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Worldwide Applications of Geosynthetics Reinforced Walls for Soil Reinforcement

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ABSTRACT

Geosynthetics have become well established construction materials for geotechnical applications in most parts of the world. Because they constitute manufactured materials, new products and applications are developed on a routine basis to provide solutions to routine and critical problems alike. Results from recent research and from monitoring of instrumented structures throughout the years have led to new design methods for different applications of geosynthetics. Because of the significant breath of geosynthetics applications, this paper focuses on recent advances on geosynthetics products, applications and design methodologies for reinforced soil using geosynthetics reinforced walls.

KEYWORDS: Geotechnical engineering, Geosynthetics, Reinforced walls, Soil reinforcement, Staged construction, Facing units.

INTRODUCTION

Geosynthetics have been increasingly used in geotechnical and environmental engineering for the past 4 decades. Over the years, these products have helped designers and contractors to solve several types of engineering problems, where the use of conventional construction materials would be restricted or considerably more expensive. There are a significant number of geosynthetic types and geosynthetic applications in geotechnical and environmental engineering. Due to space limitations, this paper will examine the advances on the use of these materials in reinforcement and in environmental protection.

Common types of geosynthetics used for soil reinforcement include: geotextiles (particularly woven geotextiles), geogrids and geocells. Geotextiles (Figure 1, Bathurst, 2007) are continuous sheets of woven, nonwoven, knitted or stitch-bonded fibers or yarns. The sheets are flexible and permeable and generally have the appearance of a fabric. Geogrids have a uniformly distributed array of apertures between their longitudinal and transverse elements. These apertures allow direct contact between soil particles on either side of the sheet. Geocells are relatively thick, three-dimensional networks constructed from strips of polymeric sheet. The strips are joined together to form interconnected cells that are infilled with soil and sometimes with concrete. In some cases, 0.5 m to 1 m wide strips of polyolefin geogrids have been linked together with vertical polymeric rods used to form deep geocell layers called geomattresses.

A wide variety of geosynthetics products can be

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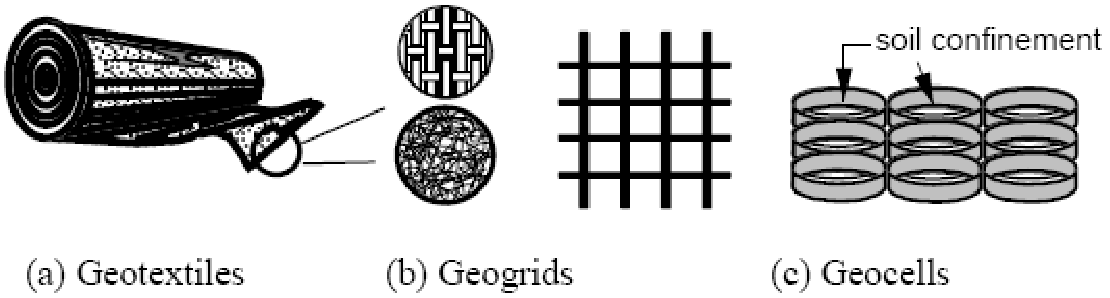
used in environmental protection projects, including geomembranes, Geosynthetic Clay Liners (GCL), geonets, geocomposites and geopipes. Geomembranes are continuous flexible sheets manufactured from one or more synthetic materials. They are relatively impermeable and are used as liners for fluid or gas containment and as vapour barriers. Geosynthetic Clay Liners (GCLs) are geocomposites that are prefabricated with a bentonite clay layer, typically incorporated between a top and a bottom geotextile layer or bonded to a geomembrane or a single layer of geotextile. When hydrated, they are effective as a barrier for liquid or gas and are commonly used in landfill liner applications, often in conjunction with a geomembrane. Geonets are open grid-like materials formed by two sets of coarse, parallel, extruded polymeric strands intersecting at a constant acute angle. The network forms a sheet with in-plane porosity that is used to carry relatively large fluid or gas flows. Geocomposites are geosynthetics made from a combination of two or more geosynthetic types. Examples include: geotextile-geonet; geotextile-geogrid; geonet-geomembrane; or a Geosynthetic Clay Liner (GCL). Geopipes are perforated or solid-wall polymeric pipes used for drainage of liquids or gas (including leachate or gas collection in landfill applications). In some cases, the perforated pipe is wrapped with a geotextile filter.

