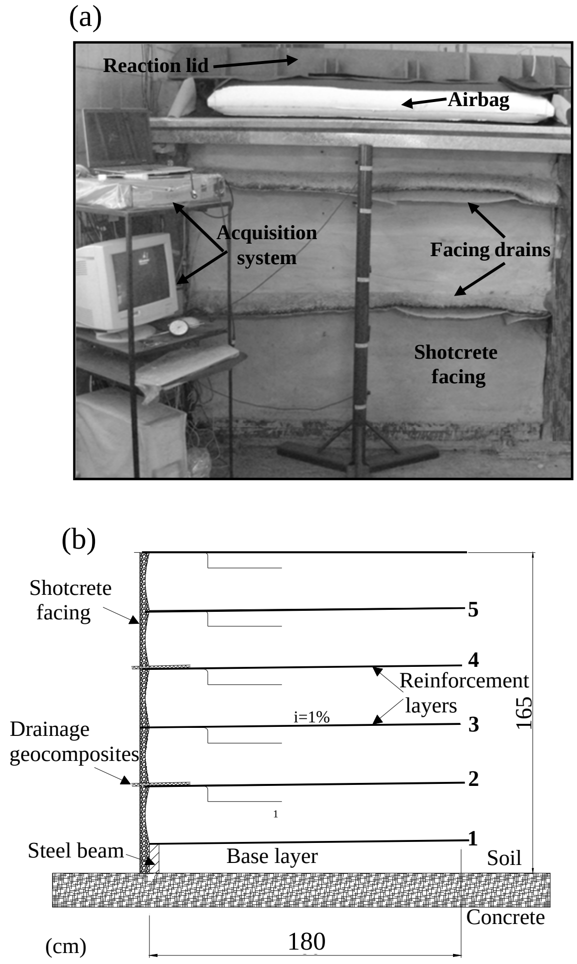

Figure 1. Geotextile reinforced wall model: (a) frontal photograph; (b)cross section.

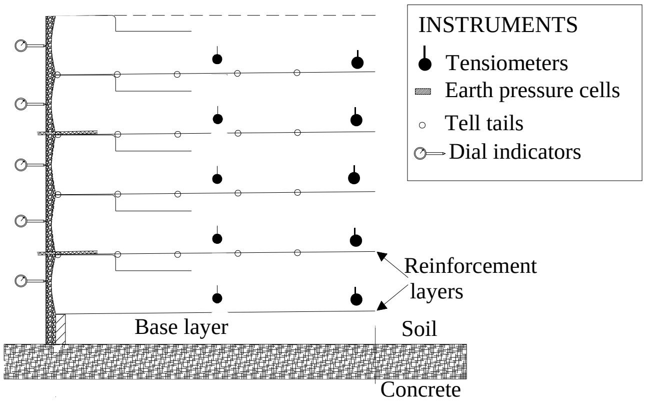

Figure 2. Instruments location.

Matric suction was monitored by tensiometers (range of -100 to 100 kPa) located in the middle of each reinforced layer at 5 cm above of the reinforcements at a distance of 80 cm and 140 cm from the face.

Internal displacements were measured by telltales. This dispositive consists of stainless steel inextensible wires, which run inside of plastic tubes used to reduce friction and to protect the wires. One end of the tell-tales is fixed to the geotextile and the opposite is connected to a small weight that is used to tension the wires and to obtain measures. Relative displacements between the weight and a reference located in a shaft behind the wall were measured during the test. Tell-tales were fixed in five points along reinforcements at 30 cm of horizontal spacing.

Other instruments were used in this research but they will not be assessed in this paper.

2.4 *Test procedure*

The test procedure consisted on the recording of instrumentation of the full scale model under uniform loading of 100 kPa Instrumentation records were registered since of the beginning of the construction during 90 days of test.

3 RESULTS

3.1 *Instrumentation results*

Figure 3 presents results from tensiometers installed at 80 cm and 140 cm from the face in each instrumented layer of the model. In general, the initial matric suctions of soil were similar for all reinforced layers and increases of matric suction were observed with time. Higher rates of matric suction increasing occurred in the lower layers, with values varying from 20 kPa to 80 kPa. In higher layers, matric suction values ranged from 20 kPa to 30 kPa.

Internal displacements measured by tell tales with time are shown in Figure 4.This Figure presents readings in points located at 0 cm, 30 cm, 60 cm, 90 cm, 120 cm and 150 cm from the face. Clearly, higher rates of displacement increases occurred as soon as the loading of 100 kPa was applied. Thereafter, small increases could be evidenced with time. In the reinforced layer 2, displacements were practically constants during the loading.

Possibly, high values of matric suction of soil during the wall life avoided reinforcement creep strains, resulting in a relatively rigid structure.

3.2 *Strains in the geotextiles*

Reinforcement strains were obtained from the relative horizontal displacements between facing and tell tales attached along the reinforcement length at different distances. The distribution of relative displacement along the reinforcement between points of measurements and wall facing in the reinforced layer 2 is presented in Figure 5. In this Figure, sigmoidal curves fitting the raw data are drawn in order to have a smooth representation of the distribution of displacements along the reinforcement length.

