High strength wovens, effective and economical geosynthetics for basal reinforcement

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ABSTRACT: Geosynthetics requirement for basal reinforcement are linked to the application and shall be written based on data characteristics. Thus, the choice of the product shall not be driven by the production technology, but only by the conformity of this product to the characteristics established during the design phase. Indeed, the characteristics depend on the manufacturing process but two products could achieve similar performance and behavior in the structure, even if they look like totally different. That means that the geosynthetic type shall never be a selection criterion. For example, geogrids which are often associated to the reinforcement function are not the unique solution and wovens or composites products may also be used as long as their properties fulfill the requirement. The geosynthetic needs for the reinforcement function are studied as well as their impact on the behaviour of structures where basal reinforcement is involved.

Keywords: Reinforcement, Tensile strength, Stiffness, Interaction, Geogrid, Wovens

1 INTRODUCTION

Embankments on soft soils, embankment on piles or bridging voids are applications in which a reinforcement of their base using high strength geosynthetics significantly improves the stability and the cost efficiency of the whole structure.

A proper design of a geosynthetics solution shall establish the link between the measured characteristics of the product and the performance expected of the structure. Particularly in Europe, the application standard prEN13251(2015) gives the characteristics of geotextiles and geotextiles related products required for use in earthworks, foundations and retaining structures. Other regional standards or guideline like BS8006 (2010) in UK or EBGEO (2011) in Germany, for example, allow calculating the design values for each relevant characteristic.

However, very often the choice of the geosynthetics is not based only on characteristics defined during the design, but also following general arguments which can be senseless for the application or pre supposed properties of a given product. Strength, stiffness, soil interaction or hydraulic properties are characteristics that need to be verified by measurement on the product and not assumed because of the production technology. This confirms that requirements and specification shall be written based on data characteristics rather than on product type that doesn't reflect their real performance. This paper proposes to highlight all the characteristics really needed for basal reinforcement, their influence on the design and if the production technology does matter to achieve the needed performance.

2 REQUIREMENTS FOR THE GEOSYNTHETICS IN BASAL REINFORCEMENT

2.1 *Requirements from application standard*

Table 1 from application standard prEN 13251(2015) gives the characteristics of geosynthetics required when used in earthworks, foundations and retaining structure. Reinforcement is indeed the main function of the geosynthetic in basal reinforcement, but separation or filtration can be required as secondary functions, particularly when the geosynthetic is between two layers of different materials (eg granular fill material and clayey subgrade).

Table 1. Function-related characteristics and test methods to be used

		Functions		
Characteristic	Test method	Filtr.	Sep.	Reinf.
Tensile strength	EN ISO 10319	A	A	A
Elongation at maximum load	EN ISO 10319	A	A	A
Stiffness at 2 %, 5 % and 10 %	EN ISO 10319	-	-	S
Tensile strength of seams and joints	EN ISO 10321	S	S	S
Static puncture resistance (CBR test)	EN ISO 12236	S	A	A
Dynamic perforation resistance (cone drop test)	EN ISO 13433	A	A	A
Friction	EN ISO 12957-1 EN ISO 12957-2	S	S	S
Tensile creep	EN ISO 13431	-	-	S
Damage during installation resistance	EN ISO 10722	S	S	S
Characteristic opening size	EN ISO 12956	A	A	-
Water permeability normal to the plane (velocity index)	EN ISO 11058	A	A	S
Durability	According to Annex B	A	A	A

Relevance of codes:
- A: relevant to all conditions of use
- S: relevant to specific conditions of use
- "–": indicates that the characteristic is not relevant for that function.

2.2 *Requirements from design standard: geosynthetics reduction factors*

Design codes, such as BS8006 (2010) or EBGEO (2011) provide the calculation method for different types of structure where basal reinforcement is involved: embankment on soft soils, above potential cavity and piled embankment. Tensile strength, elongation at maximum load and stiffness at 2%, 5% and 10% are characteristics used directly in the calculation to insure the stability of the structure and her serviceability.

All characteristics related to the durability are also given in the design codes, allowing the calculation of the long term design strength to cover all possible situations, from the installation up to the end of geosynthetics lifetime on the job site. Most of them are expressed as a reduction factor and follow the ISO/TR 20432 guideline on durability. Reduction factor given in different countries are shown in Table 2.