Because geosynthetics are manufactured materials, technological developments of the polymer and engineering plastics industries have been continuously incorporated in geosynthetics products, enhancing relevant engineering properties of these materials. Research results have also led to the development of new and more powerful design and construction methods using geosynthetics. The combination of improved materials and design methods has made it possible for engineers to face challenges and to build structures under conditions that had been unthinkable in the past. This paper describes worldwide recent advances on geosynthetics and on the applications of these materials in soil reinforcement projects.



(a) Geotextiles (b) Geogrids (c) Geocells

Figure 1: Geosynthetics commonly used for soil reinforcement (Bathurst, 2007)

OBJECTIVE

The main objective of this paper is to demonstrate the state of the art worldwide applications of geosynthetics reinforced walls for soil reinforcement. The benefits of collecting information regarding these applications would enable the geotechnical and designer engineers to maximize land use in areas that often have both difficult topographic characteristics as well as difficult soil conditions.

BACKGROUND ON DEVELOPMENTS IN GEOSYNTHETICS MATERIALS, TYPES AND APPLICATIONS

The axiom that there is nothing new under the sun regarding geosynthetics is simultaneously true and totally false. The truth is that the geotechnical problems that engineers use geosynthetics to solve are timeless: erosion, slope failure, poor bearing capacity… etc. The products used to solve these problems could also be described as timeless, as they derive from textile manufacturing techniques that date into antiquity. The falseness of this premise is revealed by the incremental advancements in the creation of geosynthetic solutions in the form of both product and geotechnical design. But what are the areas of incremental improvement in soil reinforcement? As the following capsules illustrate, there is no end in sight for innovative applications of geosynthetics.

For example, there are many developments in Mechanically Stabilized Earth (MSE) walls and slopes and in basal stabilization. The MSE concept is essentially a uniaxial force problem and is served by the insertion of tensile members the principal strength of which is uniaxial, and that property is oriented to the expected forces of failure in the design. In 1993, a textile geogrid was employed using an ultra high strength polymer (the aramid known as Kevlar) to construct a road over karst terrain as shown in Figure 2. In 2001, a 15 meter wide sinkhole opened under the road which remained intact for more than one hour against a specification time of 15 minutes. Another textile geogrid application technology advance is the development of construction techniques that permit bridge abutments to be constructed, where the sill beam rests directly on the GRS (Geosynthetic Reinforced Soil) block, while the GRS does not require a stiffening facing (Alexiew, 2008). Textile geogrid reinforcement techniques are combined with other geosynthetic systems to build steep slopes on columns and piles, over geosynthetic encased stone columns and in piled embankments (Brokemper et al., 2006). Textile geogrid constructions mitigate landslides and debris flow and withstand storm surge exposure in a working platform. Yet another polymer, PVA, works in textile grid applications to withstand high alkali environments and especially the combination of lime and cement stabilizers and PVA grids in cohesive soils, where there appears to be a synergistic effect resulting in higher strength and higher resistance to pullout failure (Aydogmus et al., 2007).

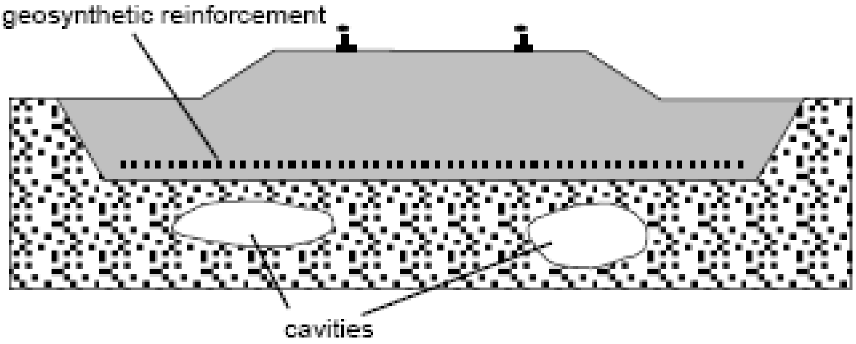


Figure 2: Reinforced embankment on unstable foundation soil

Rigid grids have also experienced innovation with the development of new punching patterns that yield triangular shaped apertures after the stretching process. The new shape has several benefits in the product profile, rib thickness and in plane stiffness, and this three dimensional structure is expected to offer improvement in confinement, which will yield improved rut resistance and better load distribution (Tensar International, 2008).

WORLDWIDE ADVANCES IN SOIL REINFORCEMENT USING GEOSYNTHETICS

Advances in Soil Reinforcement in Asia

Construction of Geosynthetics-Reinforced Soil Retaining Walls (GRS RW's) and geosynthetics reinforced steep slopes of embankments has become popular in Asia (e.g., Japan, Korea, China, Taiwan, Vietnam, Thailand, Singapore, Malaysia and India), following pioneering works in Europe and North America.