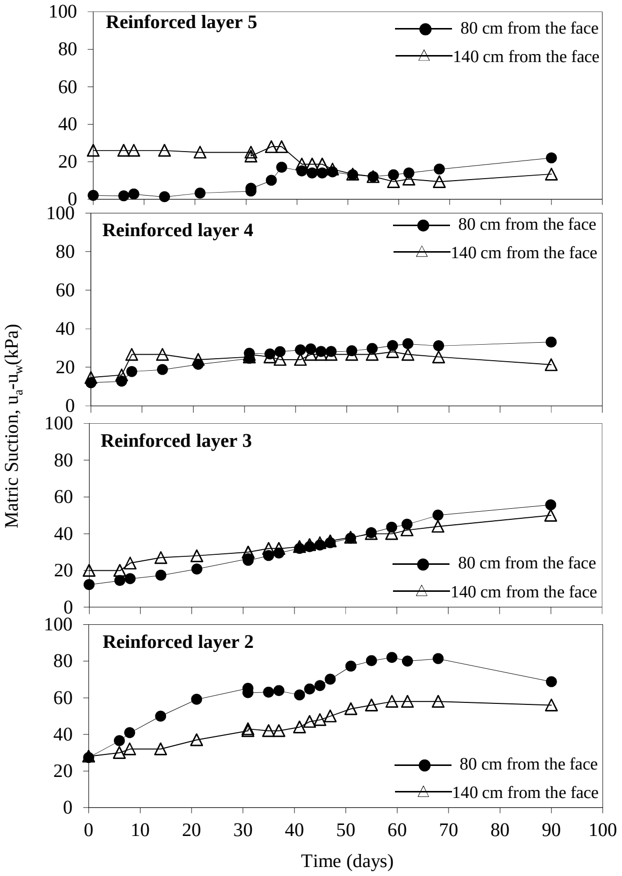

Figure 3. Matric suction measured by tensiometers with time at 80 cm and 140 cm from the face.

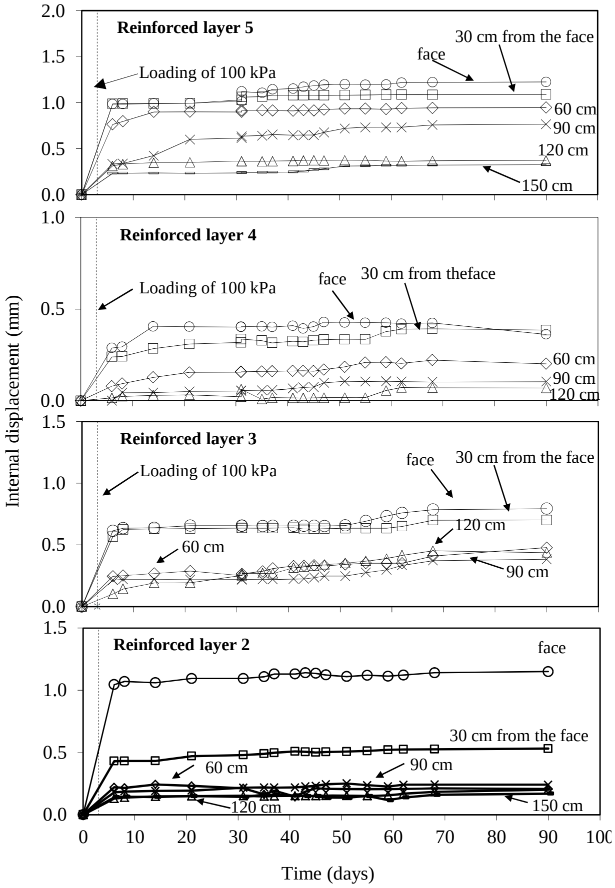

Figure 4. Internal displacements *versus* time.

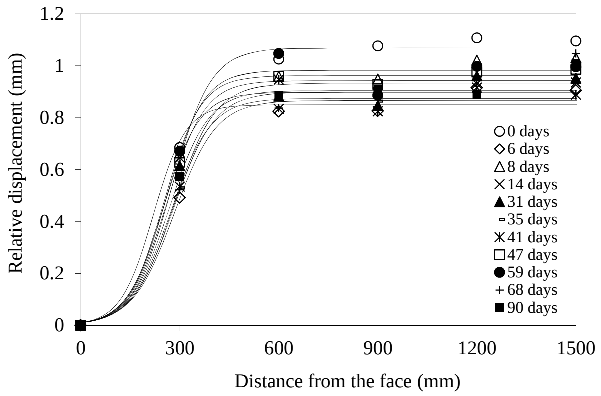

Figure 5. Distribution of relative displacements between tell tales and face along the geotextile length.

The sigmoidal fitting shown in Figure 5 was also used to evaluate the distribution of strains along the reinforcement as presented by Zornberg & Arriaga (2003). Geotextile strains values can be obtained by calculating relative movements between points of tell tales at different distance from the reference and dividing them by the initial distance between rods.

