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Geosynthetic solutions for geotechnical problems associated with approaches to bridges and flyovers

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ABSTRACT: Geotechnical engineering problems involved in the design and construction of approach embankments of bridges and grade separators are summarized. An overview of geosynthetics and their applications in bridge approaches is given. Geosynthetic solutions for embankments on poor ground viz. basal reinforcement, prefabricated vertical drains and load transfer platforms are described. Applications of geosynthetics in slope face reinforcement, slope erosion control and reinforced soil walls and slopes are presented. The evaluation of long-term design strength and durability of geosynthetic reinforcement for permanent structures is discussed.

1 INTRODUCTION

In the case of most bridge and flyover projects, the approaches are often considered to be a minor element of the project in terms of cost as well as the engineering challenges involved in design and construction. It is not uncommon to find that the approach embankment which is constructed of *earth* or *dirt* is not considered to be a *structure* at all. Hence, a proactive attempt to employ sound engineering principles for the design, specification and construction of approaches is often lacking. From the point of view of the user, a satisfactory approach to the structure is also very important and hence it is very essential that all relevant aspects of the approaches are carefully evaluated and suitable remedial measures designed to ensure the safety and serviceability of the approach throughout the design life of the structure. In this context, engineers can take advantage of geosynthetics to solve diverse problems associated with approach embankments.

2 GEOTECHNICAL PROBLEMS IN APPROACHES

2.1 *Embankments on poor ground*

Embankments founded on poor ground like saturated fine-grained soft clays and silts with low shear strength and high compressibility may fail by lateral sliding, rotational failure, foundation extrusion, bearing failure or excessive settlement. Solutions for increasing the stability of embankments include – Stage construction, flattening of side slopes, stability berms, using light-weight fills, stone columns, lime or lime-cement columns, vibro-concrete columns, preloading, vertical drains etc. Geosynthetic solutions include basal reinforcement, prefabricated vertical drains, load transfer platforms, geosynthetically encased stone columns, geofoam etc.

2.2 *Surficial stability of embankment slopes*

In the case of embankments with reasonably flat side slopes constructed on firm ground, critical failure surfaces are shallow. The reasons for this are manifold. Firstly, the shear strength of most soils is derived entirely from friction and it can be shown that for soils without effective cohesion, the minimum factor safety in an effective slope stability analysis is obtained for shallow slip surfaces. Secondly, soils at the edge of the embankment may not be compacted to high densities unless proper care is taken during construction. Thirdly environmental influences which weaken the soil – increase in water content due to precipitation, drying cracks etc. are greatest near the surface. Fourthly, progressive effects of severe erosion can culminate in shallow slips. The surficial stability of embankment slopes are greatly enhanced by slope face reinforcement (secondary reinforcement) with geosynthetics.

2.3 *Soil erosion*

Soil erosion is the removal of soil by water, wind or ice. In most geographical regions rainfall is the principal agency of soil erosion. The kinetic energy of rain drop impact dislodges and moves the soil particles, which are carried by the surface runoff. As soil particles are removed and transported by the runoff, small channels known as *rills* form, some of which become larger and deeper *gullies*. The higher velocity and greater depth of flow in the rills and gullies provide the energy required for transporting soil particles. Excessive erosion can initiate shallow slip failures and also undermine the pavement. Measures to control erosion include a properly designed surface drainage system, soil stabilization, vegetation, riprap, gabions etc. Geosynthetic products for erosion control applications include rolled erosion control products and geocells.

2.4 *Right of way restrictions*

Where site conditions permit, it is usually economical to construct an embankment with safe side slopes, typically 1v:2h to 1v:1.5h for ordinary fills. When this is not possible because of various reasons like problems in land acquisition, need to provide service roads, existence of structures or other objects which cannot be shifted etc., it becomes necessary to provide retaining walls. Geosynthetic reinforced soil walls proven and economic alternative to conventional plain and reinforced concrete retaining walls. When some additional land is available a reinforced soil steep slope could be the ideal solution.