Geosynthetics-Reinforced Soil Retaining Wall (GRS RW) having a stage-constructed Full-Height Rigid (FHR) facing is now the standard retaining wall construction technology for railways in Japan (Tatsuoka et al., 1997; Tatsuoka et al., 2007). This new type GRS RW has been constructed in more than 600 sites in Japan, and the total wall length is now more than 100 km as of March 2008. Very importantly, despite that railway engineers are generally very conservative in the structure design in civil engineering practice, the railway engineers in Japan have accepted this new type of retaining wall, and this has become the standard retaining wall construction method for railways, including bullet trains.

This new retaining wall system has the following features:

- The use of a Full-Height Rigid (FHR) facing that is cast-in-place using staged construction procedures (Figure 3). The Geosynthetics reinforcement layers are firmly connected to the back of the facing. The importance of this connection for the wall stability is illustrated in Figure 4.
- The use of a polymer geogrid reinforcement for cohesionless backfill to ensure good interlocking with the backfill, and the use of a composite of non-woven and woven geotextiles for nearly saturated cohesive soils to facilitate both drainage and tensile reinforcement of the backfill, which makes possible the use of low-quality on-site soil as the backfill, if necessary.
- The use of a relatively short reinforcement.

The staged construction method, which is one of the main features of this RW system, consists of the following steps: 1) a small foundation element for the facing is constructed; 2) a fullheight GRS wall with wrapped-around wall face is constructed by placing gravel-filled bags at the shoulder of each soil layer; and 3) a thin (i.e., 30 cm or more in thickness) and lightly steel-reinforced concrete facing (i.e., an FHR facing) is constructed by cast-in-place fresh concrete directly on the wall face after the major part of ultimate deformation of the backfill and the subsoil layer beneath the wall has taken place. A good connection can be made between the RC facing and the main body of the wall by placing fresh concrete directly on the geogrid-covered wall face.

The major structural feature of this new retaining wall is as follows. A conventional retaining wall type is basically a cantilever structure that resists the active earth pressure from the unreinforced backfill by the moment and lateral thrust force activated at its base. Therefore, large internal moment and shear force are mobilized inside the facing structure, while large overturning moment and lateral thrust force develop at the base of the wall structure. A large stress concentration may develop at and immediately behind the toe on the base of the wall structure, which makes necessary the use of a pile foundation in usual cases. Relatively large earth pressure, similar to the active earth pressure activated on the conventional retaining wall, may also be activated on the back of the FHR facing of GRS RW, because of high connection strength between the reinforcement and the facing. This high earth pressure results in high confining pressures in the backfill which will result in high stiffness and strength of the backfill. This will result in a better performance than in the case without a firm connection between the reinforcement and the facing. As the FHR facing behaves as a continuous beam supported at a large number of points with a small span, typically 30 cm, only small forces are activated inside the facing, resulting in a simple facing structure and insignificant overturning moment and lateral thrust forces activated at the bottom of the facing, which makes the use of a pile foundation in usual cases unnecessary.