Table 2. Characteristics and corresponding reduction factor

		Standard or guideline		
	Characteristic	ISO BS8006	EBGEO Germany	France XPG38064
Mechanical behaviour	Tensile creep	RF_{cr}	A1	Γ_{flu}
	Damage during installation resistance	RF_{id}	A2	Γ_{end}
	Tensile strength of seams and joints		A3	
	Dynamic effect		A5	
Chemical durability	Resistance to hydrolysis	RF_{ch}	A4	Γ_{vieil}
	Resistance to oxidation	RF_{ch}	A4	Γ_{vieil}
	Resistance to weathering UV	RF_{w}		

3 STIFFNESS: A MAJOR CHARACTERISTIC FOR BASAL REINFORCEMENT

3.1 *Geosynthetics in basal reinforcement*

Main tasks of a geosynthetic in basal reinforcement are to carry the load from the structure that the subgrade cannot afford, to control differential settlements and to resist lateral thrust of the embankment when necessary (soft soils). If ultimate strength is crucial for Ultimate Limit State (ULS) analysis a defined in Eurocode 7 EN1997, in most of the cases, strain criteria are imposed either in direct Service Limit State (SLS) analysis or by limiting deformation in ULS analysis. That means that not only the tensile strength at failure is important but also the stiffness calculated from the tensile strength at a given strain.

3.2 *Embankments on soft soil*

Slip circle failure is generally the limit state that governs the design of embankment on soft soil and tensile strength is often the main characteristics to fulfill.

However, deformation of the structure,linked to serviceability limit state can be of major importance. As affirmed in BS8006 (2010)*:" as a general guide, the maximum strain ε_{max} in the basal reinforcement should not exceed 5% for short term applications and 5% to 10% for long term conditions.(…) Where basal reinforced embankments are constructed over soft sensitive foundation soils the maximum allowable reinforcement strain may be reduced (typically < 3%) to ensure strain compatibility with the foundation soil*"

3.3 *Embankments over piles*

Piled embankments are chosen particularly to solve settlements problems, thus deformation of the structures and their components is important. For geosynthetics used as basal reinforcement, two mechanisms are related to strain: the load transfer from the embankment to the piles and the control of the differential settlements between piles.

In BS8006 (2010) calculation is done considering a maximum strain of 6% to insure that the loads from the embankment are transferred to the piles. For thin embankment, a lower strain (≤3%) may be used following Lawson (2000) who has shown that the stiffness has a great influence in the control of surface deformation.

Geosynthetics designs for piled embankment are various and several approaches exist depending on the country. Using EBGEO (2010) or CUR (2015), geosynthetics stiffness is an input parameter and allows calculation of the strength and the strain in the reinforcement.

Strain limitation may be required specifically, eg for a service limit state, but the calculations are possible only when strain geosynthetic remain lower than 6% in practice.

3.4 *Embankments over potential cavities*

Limited surface deformation is the major requirement to fulfill on top of the platform over potential cavities. BS8006 (2010) and EBGEO (2010) or Lawson (2011) give similar maximum differential settlement at the surface of 1% for roads and motorways, up to 7% for low trafficked areas and very low values for railways lines (eg <1cm and <0.2%). The corresponding geosynthetic strain varies depending on the calculation models and the thickness (H) of embankment relatively to the size (D) of the void.

For thin embankment (e.g. H/D<1), most of the vertical loads are transferred directly to the reinforcement and surface deformation are strongly linked to the geosynthetic strain. In that case, mainly the stiffness will govern the design.

For thicker layer, arching occurs partially or totally (H/D>3) and the geosynthetic strain can be larger, but stiffness remains a driving parameters. Lawson (2011) shows in figure 2 the influence of the stiffness to achieve the requirement on surface deformation.