3 GEOSYNTHETICS AN OVERIEW

3.1 *Geosynthetics – products and functions*

Geosynthetics are planar polymeric materials (synthetic or natural) used in contact with soil/rock and/or any other geotechnical material in civil engineering applications. The term encompasses a wide variety of products – geotextiles, geogrids, geomembranes, geonets, geomats, geocells, geocomposites, geostrips, geofoam etc. Depending on their properties, geosynthetics perform different functions – separation, filtration, fluid transmission, reinforcement, protection, containment, barrier and surficial erosion control. These versatile products enable innovative, safe, durable, economical and easy to construct solutions in diverse areas like roads, railways, airports, ports, mines, power plants, residential, commercial and industrial development, waste management, coastal protection, river training and bank protection, erosion control etc.

3.2 *A brief history of geosynthetics*

The historical development of geosynthetics has been summarized by Koerner &Welsh (1980), Rankilor (1981) and Koerner (1998). Herein only some of the major developments are listed, just to show that although geosynthetics are relatively new in comparison to many of the other important materials used by civil engineers, they do have a credible record of satisfactory service in diverse areas of civil engineering. Starting in the late 1950s, woven filter fabrics were used an alternative to granular filters in erosion control applications – behind precast concrete sea walls, under precast concrete erosion control blocks, beneath large stone riprap etc. In the late 1960s use of nonwoven needle punched fabrics was initiated in France, in unpaved roads, below railroad ballast, within embankments and earth dams etc., where the emphasis was on the separation and/or reinforcement functions. Geogrids were first made in the United Kingdom in the late 1970s/early 1980s by punching holes in a polymeric sheet and then drawing the sheet in one or both directions to orient the polymeric chains resulting in a stiff monolithic grid. In the early 1980s flexible textile-like geogrids were developed by weaving high tenacity polyester filament yarns into a grid and then coating the ribs with a protective polymer. The first band drain or pre-fabricated vertical drain was developed by Walter Kjellman of Sweden in the late 1930s. It had a cardboard core and a paper filter jacket. Geodrain, a PVD with a plastic core and a kraft paper filter jacket was introduced in the early 1970s.

3.3 *Applications of geosynthetics in bridge approaches*

Most of the geotechnical problems associated with bridge approaches can be solved using geosynthetics. Some of the important applications are listed in table 1. In relation to other techniques, geosynthetic solutions may be broadly classified into three groups:

- Techniques which are a direct alternative to existing methods like pre-fabricated vertical drains which are a replacement for sand drains, load transfer platforms which are like flexible pile caps, reinforced soil retain-

ing walls in place of plain or reinforced cement concrete retaining walls, geotextiles as a substitute for granular filters etc.
- Techniques which enhances the performance of conventional methods, e.g., Turf reinforcement mats which reinforces the root zone of vegetation thereby considerably enhancing the effectiveness of the vegetative cover to resist erosion.
- Techniques which do not have a corresponding precedent in the earlier practice, but can be considered as an alternative to conventional methods, e.g., basal reinforcement of embankments as an alternative to stone columns, reinforced slopes as a replacement to a retaining wall with back slope.

Table 1. Applications of geosynthetics in bridge approaches

Application	Technique	Products
Embankments on soft ground	Basal reinforcement	High strength woven geotextiles
		Geogrids
	Acceleration of consolidation	Pre-fabricated vertical drains
	Load transfer platforms	Geogrids
		Woven geotextiles
Surficial slope stability	Slope face soil reinforcement	Geogrids
		Woven geotextiles
		Reinforced non-woven composites
Embankment slope erosion control	Vegetation	Synthetic/natural mulch control netting
		Synthetic/natural open weave geotextiles
		Synthetic/natural erosion control blankets
		Synthetic turf reinforcement mats
	Soil confinement	Geocells
Earth retention	Reinforced soil retaining walls	Geogrids
		Woven geotextiles
		Reinforced non-woven composites
		Geostrips
	Reinforced soil steep slopes	Geogrids
		Woven geotextiles
		Reinforced non-woven composites