However, the use of this technique may not be efficient in this case, since the distance between measured points may be not small enough to get a real strain between points. For this reason, the raw data from tell tales was initially smoothed by fitting the data to a sigmoidal curve. Thus, the distribution of strains along the geotextile length could be obtained by deriving the displacement function as:

$$\varepsilon = d\left(-\frac{1}{a+be^{-cx}}\right)/dx \qquad (1)$$

where d is the tell-tale displacement, x is the distance from the face to the measured point, and a, b and c are parameters defined by the fitting of sigmoidal curves to the raw data using the minimum squares technique. This technique was used in a GSE field case by Zornberg et al. (1995).

The distribution of strains in each instrumented layer is showed in Figure 6. The strain levels were very small with maximum value of 0.43 % in the reinforced layer 2 and minimum value of 0.15% in the reinforced layer 4. Additionally, no relaxation or retraction of reinforcements could be observed.

A consistent distribution of strains was obtained by the derivation of a sigmoidal fitting and a Rankine failure surface seems properly fit it, assuming friction angle from CU triaxial test in unsaturated samples.

The effect of matric suction on the stiffness of soil can be a good explanation for very small strains and displacements even using extensible reinforcements as nonwoven geotextiles. Additionally, interface shear behavior is absolutely improved under unsaturated conditions (Khoury et al. 2010). Other aspect is the tensile and creep behavior of nonwoven geotextiles under confined conditions (McGown et al. 1982).

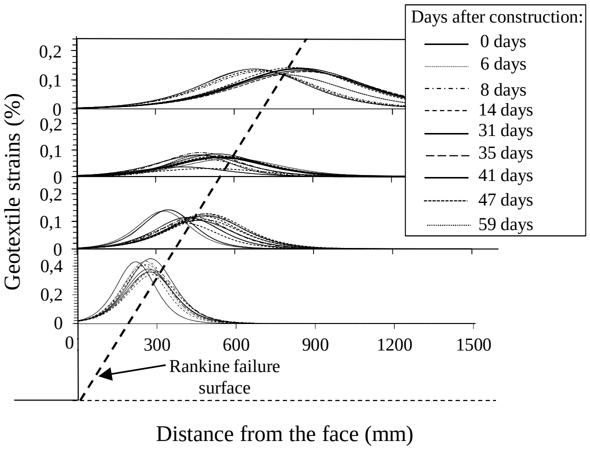

Figure 6. Distribution of strains.

3.3 Limit equilibrium analysis

Factors of safety were calculated by limit equilibrium analyses in order to compare design parameters and measured values. Limit Equilibrium analyses were conducted using the technical software UTEXAS3 from the University of Texas, by Wright (1990). This software allows analyzing slopes and walls inputting reinforcement contribution and interpolating negative pore water pressures (matric suction) in the soil.

The effect of matric suction on the factor of safety and reinforcement peak strains can be better understood in the Figure 7, where the factor of safety and reinforcement peak strains are plotted as function of the average of matric suction measured by all the tensiometers installed in the model. From this plot, the factors of safety increased linearly with matric suction and a better stability could be noted with the time.

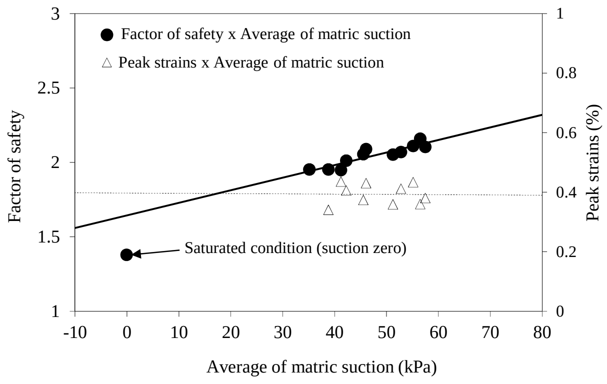

Figure 7. Limit equilibrium analyses: effect of matric suction on factors of safety and reinforcement peak strains.

No significant changes in measured values of peak strains with matric suction could be evidenced, and significantly small levels of strains were noticed. Therefore, small forces were mobilized by reinforcement, and, possibly, this structure would be stable even without reinforcements. In this case, reinforcements perform purely the constructability function.

Figure 8 summarizes the slip surfaces obtained from limit equilibrium analyses inputting matric suction values. This analysis was conducted in order to compare failure surface location from measured peak strains and predicted slip surface.

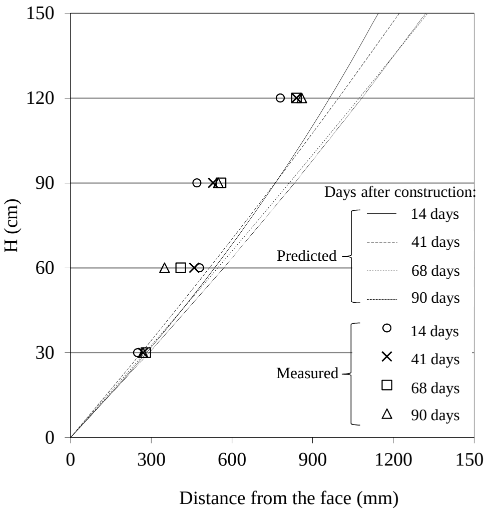

Figure 8. Slip surfaces from equilibrium limit analyses in different times.