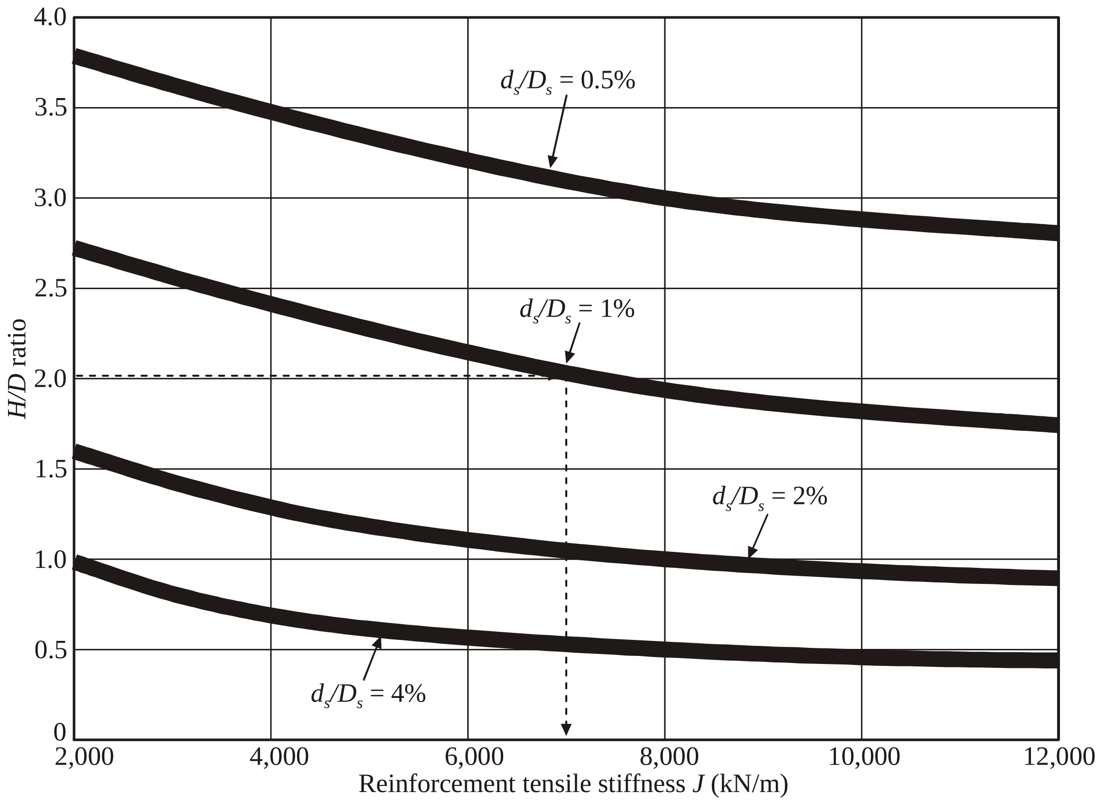

Figure 4. Effect of *H/D* ratio and reinforcement stiffness *J* on surface differential deformations d_s/D_s for $D \le 6$ m.

Figure 2: Effect of H/D ratio and stiffness on surface differential settlements ds/Ds for D≤6m.

4 PRODUCT BEHAVIOUR IN BASAL REINFORCEMENT

4.1 *Embankments on soft soil*

The reinforcement of embankments on soft soils results mainly from a stability analysis at the Ultimate Limit State (ULS). However in some cases, Serviceability Limit State could impose a limitation of the working strain. BS8006 (2010) states that " the maximum strain ε_{max} in the basal reinforcement should not exceed 5% for short term applications and 5% to 10% for long term conditions.(…). Where basal reinforced embankments are constructed over soft sensitive foundation soils the maximum allowable reinforcement strain may be reduced (typically < 3%) to ensure strain compatibility with the foundation… ".

Thus, the choice of the product used to reinforce will be based mainly on the tensile strength curve and the shape of the product has no importance if it fulfills the specification.

4.2 *Embankments over piles*

Tests series on piled embankment carried out by Deltares (Van Eekelen et al 2012) did not highlight difference of performance between geotextiles or geogrid having the same mechanical characteristics. Figure 1 shows the load part A corresponding to the load directly transferred to the piles and the load part B transferred to the geotextiles or the geogrid. The author concluded that" the concept of trapping grains within the geogrid gaps either does not occur in these tests or (if it does) does not lead to any observable benefits over surface friction alone."

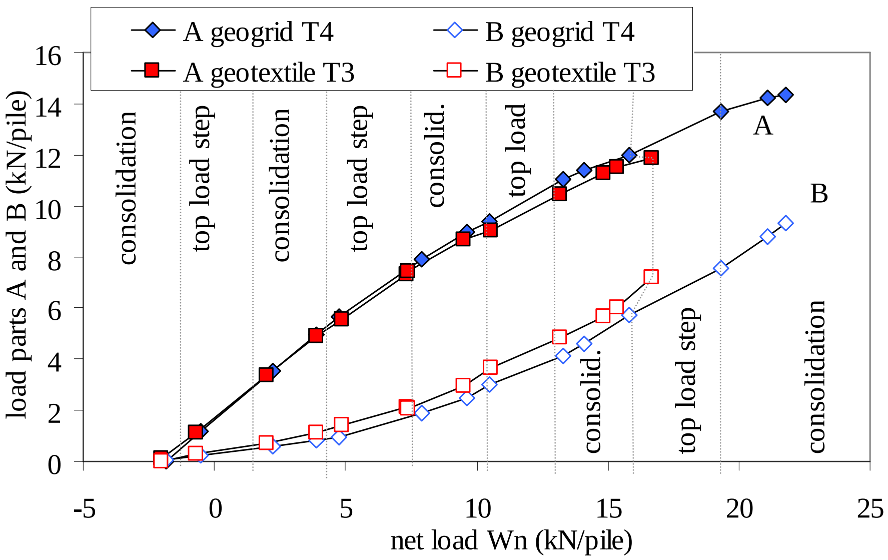

Figure 1: Compared load distribution geotextiles and geogrid

Experiments at full scale during the ASIRI project (2012) , show some benefits of an additional geogrid in the middle of the granular layer. However, when the geosynthetic installed as a single layer in the lower part of the platform, the Deltares tests could not show significant differences.