4 GEOSYNTHETIC SOLUTIONS FOR EMBANKMENTS ON SOFT GROUND

4.1 *Basal reinforcement of embankments*

4.1.1 *Failure modes for basal reinforced embankments on poor foundations*

The modes of collapse of basally reinforced embankments on poor foundations are shown in figure 1. Loss of serviceability can occur due to excessive settlement and also excessive strains in the reinforcement.

4.1.2 *Design*

Design procedures for basal reinforced embankments on poor ground are available in BS 8006 (1995), Jewell (1996), Holtz et al. (1998). A comprehensive review of the behavior of reinforced basal reinforced embankments has been presented by Rowe & Li (2004). The objectives of design are to ensure that the various ultimate and serviceability limit states are not reached during the design life of the embankment.

4.1.3 *Properties of reinforcement*

The different modes of failure for the basal reinforcement are – failure by rupture, failure in bond and failure by excessive strain. Consequently the requirements to be satisfied by the reinforcement are:
- The reinforcement should have adequate long-term design strength. The long-term design strength is calculated by applying reduction factors to the characteristic short-term tensile strength
- The reinforcement should develop sufficient bond with the soil so as to prevent the sliding of the embankment along the surface of the reinforcement or pullout of the reinforcement.
- The strains developed in the reinforcement should not exceed predetermined values derived from serviceability limit state considerations. BS 8006 : 1995 recommends that as a general guide maximum strain in the basal reinforcement should not exceed 5% for short-term and 5 to 10 % in the long-term.

To meet the above requirement, a product with high tensile strength, low elongation and low creep is required. The preferred products are high strength woven polyester geotextiles or high strength polyester geogr-

geogrids. Since for embankments the length is much greater than the width, reinforcement is required only in the direction perpendicular to the longitudinal axis of the embankment. Hence, reinforcement needs to have high strengths only in the longitudinal direction, with a minimum strength in the transverse direction. Currently products with tensile strength as high as 1000 kN/m are available in the market.

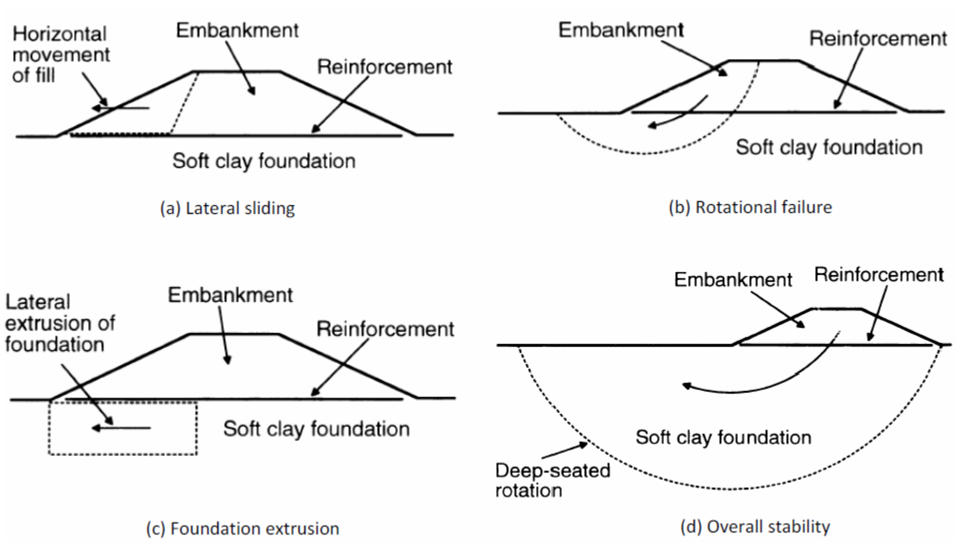

Figure 1. Modes of collapse of basal reinforced embankment on poor ground (after BS 8006:1995)