Rankine failure surface (Fig. 6) showed better agreement than a circular slip surface from limit equilibrium analyses, even though factors of safety using Rankine stress state are much more conservative. Additionally, no influence of matric suction was observed on potential slip surface shapes, neither on failure surfaces from measured strains.

4 CONCLUSIONS

The following conclusions can be drawn from the analysis of the data collected as part of this investigation:

- Significantly small internal displacements and reinforcement strains illustrated the positive effect of matric suction on the wall's performance.
- Although the matric suction increased with the time, no reinforcement retraction was observed. Still, no changes on peak strains with time were noted. Thus, creep strains were canceled by the soil matric suction.
- Limit equilibrium analyses have shown the increase of factor of safety with matric suction. The relationship between reinforcement peak strains with increasing of factor of safety was horizontally linear, which means no changes of strains with matric suction.
- Small forces were mobilized by reinforcement, and, possibly, this structure would be stable even without reinforcements. In this case, reinforcements perform purely the constructability function.

Therefore, the structure have proved to work significantly well under unsaturated condition due to the increase of soil stiffness. As a result, small forces are transmitted to the reinforcements and low strength material can be adopted. Restriction of wetting front by means of drainage system and/or water barriers, and the use of unsaturated poorly draining soils, can be an economical alternative for retaining walls or reinforced slopes.

5 REFERENCES

American Association of State Highway and Transportation Officials (AASHTO), 2002. Standard Specifications for Highway Bridges, seventeenth ed., Washington, DC, USA.

Ehrlich, M., Vidal, D., Carvalho, P. A., 1997. Performance of Two Geotextile Reinforced Soil Slopes. Proceedings of International Symposium on Recent Developments in Soil and Pavement Mechanics, 415-420.

Federal Highway Administration (FHWA), Elias, V., Christopher, B.R., 2010. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines. FHWA-SA-96-071, Washington, DC, September, 371pp.

Khoury, C. N., Miller, G. A., Hatami, K., 2010. Unsaturated Soil-Geotextile Interface Behavior. Geotextile and Geomembranes, 29, 17-28.

Koerner, R. M. and Soong, T. Y., 2001. Geosynthetic reinforced segmental retaining walls. Geotextiles and Geomembranes, 19(6), 359-386.

McGown, A., Andrawes, K. Z., Kabir, M. H., 1982. Load-extension testing of geotextiles confined in-soil. Proceedings of International Conference on Geotextiles, 1982, Las Vegas, Estados Unidos, 793-798.

Wright, S.G., 1990. UTEXAS3 A computer program for slope stability analyses calculation. Shinoak Software, Austin, Texas.

Yoo, C., Jung, H. Y., 2006. Case History of Geosynthetic Reinforced Segmental Retaining Wall Failure. Journal of Geotechnical and Geoenvironmental Engineering, ASCE 132 (12), 1538–1548.

Zornberg, J.G., Arriaga, F., 2003. Strain distribution within Geosynthetic- reinforced slopes. Journal of Geotechnical and Geoenvironmental Engineering, 129 (1), 32 – 34.

Zornberg, J. G., Christopher, B. R., Mitchell, J. K., 1995. Performance of a geotextile reinforced slope using decomposed granite as backfill material. Proceedings of Second Brazilan Simposium on Geosynthetics applications, São Paulo, 19-29.

Designing with Marginal Fills: Understanding and Practice

J. Raja, N. Dixon & M. Frost
Loughborough University, Loughborough, United Kingdom

I. Fraser
Tensar International Ltd, Blackburn, United Kingdom

G. Fowmes
Waste Recycling Group Ltd, Northampton, United Kingdom

ABSTRACT: Some of the most sustainable and economical benefits of using geosynthetics are found in reinforcement applications. These applications allow the use of lower quality on-site material such as fine grained soils often referred to as ‘marginal fills’. This paper identifies the state of practice and understanding of designing with these soils in applications such as embankments, slopes and retaining walls. Designers often rely on published guidance documents and the paper discusses the influence BS 8006 (2010) has on the use of ‘marginal fills’ in construction and how the need for clearer more specific guidance. The study highlights that often well compacted fine grained fills placed close to optimum moisture content generate suctions, and this results in relatively high strength interaction between the fill and geosynthetic reinforcement. In cases where a fine grained fill with high moisture content is used, geosynthetic reinforcement that provides in-plane drainage may be beneficial.

1 INTRODUCTION

In the context of this paper marginal fills are defined as lower quality, poor draining, cohesive fills with a high content of fines and often possessing low mechanical characteristics, such as low shear strength. With marginal fills often being easily available and providing both economic and sustainable benefits they are becoming a popular alternative to high quality granular fill. However there are still some uncertainties in the use and designs using these materials. This paper aims to investigate these further. There are a number of different applications in which marginal fills can be applied and this paper focuses on backfill/fill applications such as embankments/slopes and reinforced walls. The reasoning behind this is that often it is in these applications where the design and use of marginal fills lacks clarity. The main areas of the paper relate to:

- Developing an understanding of the function of geosynthetic reinforcement and the design process.
- Understanding the current design principles and processes when applying marginal fills.
- Reviewing the guidance material provided particularly in BS 8006 (2010) to see whether there is a lack of clarity around fill material selection.