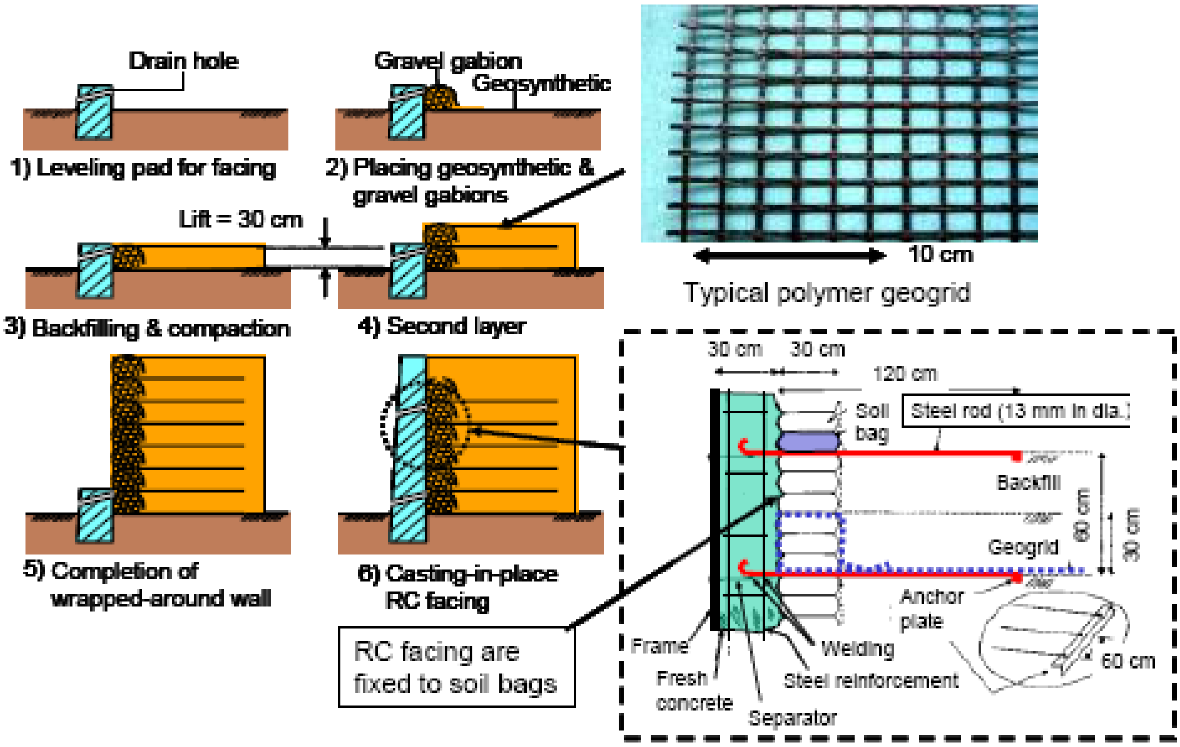


Figure 3: Staged construction of a GRW RW with an FHR facing

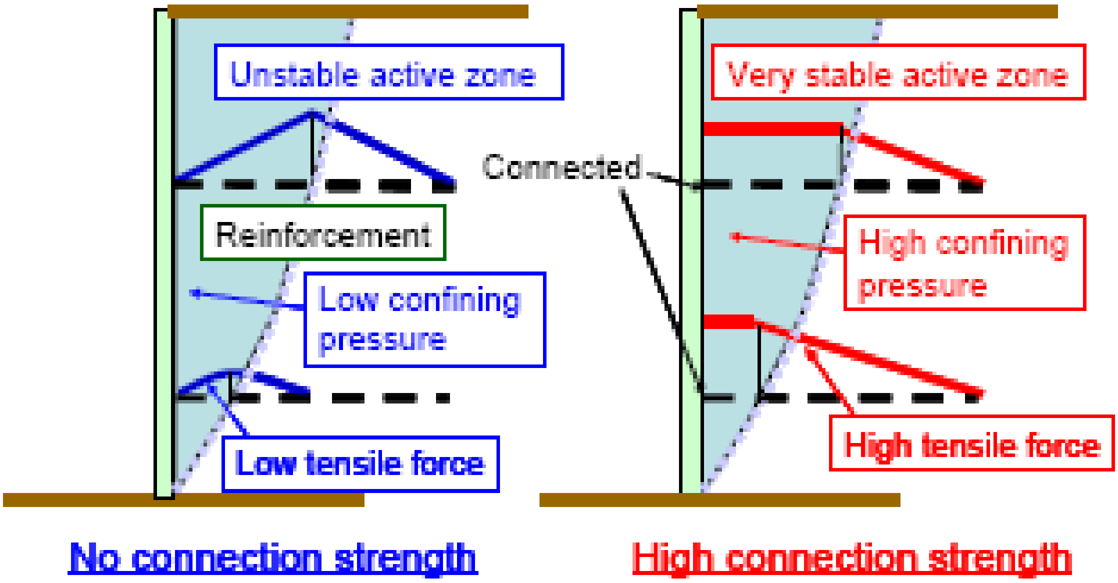


Figure 4: Effects of firm connection between the reinforcement and the facing (Tatsuoka, 1993)

A significant number of case histories until today have shown that the construction of GRS RW having a stage-constructed FHR facing is very cost-effective (i.e., a much lower construction cost, a much higher construction speed and the use of much lighter construction machines), therefore a much less total emission of CO_2 than in the construction of conventional types of retaining walls. Yet, the performance of the new type of retaining wall can be equivalent to, or even better than, that of conventional type soil retaining walls. The general trend of construction of elevated transportation structures in Japan is a gradual shifting from gentle-sloped embankments towards embankments supported with retaining walls (usually RC cantilever RWs with a pile foundation), or RC framed structures for higher ones, and then towards GRS RWs having a stage-constructed FHR facing. It is expected that this new retaining wall technology is adopted and becomes popular in not only other countries than Japan in Asia but also in many other countries outside Asia.

