DESIGNING WITH GEOTEXTILES BASED ON STRESS ENERGY FACTORS

E. R. Steen
Fibertex A/S, Technical Division, Construction, Aalborg, Denmark

ABSTRACT: As the mechanical properties of geotextiles are essential in most applications, this paper focuses on the use of the mechanical properties as the major design parameter. The hot topic in design strength for geotextiles is the energy absorption, as the energy absorption is a way to express the combination of a given geotextiles strength and elongation properties. This paper will discuss the differences in between the use of energy absorption originated from the STRIP tensile strengths of geotextiles versus the use of energy absorption originated from the CBR puncture resistance of geotextiles. Furthermore, discuss the present well-known outcome of stress-strain calculations and present a simplified classification system that combines both the STRIP tensile strength and the CBR puncture resistance.

1 INTRODUCTION

Ever since geotextiles saw the day of birth in the early sixties, there has been ongoing research in the design methods and design parameters. The present trend with design methods is going from application design toward design for the geotextile functions respectively, separation, filtration, drainage, protection and reinforcement. The main difference between the application design and the design for functions is that the designing for functions concentrates on the parameters of the geotextile only, whereas the designing for applications cover the entire construction.

Hydraulic properties as water flow and pore opening size of the geotextile are important figures, and depending of the application and local condition on the project site they should always be taken into consideration together with the mechanical properties. However, this paper will focus on the use of the mechanical properties as the overriding design parameter, and this done in view of the fact that the mechanical properties are essential in most applications. The mechanical properties of geotextiles are normally divided into two parts, installation and usage, and depending on the construction and the loads on the construction either one can be the designing factor. The hot topic in design strength for geotextiles is the energy absorption and the stress energy index is becoming a way to express the combination of a given geotextiles strength and elongation properties.

In order to present simplified codes of practice for the selection of geotextiles in road construction, several set of rules have been born over the years. E.g. the German classification system primary based on CBR puncture resistance and the Nordic NorGeoSpec classification system primary based on STRIP tensile strength.

This paper will discuss the differences in between the use of energy absorption originated from the STRIP tensile strength of geotextiles versus the energy absorption originated from the CBR puncture resistance of geotextiles. Furthermore, discuss the present well-known outcome of stress-strain calculations, and with basis in obligatory considerations regarding safety factors, present a more simplified classification system combining both the STRIP tensile strength and the CBR puncture resistance and include the use of the stress energy index. This achievement is done primary based on personal research and experiences in the field.

2 REQUIREMENTS OF THE GEOTEXTILE

Today, the designers, engineers, consultants and other experts within the geotechnical field are equipped with obligatory knowledge about the calculation of an extensive variety of specific sections on construction sites. Any mechanical characteristics required of the geotextile can be determined very accurate for each section. However, as variations in both material composition and water content often vary very much even within well-defined sections at the construction sites, the exact calculated figures of what's needed of required characteristics of the geotextile will nevertheless be considered as average values and successive be added varying safety factors.

2.1 *Energy absorption*

One of the first official approved conversion factors between rigid and extensible geotextiles was presented in the first Swiss “Geotextile-handbook” from SVG (1985) where the tensile strength at break was multiplied with the elongation at break. This practicable outcome has ever since been a simplified method to compare e.g. woven and nonwoven geotextiles, as a rigid geotextile has to be considerably stronger than an extensible geotextile in order to fulfil the same mechanically functions.

This simplified method of multiplying the maximum tensile strength of a given geotextile with the maximum elongation of the same geotextile, have nevertheless brought up the development of the present terminology of energy absorption and successive stress energy index.

2.1.1 *- Originated from STRIP tensile strength*

The Swiss "Geotextile-handbook" seems in principle, to be the concept of motive that has brought the NorGeoSpec into existence. EIKSUND, WATN AND RATHMAYER (2002) have introduced the energy requirement originated from STRIP tensile strength to allow for a larger span in geotextile properties. Geotextiles with lower failure strain can compensate with higher strength to achieve the same failure energy. The stress energy index W_T is calculated according to the following equation:

$$W_T = ½ \cdot T_{fa} \cdot T\varepsilon_a \quad (1)$$

Where T_{fa} and $T\varepsilon_a$ refer to the average of machine and cross machine direction tested according to EN ISO 10319, and is the strengths and elongations at break in machine and cross machine direction respectively.