4.2 *Prefabricated vertical drains*

4.2.1 *Objectives and applications of prefabricated vertical drains*

Approach embankments on soft and compressible deposits of clay may undergo large amount of settlement, most of which is due to the consolidation of the clay. Due to the very low permeability of the clay, bulk of the consolidation settlement occurs after the construction is over. Earthen embankments are flexible structures which can tolerate reasonably large settlements. However, the structural integrity and serviceability of the pavements supported on the embankment could be affected by large post construction settlements. An equally important concern is the stability of the embankment. Where the foundation soils are too weak to support the embankment, one possible solution is to construct the embankment in stages. However, because of the very slow rate of consolidation and corresponding strength gain, this technique may not be practically viable in many projects because of time constraints.

One of the most popular and economic solutions to the above problems is to install band drains or prefabricated vertical drains (PVDs) in the compressible clay stratum, which may be combined with some surcharge loading (preloading) in some cases. Band drains or PVDs comprise a polymer core and a nonwoven geotextile filter jacket. The core is typically 100 mm wide and 3 to 6 mm thick and may be an extruded profile of corrugated or fin type, studded or a thermally bonded assemblage of extruded monofilaments.

PVDs accelerates the consolidation process in three ways:

- When PVDs are installed at a close spacing, the length of the drainage path (the distance a particle of water has to travel to reach a drainage boundary) is shortened.
- The primary direction of flow within the soil is horizontally towards the PVDs. Most deposits of soil has some kind of horizontal stratification with higher permeability in the direction parallel to the stratification than in a direction perpendicular to the stratification.
- In the case of soils with relatively thin but highly pervious seams, large amount of flow occurs through the seams.

The objectives of using PVDs are twofold. Firstly, to minimize post construction settlements of the embankments so that there is no adverse effects on the pavements. Secondly, to accelerate the rate of increase of shear strength, so that where stage construction techniques are adopted, the waiting periods between the stages can be reduced drastically and the project can be completed within a much shorter time.

4.2.2 *Design*

The basic objective of design is to ensure that the specified degree of consolidation (which is usually 90 %) is achieved within the stipulated time. The primary variables involved are the characteristics of the drain, the spacing and the depth. Design methods for PVDs are based on the theory of radial consolidation which was originally developed for vertical sand drains by Barron (1948). Barron's work was modified by Hansbo (1979) to be applicable for band shaped drains and to include considerations of disturbance and drain resistance effects. One of the important assumptions made here was to assign an equivalent diameter for the band drain (which has a rectangular cross-section) which is defined as the diameter of a circular drain which has the same theoretical radial drainage performance as the bad-shaped drain.

4.2.3 *Properties of PVDs*

The function of the core is to transmit the water entering through the filter jacket to the drainage boundaries. Therefore the most important property of the core is its discharge capacity. It should be noted that as the clay stratum consolidates and settles, the PVD also would undergo considerable deformation. The core should retain its integrity and continuity and the required discharge capacity even in the deformed/buckled state. The major functions of the filter jacket is to prevent the intrusion of soil into the flow channels of the core, to serve as a filter which allows water to enter the core while minimizing the passage of fines. Usually a non-woven geotextile with adequate stiffness and high permeability is used as filter jacket. The PVD should also have adequate strength to withstand the stresses during installation and also have sufficient flexibility to deform without rupture and loss of continuity during service. The service life of PVDs are usually short – of the order of a few months to one/two years and hence durability of PVDs manufactured from polymeric materials is not normally a concern in most cases.