The paper aims to clarify the use of marginal fills when combined with geosynthetics and identify any factors that may be limiting their use. It will also consider ways in which these factors could be addressed.

2 REINFORCEMENT WITH GEOSYNTHETICS

2.1 *Introduction*

When a geosynthetic is combined with soil to provide the function of reinforcement the soil is then referred to as ‘Reinforced soil’. ‘Reinforced soil’ has improved mechanical characteristics such as increased tensile and compressive strengths In general when a geosynthetic is used to reinforce a geotechnical structure its main task is to resist applied stresses or to prevent unacceptable deformations.

2.2 *Design Processes*

The literature reviewed presents a number of different design processes and methods. Although there are differences in the approaches and no uniformly agreed method, all the methods do however require the same general design parameters. Also all the methods show a high level of importance on the soil-geosynthetic interaction characteristics. The properties of the backfill being employed ultimately govern the stability of the structure. The majority of design methods being used are for good quality fills such as free draining granular fill, with only a few methods considering the effects of cohesive soils. There is a lack of clarity in the design process and analysis for these fine grained fills.

2.3 *Materials*

Geosynthetics most commonly employed in reinforcement applications are geogrids, geotextiles and geocomposites. Each of these geosynthetic products can provide a variety of strength and drainage properties, dependant on their manufacturing technique. Geogrids can be woven or extruded and allow drainage in the normal direction via high permeability through their apertures that are filled with soil. They provide very little lateral drainage in the plane of the geosynthetic and therefore can be considered to be impermeable in that direction.

Geotextiles used as reinforcement can provide some lateral drainage. The degree of in plane transmissivity depends on whether they are woven or non-woven and on the confining stress, with non-woven geotextiles having a higher transmissivity. For the purpose of this paper, because of their low transmissivity, woven geogrids and geotextiles can be considered to be impermeable reinforcement in the plane of the geosynthetic.

3 APPLICATION OF MARGINAL FILLS

3.1 *Introduction*

Use of marginal backfills has proven economical and environmental benefits, hence there are strong reasons for increased use. With proven benefits the question arises however as to why they are not being used more widely? The engineering properties of marginal fills can create concern for designers.

With a number of different design methods for traditional backfills and ambiguity on which design method is most suitable, this situation is not any clearer for marginal backfills. However there is a substantial body of evidence of applications where marginal backfills have been applied successfully. Also, with research and technological advances in the type of geosynthetics being available, the less favorable soil mechanical properties may be balanced using more technical geosynthetic products.

3.2 *Excess Pore Water Pressures*

There has been significant research carried out in order to recognise the problems behind the application of marginal/cohesive fills and to provide a possible solution. One of the biggest challenges relates to poor drainage capabilities when utilising wet materials.

A noteworthy piece of research was carried out by Rowe & Jones (2000) who looked at the innovative properties of geosynthetics. They focus on the issue of wet cohesive fills and the problems that arise with their use, such as low strength, high moisture content, creep and low bond strength between the reinforcement and the soil. Marginal/cohesive fills have high fines content and early research showed that the relative volume of the fine grained portion of the fill controlled the shear strength of the reinforced soil (Schlosser & Long, 1974). Soils classed as marginal/cohesive can have a wide range of different properties, with those marginal fills with lower fines content having increased shear strength properties compared to those with a higher fines content. This means that certain categories of marginal fills may be suitable for specific applications.

A number of trials/case studies have been carried out with the use of impermeable reinforcement to understand the interaction between the reinforcement and wet cohesive soils. Research by Murray & Boden (1979), Ingold (1979) and Lee (1976) led to the conclusions that the insertion of impermeable reinforcements in a clay fill can lead to excess pore water pressures at the soil-reinforcement interface. This is claimed to cause a reduction in the soil-reinforcement bond and reduces the overall strength of the structure in the short term (Rowe & Jones, 2000). A conclusion is that if there was a method of reducing or eliminating the excess pore water pressures, this would result in more stable structures. This led to the concept of including a permeable reinforcement element which may also act as a drainage layer.

It should be noted that many reinforced soil structures and earthworks have been successfully constructed utilising cohesive fills at near optimum moisture content and reinforcements which are defined in this paper as impermeable.

Use of marginal fills and applications as backfills in reinforced soil structures, has been researched by Mitchell & Zornberg (1995). Their work also recognises the problems surrounding pore water pressure generation and the inclusion of permeable reinforcing elements. Mitchell & Zornberg (1995) discuss an experiment carried out by the Transport and Road Research Laboratory (TRRL), U.K. This was used to investigate the feasibility of wet cohesive fills, by constructing a full-scale experimental reinforced wall. The construction and instrumentation used is described by Boden et al. (1978). The pore water pressures were measured during construction of the embankment and the tests showed the generation of high construction excess pore water pressure.

High excess pore water pressure can have a number of undesired effects on cohesive soils. The clay minerals within the soils can often attract and absorb water leading to the soil swelling in volume. This increase in soil pore pressure and volume could lead to large deformations, reduction in shear strength and possible failure. Seasonal changes in moisture content through wetting and drying can cause significant volume changes and reduction in shear strength via a progressive failure mechanism.