4.3 *Embankments over potential cavities*

When a cavity grows up to top of the subsoil, the first task of a geosynthetic consists to maintain the structure above combining separation and reinforcement to be able to support the load. Separation is needed, because any part of fill going through the geosynthetic will result in more deformation of the structure above.

Only geosynthetics with small opening size, such as woven or composites able to separate are suitable when used at the base of the reinforced structure.

5 CHARACTERISTICS VS PRODUCT TYPE?

5.1 *Ultimate Tensile Strength*

Ultimate Tensile Strength (UTS) is the strength at the failure of the geosynthetic and depends on the raw material, the quantity of material.

Very high strength geosynthetic (eg 2000 kN/m) can be produced using the weaving technology, thus once again, the performance shall drive the choice of the reinforcement rather than the appearance (type of geosynthetic).

On a pure ULS analysis, a product working as a tension membrane and that breaks at 6% requires 19% more strength than a product that breaks at 10%, all others parameters the same (durability, damage). Without the need to respect a strong serviceability criterion, a product breaking at low elongation may be not economical.

5.2 *Strain strength curve, isochronous curves and stiffness*

Stiffness characterizes the capacity of a geosynthetic to resist to the deformation under load, but the response is not linear and stiffness is related to a given strain. Stiffness depends on the raw material, the quantity of material and the geosynthetic construction.

It doesn't matter if a raw material is stiffer than others, as long as the products fulfill the requirement.

5.3 *Interaction*

Interaction between soils and geosynthetics is of high importance in reinforcement applications. It‘s the process that defines how the load coming from the soil are transmitted to the geosynthetics. Interaction is involved in two possible mechanisms: sliding of the soil mass on the geosynthetics and pull-out of the geosynthetic in the anchorage zone.

Interaction between geosynthetic and soil depends on the type of geosynthetic and the soil grain size distribution. The interaction of geogrids with adjacent soil is by a combination of end-bearing and surface friction whereas that of woven geotextiles is by surface friction alone. However, end-bearing occurs only if the aperture size is sufficient. By definition of EN ISO 10318 (2015), a geogrid shall have opening larger than the constituent. That means the proportion of the plane sliding area that is solid should be higher than 0.5.

High strength grids, those with tensile strength above 400 kN/m, are generally below this limit of 0.5. Thus, the interaction between the soil and these grids will occur mainly by friction and will not differ strongly from geotextiles, wovens or composites. Particularly with fine granular soil such as sand or material containing fines, the difference may be negligible as shown on table 3.

Table 3. Interaction at different interface – Kiwa test report (2015)

	Interface Friction angle δ	Interaction coefficient α
PET Woven 400/50 vs sand (ϕ=38°)	31,5°	0,78
PET Grid 400/30 vs Sand (ϕ=38°)	31,9°	0,79

6 BASAL REINFORCEMENT WITH HIGH STRENGTH WOVENS

With more than 20 years of experience, geosynthetics and particularly high strength PET wovens have proved their effectiveness in reinforcing the base of embankments constructed over soft soil, areas prone to foundation void formation or piles.

Orsmond (2008) described in detail the reinforcement over piles used to support the A1/N1 link between Belfast and Dublin that crosses very soft silt and peat area. Other example of the high speed railways line crossing either zone of potential cavities and soft soil where a piled embankment was used is described in several publications Nancey et al (2012), Nancey (2013).

7 CONCLUSION

Basal reinforcement of embankment by geosynthetics is today a current technique. Design of the reinforcement relies on accurate design methods depending on the application: embankments on soft soils, embankment on piles or bridging voids. European standards define the design rules, providing the needed level of safety and the decisive characteristics of the geosynthetic to be required. Geosynthetic have to be chosen for their capability to fulfill the specification and not based on their production technology. For basal reinforcement, high strength Polyester woven geotextiles have demonstrated their ability to achieve high performance and appear as a reliable and economical solution.

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