The additional calculation of actual 95% confidence limit for the stress energy index, as required in the NorGeoSpec, is complicated and the author of this paper will like to point out, that this precaution already should have been compensated for by the decision of required characteristics on each of the chosen specification profiles. In order to make simplified codes of practise, relevant safety factors should already have been added in the profiles. On most of the producers technical data sheets are the mean values for maximum strengths and maximum elongations already given with the normally 95% confident interval and the figures are immediate to use when selecting appropriate grades of geotextile.

2.1.2 *- Originated from CBR puncture resistance*

In order to give the end-user a tool to find the geotextile, that fits best for his application, and to give the producers fair contests, the German geotextile people have since1980 used a geotextile-robustness-classification GRC system by classifying the robustness of geotextiles against mechanical damage. For woven geotextiles the system is based on the STRIP tensile strength EN ISO 10319, and for nonwoven geotextiles, the classification system is based on the CBR puncture resistance tested according to EN ISO 12236 and is the mean penetration force at maximum minus the standard deviation.

As with the NorGeoSpec classification profiles, the author of this paper will like to point out, that the deducting of the penetration strength of the geotextile with the standard deviation would not have been necessary if relevant safety factors have been added in the classification profiles. Furthermore, the mean CBR puncture resistance minus the standard deviation is not given on all technical data sheets from the producers nor required on the CE marking accompanying documents. On the CE marking accompanying documents, are for the Static CBR puncture resistance test only required the mean value and tolerance value, and this is given with the normally 95% confident interval and the figures are immediate to use when selecting appropriate grades of geotextile.

It is obvious, that the use of the CBR puncture resistance test for the determination of stress energy factors also is an analogous possibility as with the stress energy factors based on the STRIP tensile test. However, WILMERS (2002) has uncovered the discussions taking place in Germany regarding the use of a modulus or of the working force as basis for the GRC. Lot of research work has been done about damage during installation and whether the resistance to damage could be classified by index tests using the elongation during tensile strength or during static puncture strength, and he has concluded, that the use of working force or of energy absorption will not give the mean to a clearer distinction of the behaviour of different products on real site conditions. Consequently, the German geotextile people have decided to continue with the Geotextile-Robustness-Classification GRC, originated from STRIP tensile strength for woven geotextiles and originated from CBR puncture resistance for the nonwoven geotextiles without changes.

2.2 *Site conditions*

Many site tests have been carried out over the years in order to select an appropriate geotextile restraining sufficient mechanical properties to withstand damage during installation. As can be seen from the below Figure 1 and Figure 2, which is taken from one of such site tests, both the strength and elongation properties of the geotextile are important figures, and the impact from the falling heavy rock illustrates clearly the influence of some of the installation stresses.

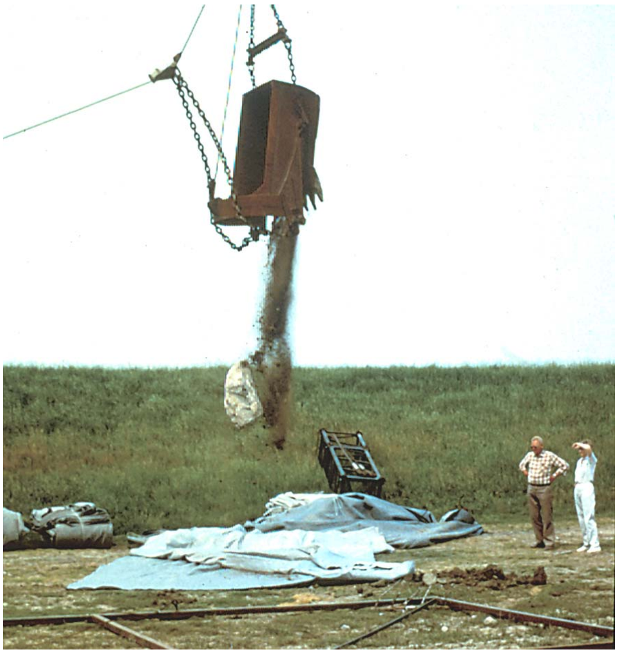

Figure 1 Dropping of heavy rock during site test of geotextile

Figure 2 No holes in the geotextile, only a hollow in the ground

Several parameters are to be taken into account when discussing the shape of the hollow in the ground caused by such site testing of geotextile; e.g. the load of the falling rock, the high from which the rock is falling, the bearing capacity of the ground and the strength and elongation properties of the geotextile. It is obvious, that the lesser bearing capacity we have in the ground or heavier load we are using for the falling rock and the more height from which the rock is falling, the deeper shape of the hollow will appear in the ground.