5 SLOPE FACE REINFORCEMENT

Slope face stability is often a problem with approach embankments slopes and the reasons for this have already been described in section 2.2. One of the techniques to improve the stability of slope faces is to provide slope face reinforcement or secondary reinforcement. A suitable geotextile or geogrid of 1.0 m to 1.5 m length is placed at a vertical spacing of 200 to 500 mm along the edge of the slope. The tensile strength of the reinforcement is not very important, however the product should have adequate strength to survive the installation process. In most cases, it is not necessary to conduct a slope stability analysis for this kind of application.

The geosynthetic reinforcement provides confinement to the fill at the edge of the embankment, thereby serving as compaction aid ensuring proper compaction of the soil. The reinforcement also intercepts potential shallow slip surfaces.

6 GEOSYNTHETICS FOR SLOPE EROSION CONTROL

6.1 *Geosynthetic enhanced vegetation*

Vegetation is one of the most commonly used, economic and eco-friendly methods for the protection of embankment slopes from erosion. However, there are many situations where ordinary vegetation may not be sufficient to provide satisfactory levels of protection. The performance and durability of vegetation can be considerably enhanced by the use of geosynthetic erosion control products. In applications where the products are required to function only till the vegetation is fully established, biodegradable materials like jute or coir are preferred. Alternately, photodegradable (not stabilized against ultraviolet radiation) synthetic materials are also used.

The functions of these products may include one or more of the following:

- Protect the slope surface from the impact of rain drops, especially during the initial period till vegetation is fully established
- To hold the biodegradable mulch in place
- To act as a series of tiny check dams to reduce the velocity and erosive power of the surface runoff.
- To promote higher density of root growth
- To reinforce the root zone of the vegetation

6.2 *Rolled erosion control products*

In the late 1960s, faced with the limitations of conventional mulching techniques, manufacturers initiated the development of what has become a diverse group of products known as rolled erosion control products (RECPs). Various prefabricated products supplied in a roll form include mulch control nets, open weave geotextiles, erosion control blankets and turf reinforcement mats.

Mulch control netting is a planar woven natural fibre or extruded geosynthetic mesh used as a temporary degradable RECP to anchor loose fibre mulches. These are rolled out over the seeded and mulched areas and stapled or staked in place. Open weave geotextile is a temporary degradable RECP composed of processed natural or polymer yarns woven into a matrix, used to provide erosion control and facilitate vegetation establishment. The closely woven construction of these materials enables them to provide erosion control with or without the use of an underlying loose mulch layer.

Erosion control blanket is a temporary degradable RECP composed of processed natural or polymer fibers mechanically, structurally or chemically bound together to form a continuous matrix to provide erosion control and facilitate vegetation establishment. The most widely used erosion control blankets are made from straw, wood excelsior, coconut, polypropylene or a combination thereof stitched or glued together or into/between biaxially oriented process nettings or woven natural fiber nettings. These materials, some available with seed pre-incorporated into their structures, are rolled out in intimate contact with the soil surface and anchored with staples, stakes and / or anchor trenches. ECBs are applicable on sites requiring greater, more durable and / or longer lasting erosion protection. Since these degradable materials are designed to provide temporary erosion protection, they generally are limited to areas where natural, unreinforced vegetation alone will provide long-term soil stabilization.

Turf reinforcement mat is a long-term non-degradable RECP composed of UV stabilized, nondegradable, synthetics fibers, filaments, nettings and / or wire mesh processed into three dimensional reinforcement matrices designed for permanent and critical hydraulic applications where design discharges exert velocities and shear stresses that exceed the limits of mature, natural vegetation. Vegetation reinforced with TRMs has become an acceptable, cost effective and environmentally friendly alternative of proven performance to rock riprap and other forms of non vegetative lining materials. TRMs are often used in situations where the "green" alternative is preferred to hard armor.