Advances in Soil Reinforcement in North America

This section is focused on developments in North America related to Geosynthetics Reinforced Soil (GRS) walls. In North America, the current common approach for the design and analysis of geosynthetics reinforced soil walls is the AASHTO (AASHTO, 2002) Simplified Method. The approach is based on limit-equilibrium of a "tied-back wedge" for internal stability, and its origins can be traced back to the early 1970's (Allen and Holtz, 1991; Berg, 1998). The same Allowable Stress Design (ASD) approach is proposed in the Canadian Foundation Engineering Manual (Canadian Geotechnical Society, 2006) which is an important guidance document for geotechnical engineers in Canada. For segmental retaining walls constructed with discrete dry-stacked module concrete facing units, the most important reference is the guidance document published by the National Concrete Masonry Association. Nevertheless, this growth has been largest in the private sector compared to state, province and federal funded-projects. The experience of the writers is that specifications for backfill and modular facing components tend to be stricter for government projects, and there continue to be reservations in some jurisdictions regarding the durability of dry cast masonry modular facing units in harsh (freeze-thaw) environments.

Many suppliers of segmental retaining walls components (facing units and/or reinforcement materials) have developed computer design aids to facilitate design. However, generic programs are also available. Program SRWall 3.22 is a full implementation of the NCMA manual for static load environments and the seismic supplement for earthquake design of this class of structure. Program MSWE 3.0 (Leshchinsky, 2006) allows the engineer to design complex geometries for geosynthetics reinforced soil walls using AASHTO (2002) for ASD, AASHTO (2007) for LRFD design and the NCMA (ASD) method.

A brief summary of developments related to geosynthetics reinforced soil wall technology and practice in North America is as follows:

Cohesive-frictional soil backfills: The use of cohesive-frictional soils as a cheaper alternative to "select" granular fills continues to grow. This is in part due to increasing confidence as more projects are completed using these soils, and the recognition that materials with a large fines content can be used as the backfill provided that adequate attention is paid to compaction control during construction and good drainage practice is carried out, particularly at the backfill surface. Nevertheless, the use of these materials is largely restricted to private sector projects. A summary of recent experimental walls that have been monitored after being constructed with c-ϕ soils appears in the papers by Miyata and Bathurst (Miyata and Bathurst, 2007) and Bathurst et al. (2008).

Facing units**:** A very large number of proprietary masonry concrete units are available on the market today. The units vary in size and may be hollow or solid. They have a range of facing appearances and include concrete shear keys, pins or clips for alignment and in some cases for layer shear transfer. However, the use of larger modular block facing units formed from unreinforced wet-cast concrete is growing. The concrete is typically return concrete from wet concrete batch plants. These modular units are often 1 m^3 or larger. Most are solid with concrete shear keys, but some systems are hollow to reduce the mass of concrete. The attraction of these systems to designers is that they are very stable and help ensure a durable facing with good long-term facing alignment. A recent novel development that has appeared in the market place is a product that uses plastic molded shapes to entirely replace the concrete in conventional systems. The units lock together between courses and the interior components filled with granular soil. A range of different facing appearances is achieved by using different (patterned or textured) thin plastic panels that snap on to the internal molded unit.

Figure 5 illustrates the three construction steps that have been implemented in North America as a state of the art technology and practice.

Figure 5: Construction steps of geosynthetics reinforced walls in North America: A) Geosynthetics modular "block" unit components; B) Construction of GRS wall with geosynthetics modular "block" units; and C) Completed bridge abutment

CONCLUSION

Geosynthetics have great potential to be used as cost-effective solutions for several engineering problems. This paper presented recent advances in geosynthetic products, on the utilization of these materials in reinforced soil structures. Manufacturing of geosynthetic products allows incorporating recent advances in material sciences. Therefore, the expectation is that innovations in products, types and properties will continue to take place, adding to the already vast range of applications of these materials.

Geosynthetics reinforced soil retaining walls present better performance than traditional retaining walls under dynamic loadings, and this has been demonstrated by a number of case histories of prototype structures that have withstood severe earthquakes. Thus, this type of structure can be cost-effective, not only under static loading, but also in regions where significant seismic activities are expected. New construction methodologies have also broadened the applications of geosynthetics reinforced soil retaining walls which include new facing units, and that reduces the construction time and costs in addition to allowing better aesthetic conditions for the final structure.

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