The use of a reinforcing element that also enables drainage may allow control of pore water pressures through dissipation of excess pore water pressures. The reinforcing material can be permeable in the normal direction, which will allow the passage of water from the soil to that below, but more significant is the requirement for in plane drainage capacity as this reduces drainage path lengths and speeds up dissipation of excess pore pressures (Rowe & Jones, 2000). This approach of promoting lateral drainage in combination with soil reinforcement is also considered by Christopher et al. (1998). Christopher et al. (1998) provide complete design guidance for reinforced soil structures with wet marginal backfills. In this paper Christopher et al. (1998) state three adverse conditions of pore water pressure generation and/or loss of strength due to wetting, that can be of concern when reinforcing marginal/poor draining backfills. The three conditions are (see Figure 1):

a) Generation of pore water pressures within the reinforced fill
b) Wetting front advancing into the reinforced fill
c) Seepage configuration established within the reinforced fill

Christopher et al. (1998) suggest that the use of permeable reinforcements could be employed to control the three conditions mentioned. The use of permeable reinforcement does not just address stability problems but can have significant construction benefits, by helping in the compaction of the fill (Indraratna et al., 1991). An example of a particular permeable reinforcement is a nonwoven geotextile. Although a suitable nonwoven geotextile has good drainage characteristics, tests on the development of soil-reinforcement bond (Smith et al. 1979) show that nonwoven geotextiles do not have high strength or in-plane stiffness. The solution could be to combine existing materials to form a composite, for example a nonwoven geotextile with a geogrid.

The creation of a composite material that has both drainage and reinforcement functions is considered a possible solution to designing with wet marginal fills. Work by Heshmati (1993) studied the effects of combining a drainage material with a geogrid in wet clay soil. He concluded that the drainage and reinforcement functions were both as important as each other in producing a stable structure.

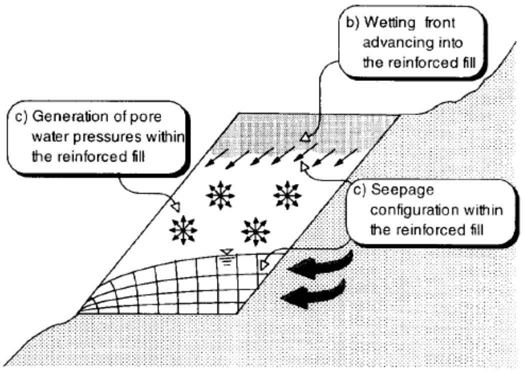

Figure 1. Reinforced marginal fill: Different conditions of concern (Christopher et al., 1998)

3.3 *Is there a need for a Composite Material?*

It is clear that significant research has been carried out in to the drainage properties of marginal/cohesive fills. The research shows that in order to utilise wet marginal fills there is need for a geosynthetic that provides both drainage and reinforcement functions. However although this may be true for cases of fill with high moisture content, many reinforced structures utilising marginal/cohesive fills have been constructed with the use of impermeable reinforcements.

The work carried out by Rowe & Jones (2000), Christopher et al. (1998), by Murray & Boden (1979), Ingold (1979) Lee (1976) and others (Section 3.2) focuses on the issue of excess pore water pressures. This is one of the main reasons a permeable reinforcement may be suggested, in order to dissipate these high excess pore water pressures. However a number of studies have shown that for reinforced structures constructed of cohesive fills compacted close to optimum moisture content, the pore water pressure is negative following compaction.

Dobie (2010) discusses a study by Farrar (1978) which presents pore water pressure data from a highway embankment constructed using compacted London Clay. The fill was constructed over an 18 month period and pore water pressure measurements were taken straight after construction, two years and four years later. The results (Figure 2) showed that the upper 8m of the fill remained in suction and positive pore water pressures were recorded below this level. This helps to add to the conclusions made by Dobie (2010) that a well compacted clay fill is likely to be in a state of suction up to sizeable depths. Pore water pressures only become positive at the base of fills higher than 10 to 15m. This is however dependent on the moisture content at placement, with lower suctions achieved if the clay is placed at moisture contents wet of optimum.

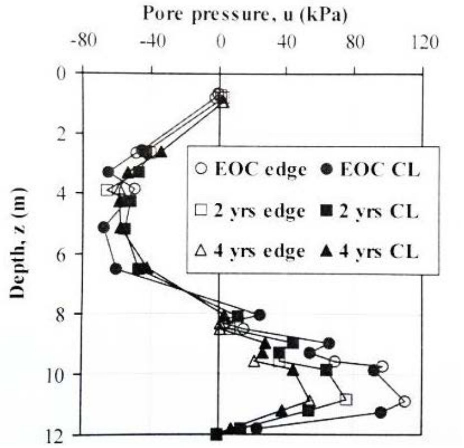

Figure 2. Profile of pore pressure versus depth in London Clay highway embankment (Dobie, 2010)

The conclusions made by Dobie (2010) and the findings from work carried out by Farrar (1978), Penman (1978) and Liu et al (1994) indicate that in many cases high excess pore water pressure are not generated, rather the reinforced structure is in a state of suction, or negative pore water pressure. This means that the use of a composite drainage-reinforcement geosynthetic would be unnecessary and uneconomical. The more economical and practical solution would be to employ impermeable reinforcements, with other commonly used drainage methods, such as surface drains and mineral drains at the base of the fill, to control the availability and ingress of water that may result in loss of the suctions and softening of the clay over time.