6.3 *Geocells*

Geocells are defined as a three-dimensional, permeable, polymeric (synthetic or natural) honeycomb or web structure, made of strips of geotextiles, geogrids or geomembranes linked alternatingly and used in contact with soil/rock and/or any other geotechnical material in civil engineering applications. The concept of cellular confinement of soils was first experimented by US Army Corps of Engineers in the late 1970s. Today a large range of products are available in the market with different cell areas and heights, with perforated or non-perforated cell walls and in different colours for various applications. Geocells can be filled with different materials depending on site conditions and project requirements – top soil with vegetation, aggregates or crushed stone, concrete of required strength and suitable surface finish or a combination of these materials.

One of the most popular applications of geocells is the protection of slope against erosion. The three dimensional cellular structure of the geocell provided a high degree of confinement to the infill materials enabling it to resist erosion. The geocell acts as small check dams in the surface layer of soil, and minimizes the downward movement of embankment fill. It also reinforces the root zone of vegetation by encapsulating and interlocking with roots. The perforations in the cells walls considerably improve the interlock with the roots. Geocells help to prevent the formation of rills and gullies, particularly in areas where concentrated surface flows may occur.

7 GEOSYNTHETIC REINFORCED SOIL RETAINING WALLS

7.1 *Reinforced soil structures*

Reinforced Soil structures may be defined as a composite earth structure wherein soils (or other suitable fills) are internally stabilized by the inclusion of discrete layers of reinforcement materials which are generally placed horizontally, between successive lifts of fill during construction. The modern era of reinforced soil technology began with the invention of Reinforced Earth by Henry Vidal in the early 1960's in France. Since then reinforced soil has evolved into an advanced construction technology used all over the world for a wide range of applications. Today different forms of soil reinforcement (steel strips, bar mats, welded mesh, geogrids, geotextiles, geostrips etc.) are combined with different types of facings (full-height concrete panels, discrete concrete panels, segmental concrete blocks, gabions, welded steel wire mesh etc.) for the construction of a amazing variety of reinforced soil walls and steep slopes. Thus reinforced soil is a proven and mature technology which is more than forty years old and requirements for successful practice are well-understood and established in several codes of practice.

7.2 *Components of reinforced soil walls*

A reinforced soil wall consists of soil reinforcement, facing, foundation leveling pad, fill and drainage bay. When a soil reinforced with tensile inclusions deforms under load, tensile strains and forces are induced in the reinforcement because of the bond between soil and reinforcement. The fill combined with the reinforcement becomes a coherent composite material, which is internally stable and which can resist the earth pressures imposed by the retained fill by virtue of its mass.

Facing is the relatively thin skin element provided on the face of the reinforced fill and it performs the following functions - to contain and confine the fill materials during construction so as to ensure proper compaction of fill near the face, to prevent raveling and erosion of soils near the wall face, to provide local support to the soil between reinforcement layers, to anchor the reinforcement in the active zone and to provide an acceptable finish and attractive appearance. Most common types of facing used for structures to support approach embankments are precast concrete discrete panels and precast concrete modular units (segmental blocks). However, other types of facings like gabions and welded wire mesh have also been successfully used.

7.3 *Design*

The various modes of collapse of a reinforced soil wall are:
- External failure modes where the failure occurs along surface outside the reinforced soil zone – sliding along the base, bearing failure
- Internal failure mode where the failure involves the reinforcement – internal sliding along the surface of the reinforcement, rupture of the reinforcement and pullout of the reinforcement.
- Facing failures – failure of the connection between facing and reinforcement, bulging, toppling
- Compound failure wherein the failure surface passes partly within and outside the reinforced soil zone.
- Global failure when the entire structure may fail along a deep seated slip surface

Loss of serviceability of a reinforced soil wall could occur either because of excessive vertical settlement or excessive lateral deformations.

Design procedures are available in several codes and guidelines – BS 8006 (1995), Berg et al. (2009a), Geotechnical Engineering Office (2002), Nordic Geosynthetic Group (2004) etc.