In cases where the fill is very wet or high structures are constructed (greater than 15m) in-plane drainage may be of benefit. In these cases a composite material or a combination of geosynthetics providing both drainage and reinforcement may be beneficial.

3.4 *Deformation and Limit State Design*

One of the biggest challenges associated with the use of marginal fills to build reinforced structures is the anticipated increase in horizontal and vertical deformations. These deformations can occur both during and after the construction phase, with ‘high fines’ soils more likely to deform than granular fills. Christopher & Stulgis (2005) highlight several issues that may arise from increased deformation that should be considered in the design:

- Maintaining wall alignment during and after construction
- The possible deformation of supported structures
- Down drag on the back of facing units and connections
- Increased risk of tension cracks

In order to control the short and long term deformations it is important to understand and control moisture in the soil. As Christopher & Stulgis (2005) mention, fine-gained soils placed a few percent dry of optimum often strain-soften and therefore lose strength. This leads to higher deformations and a loss in soil/ reinforcement bond strength. Long term movement in dry fine-grained soils is also possible from hydro-compaction. Fine-grained soils placed wet of optimum will consolidate and thus deform over time. It is very difficult to predict the level and amount of deformation even for structures with good quality backfill, so with marginal ‘high fines’ backfill the situation is no clearer. As Mitchell & Zornberg (1995) state, horizontal displacement depends on a number of different factors which include compaction efforts, reinforcement and facing properties.

The use of a permeable geosynthetic may help to address the drainage issues related to marginal backfills and in turn speed up the consolidation process. However drainage does not change the magnitude of deformations. Care should be taken as incorrect use could provide a path for water to enter the structure.

It is worth considering however the application of the structure when designing for deformation. Certain applications such as an embankment that is not supporting any loads may have a higher serviceability limit state, hence higher than normal deformations may not be a concern. Dealing with each application on an individual basis will allow more designs to be carried out with serviceability limit state in mind, in particular those applications where high deformations may not be critical or lead to failure.

4 DESIGN DOCUMENTATION

4.1 *Introduction*

On an international level there is a range of different guidelines and standards employed in the design of reinforced soil structures. In the UK British Standards BS 8006(2010) is referred to for guidance. In order to completely understand the use of marginal fills and how they are accounted for, it is important to assess relevant guidance in currently available standards.

4.2 *BS 8006:1-2010*

BS 8006(2010) is the code of practice for strengthened / reinforced soils and other fills. The document goes in to detail into on design methods for reinforced structures as well as the testing procedures and stability checks.

BS 8006(2010) provides detailed guidance notes for an experienced user or designer. It is more than adequate for a designer/engineer using standard fills and working on a common application. However as mentioned previously one of the biggest benefits of reinforcement via geosynthetics is that it allows the use of poorer quality site material. Not only does this have cost benefits but considerable sustainability gains. The reduction in virgin material required as well as less transport of new/waste material leads to significant carbon footprint reductions. The problem is that this document leaves a lot of uncertainty with respects to use of marginal fill materials, leading designers/engineers to use conservative approaches, implying there would be a risk employing a geosynthetic solution using marginal fills, and hence encouraging more 'traditional' solutions or use of high quality granular fill materials. One example of this is found in BS 8006(2010) clause 3.1.3.2., where it is stated that 'General cohesive fill' as defined in the Specification for Highway Works (1) should not be used in the construction of reinforced soil walls or abutments and may be used with caution in steep slopes. With marginal fills often being classed as cohesive fills, this statement is potentially prohibiting the use of marginal fills and encouraging unsustainable and uneconomical design solutions.

More work and testing needs to be carried out in order to gain data on the interaction of geosynthetics with a range of materials. This testing and experimentation should then allow the BS 8006(2010) to class materials based on their mechanical characteristics and physical properties. This could lead to the creation of a framework, which would allow fills that are currently considered marginal to be used for specific applications, thus increasing their utilisation. This would help to reduce uncertainty and ambiguity, and allow designers to obtain the mechanical characteristics of their onsite material, and assess whether it is suitable for use with geosynthetics.

5 CONCLUSION

A review of the literature has presented some valuable findings and has clarified uncertainties surrounding the design and use of marginal fills. Although use of marginal fills provides proven sustainable and economical benefits they are still seldom utilised. Some key conclusions can be made from this review

The design process and methods are not simple or straight forward. There are a number of different design methods available, with no uniformly agreed process. The design methods also produce a wide range of variability in the results of analyses. With few methods incorporating the use of low quality fills such as fine grained soils.