7.4 *Properties of geosynthetic reinforcement*

The important structural properties of the reinforcement are the long term design strength, interface frictional properties (bond strength between reinforcement and soil) and the connection strength between reinforcement and facing (where applicable). The long term design strength is calculated by applying reduction factors to the short-term characteristic tensile strength of the reinforcement. The reduction factors to be applied are for creep, installation damage and durability. Where applicable additional factors to take into account manufacturing variations and uncertainties involved in extrapolation of test data and weathering may also be applied. Some of the important aspects involved in the evaluation of long-term deign strengths and the assessment of durability of geosynthetics is discussed in section 9.

The interface friction characteristics of geosynthetic reinforcement are evaluated using large shear box tests and pullout tests. The results are usually expressed in the form of a coefficient of interaction in direct sliding (obtained from large shear box tests) and a coefficient of interaction in pullout (obtained from pullout tests). Determination of connection strength between the reinforcement and facing units would normally require specialized test facilities, depending on the mechanism of connection employed – mechanical connection devices or frictional connection.

7.5 *Advantages of reinforced soil walls*

Geosynthetic reinforced soil walls have become quite popular for various applications including approach embankments of bridges and grade separators because of several advantages like:

– Ability to accommodate appreciable amounts of differential settlements because of the inherent flexibility of the construction
– Proven ability to withstand earthquakes because of the flexibility of the structure and also the reserve strength in the reinforcement (which is designed for creep) in the case of transient loads
– Availability of wide range of facings and reinforcements to suit a wide spectrum of site conditions and project requirements
– No need of any deep excavations for foundations or any space in front of wall for propping, formwork etc., which could be a significant advantage in urban locations
– Easy and fast construction due to use of precast incremental facing units
– Appreciable cost savings which increases as wall height increases

8 REINFORCED SOIL SLOPES

8.1 *Reinforced soil walls versus slopes*

Conventional concrete retaining walls have a near vertical face and unreinforced embankment slopes are usually flatter than 45°. However, it is possible to construct reinforced soil structures with face angles of up to 90° with horizontal. Reinforced soil walls with some types of facings are constructed with appreciable batter. This poses the question whether a particular structure is a wall. There seems to be no unanimous consensus on the critical face inclination above which a structure is classified as a wall and below which it is a slope. Still, based on current practice, the transition point is considered as 70° to the horizontal. There are some who argue that this has no rational basis and a more realistic value would be 80°.

Whether a reinforced soil structure is designed as a wall or slope has several important practical implications for the practitioner.

– The design methodology is different for walls and slopes. Walls are designed using an earth pressure approach, whereas slopes are designed using a rotational slip surface or a two-part wedge approach. Thus a structure with a face inclination of 71° (designed as a wall) and 69° (designed as a slope) may have significantly different reinforcement layout.
– As per most codes and international specifications, reinforced soil walls require a minimum embedment of one-twentieth of height or 0.5 m whichever is more. However, embedment is generally not required for reinforced slopes, unless dictated by special reasons.
– Specifications for walls require that a granular fill be used. Most international specifications, limit fines content (passing 75 microns sieve) to a maximum of 15 %. In the case of slopes, it is generally considered that a lower quality fill would be satisfactory. e.g. Berg et al. (2009b) states that a soil with percentage fines ≤ 50 % and plasticity index ≤ 20 is generally considered satisfactory for reinforced slopes. This while walls may require imported fills, slopes could be constructed with local soils.

Thus, a reinforced soil slope could be designed much more economically than a reinforced soil wall.

8.2 *Components of reinforced soil slopes*

Like walls, reinforced soil walls also consist of soil reinforcement, fill, facing and drainage materials. A levelling pad is not normally required for a slope. The function of the soil reinforcement in a reinforced slope is very similar to that in reinforced soil walls. Geogrids and woven geotextiles may be used as reinforcement. When the fill has appreciable fines content, it may be of advantage to use a reinforced non-woven composite as the reinforcement. This has a non-woven geotextile base which is reinforced with high tenacity polyester filament yarns. The high strength polyester yarns perform the function of reinforcement, while the nonwoven geotextile helps in the dissipation of excess pore-pressures developed in the soil.