The use of marginal fills has been the topic of extensive research. This has shown that poor drainage characteristics of a wet marginal fill can provide hindrance to its use. One possible suggested way of overcoming this problem is by including a permeable reinforcement. The permeable reinforcement may help to provide drainage in both the normal and lateral directions. In order to fulfill both the drainage and reinforcement functions, a composite product may be used. The use of such a composite material or permeable reinforcement may however be unnecessary in many applications. Studies have shown that in many instances a clay fill compacted close to optimum moisture content can produce a reinforced structure that contains significant suctions (negative pore water pressure). In these cases, reinforcement defined as 'impermeable' in this paper in combination with adequate drainage such as surface and toe drains would be appropriate. The need and requirement for a composite material or geosynthetic with in-plane drainage would only be in cases where fine grained soils with high moisture content are used as fill.

The problems faced by the use of marginal fills are also highlighted in BS 8006(2010) with certain clauses prohibiting their use. There seems to be a very strict approach to the mechanical characteristic of the fills that can be used. It may be argued that in some cases the standards are employing over-cautious guidelines. With the standards being very strict on the range of fill materials that can be used, this reduces the number of potential applications.

This study has helped to identify that marginal fills could be utilised to a much higher degree. Previous work and research has helped to justify this conclusion. However further work needs to be carried out to clarify ambiguities in the design methods and selection of fills. Collating data from tests and previous work could help to develop a database of acceptable fill materials, which could be used as a reference table for engineers and designers. In order to improve the use of marginal fills, sections within guidelines such as the British Standards should be created focusing on the specific engineering properties for a wide range of reinforcement applications. It could be concluded that overall the state of understanding in the topic is good, but the state of practice is lagging behind and the authors encourage practitioners to consider the utilization of marginal fills whenever commercially and/or environmentally beneficial.

6 REFERENCES

Boardman, D.I., 2000. Investigation of the consolidation and pullout resistance characteristics of the Paradrain geotextile. Geotechnical research report, Newcastle University, pp.75.

BS8006-1:2010. Code of practice for strengthened/reinforced soils and other fills

Christopher, B.R., Zornberg, J.G., & Mitchell, J.K., 1998. Design Guidance for Reinforced Soil Structures with Marginal Soil Backfills. *Proceedings of the Sixth International Conference on Geosynthetics*, Atlanta, Georgia, March 1998, Vol. 2, pp. 797-804.

Christopher, B.R. & Stulgis, R.P., 2005. Low Permeable Backfill Soils in Geosynthetic Reinforced Soil Walls: State-of-Practice in North America. *Proceedings of GRI 19 Las Vegas*, NV, December 2005.

Dobie, M., 2010. Practical use of clay fills in reinforced soil structures. *Development of Geotechnical Engineering in Civil Works and Geo-Environment*, Yogyakarta, December 2003

Farrar, D.M., 1978. Settlement and pore-water pressure dissipation within an embankment built of London Clay. *In Institution of Civil Engineers, Clay fills*: 101-106, 14-15 November 1978: ICE, London.

Heshmati, S., 1993. The action of geotextiles in providing combined drainage and reinforcement to cohesive soil. PhD Thesis, University of Newcastle upon Tyne.

Indraratna, B., Satkunaseelan, K.S. & Rasul, M.G., 1991. Laboratory Properties of a Soft Marine Clay Reinforced with Woven and Nonwoven Geotextiles. *Geotechnical Testing Journal*, ASTM, Vol. 14, No. 3, pp. 288-295.

Ingold, T.S., 1979. Reinforced clay - a preliminary study using the triaxial apparatus. *Proc. Int. Conf. On Soil Mechanics and Foundation Engineering,* Brighton

Lee, K .L., 1976. Reinforced earth - an old idea in a new setting. *Int. Symp. New Horizons in Construction Materials*, Envo. Pub. Co., Pennsylvania, Vol.1.

Liu, Y., Scott J.D. & Sego, D.C. 1994. Geogrid reinforced clay slopes in a test embankment. *Geosynthetics International*, Vol 1, No 1, 67-91, Industrial Fabrics Association International, USA, January 1994.

Mitchell, J.K. & Zornberg, J.G., 1995. Reinforced Soil Structures with Poorly Draining Backfills. Part II: Case Histories and Applications. *Geosynthetics International*, Vol. 2, No. 1, pp. 265-307.

Murray, R.T. and Boden, B., 1979. Reinforced earth wall constructed with cohesive fill. *Proc. Int. Conf. On Soil Reinforcement*, Paris: 565-577

Penman, A.D.M. 1978. Construction pore pressures in two earth dams. *In Institution of Civil Engineers, Clay fills:* 177-188, 14-15 November 1978: ICE, London.

Rowe, R.K. & Jones, C.J.F.P., 2000. Geosynthetics:Innovative materials and rational design. Proceedings of the International Conference on Geological and Geotechnical Engineering, GeoEngineering 2000, Vol. 1, Melbourne, Australia, pp. 1124–1156.

Schlosser, F. & Long., 1974. Recent results in French research on reinforced earth. *Journal of the Construction Division*, ASCE, Sept.: 223-237.

Smith, M.S., Bell, A.L. & Du Bois, D.D., 1979. Embankment construction from marginal material. *Proc .Int. Conf. on Soil Reinforcement*, Paris.