Slopes flatter than 45° normally do not require any facing. The reinforcement is extended up to the face. Often secondary reinforcement is provided between the primary reinforcement to improve face stability and as a compaction aid. A facing is required for slopes steeper than 45° and normally a soft facing is used. This comprises of three elements – extending the reinforcement up the slope face and wrapping back into the fill, arrangement to contain the fill during construction (soil filled bags, welded wire mesh panels or climbing formwork etc.) and vegetative cover.

8.3 *Design*

The ultimate failure modes for reinforced soil slopes are the following:
– External stability – bearing and tilt failure, forward sliding and slip failure around reinforced soil block

- Internal stability – tensile failure of reinforcement and bond failure of reinforcement
- Compound stability – tensile failure of reinforcement and bond failure of reinforcement

Loss of serviceability could occur due to:

- Excessive settlement of the foundation
- Excessive post construction strains in the reinforcement
- Excessive post construction creep strain in saturated fine-grained fills

Design procedures are available in several codes and guidelines – BS 8006 (1995), Berg et al. (2009b), Geotechnical Control office (2002), Highways Agency (1994), Nordic Geosynthetic Group (2003) etc.

9 DURABILITY AND LONG-TERM DESIGN STRENGTH OF GEOSYNTHETICS

9.1 *Degradation of geosynthetics*

Geosynthetics are used as critical components of permanent structures with service life of 100 to 120 years. Hence, assessment of durability is a very important consideration in material selection and design. The major modes of degradation of geosynthetics may be summarized after ISO TS/434 (2008) as follows:

- Weathering: reduction in strength due to exposure to atmosphere (principally due to ultraviolet radiation) prior to installation in the case of buried geosynthetics or during service in the case of permanently exposed materials
- Installation damage: mechanical damage during placement, spreading, grading and compaction of fill materials on the geosynthetic material.
- Creep: polymers undergo creep under sustained load and ultimately rupture. However, this does not necessarily mean that strength goes on reducing under a constant load. It should be noted that It has been predicted on the basis of accelerated tests that many geosynthetics exposed to sustained load do not in fact significantly diminish in strength until close to the end of their predicted life
- Chemical and biological damage: The principal chemical degradation mechanisms are oxidation in the case of polypropylene, oxidation and environmental stress cracking in the case of polyethylene and hydrolysis in the case of polyester. Most polymers used in geosynthetics are not significantly affected by biological organisms.

9.2 *Long-term design strength*

One of the most authoritative guideline for the evaluation of long-term design strength of geosynthetics is ISO TR/20432. The LTDS is calculated by applying reduction factors to the characteristic (defined as the 95 % confidence limit) tensile strength of the material. The reduction factors are:

- RF_{CR} for creep rupture derived from conventional sustained load creep tests and accelerated creep tests
- RF_{ID} for installation damage derived from installation damage testing simulating the range of fill materials, lift thickness and compaction procedures
- RF_{W} for weathering with value depending on the time of exposure and the result of weatherometer testing
- RF_{CH} for chemical and biological degradation – default values based on index characteristics of the materials may be used in most normal conditions. However in the case of materials exposed to severe conditions, site specific performance testing may be required to evaluate the reduction factor.

Reliable test procedures have been developed for the determination of all the reduction factors and hence it is possible to predict the long term design strength with a high level of reliability.

10 SUMMARY AND CONCLUSIONS

Geosynthetics comprise a wide range of polymeric materials which can perform variety of functions which makes them indispensable in current civil engineering practice. Geosynthetics have extensive applications in devising safe, reliable and economic solutions to almost all geotechnical engineering problems associated with bridge approach embankments. Proven internationally accepted design methodologies are available for most applications and it is possible to predict the long-term performance of these materials with a high level of reliability.

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