The placement of the geotextile sample on the ground prior to the dropping of the falling rock can be done in two ways respectively, freely placed or locked along the edges. When freely placed, regardless the technical properties of the geotextile, the influence of the geotextile on the shape of the hollow is less than if the geotextile is locked along the edges. When the geotextile is locked along the edges, the technical properties of the geotextile will be more utilized and influence on the shape of the hollow.

When the geotextile is locked along the edges during such site tests, the results will reflect the risk for damages during installation more, than if the geotextile was freely placed on the ground. The risk for puncturing of the geotextile will be larger the less elongation property of the geotextile. Hence, to compensate for less elongation property of the geotextile, the geotextile need considerably higher strength in order to counteract for the attempt to generate more elongation of the geotextile than possible in the impact area.

The stress exerted on the geotextile is multi-axial and is not limited to a single (plane strain) mode of tension/stress. Consequently, and in order to convert the test to illustrate possible installation damages (the geotextile is normally locked along the edges due to loads of adjacent rocks), and the spherical shape of the hollow in the ground can be considered of more biaxial character. It is obvious, that the stresses in the geotextile should not be considered as just stresses in one direction only. The stresses, which have to be obtained of the geotextile, need to be determined with focus on actual application of the geotextile, which normally will bring about requirement of mechanical properties of the geotextile in more than just one direction.

2.3 *Application standards*

The ten existing European application standards are used as basic for describing the geotextiles and characteristics relevant to the intended use. This involves the manufacturers, designers, end-users and other interested parties to define which function and conditions of use that are relevant.

Site tests, as described in the previous section, can be positioned with normative reference to EN 13249, Geotextiles and geotextile-related products - Characteristics required for use in the construction of roads and other trafficked areas (excluding railways and asphalt inclusion).

Each individual application standard always deals with the functions relevant for the application, and in this standard respectively, filtration, separation and reinforcement. For all three relevant functions is the Strip tensile strength and the CBR puncture resistance of the geotextile required for harmonization. Which is, however, with an exception for the filtration, where the CBR puncture resistance is only relevant to specific conditions of use. It is noted, that the CBR puncture resistance may not be applicable for some types of products, e.g. geogrids. Furthermore, that the use of only one, either Strip tensile strength or CBR puncture resistance, is sufficient in the specification. Consequently, and with focus on the application standard only, the Strip tensile strength seems *spontaneously* to be the only comparative information including all kind of products, woven, geogrids or nonwovens.

2.4 *Discussion on the requirements of geotextile*

The many various application of geotextiles, until now embodied in 10 harmonized application standards covers, besides the road construction, also the need for geotextiles that are stronger in one of the directions e.g. for use in retaining structures. It is obvious, that the requirements of some of the geotextiles in retaining structures specify the Strip tensile strength only, and specify very high Strip tensile strength in one direction only.

However, in road constructions, we have to deal with characteristics relevant for each specific type of geotextile. We cannot compare the mechanically characteristics of woven, geogrids or nonwovens uncritically either by the use of the Strip tensile strength only or by the use of the CBR puncture resistance only. The CBR puncture resistance is not applicable for all types of products, and the STRIP tensile strength is not adequate for all type of nonwovens. An ingenious producer can take advantage of the way the STRIP tensile test is carried out and manufacture his product in a way so that it favour high strength with successive high elongation in both machine and cross machine direction, however, not at the same time. Which means, that when following the test procedures, successive high values can be obtained in both directions, but when installed and affected of the stresses at site condition, the product will not be able to withstand the expected stresses but will break.

No chain is stronger than the weakest link, and converting this common knowledge into geotextile matters, we must try, not to let theoretically conceptions overrule common sense. When using a geotextile with high strength and high elongation in the same direction but low strength and low elongation in the other direction, this geotextile will, according to the NorGeoSpec profiles be accepted with average values in the STRIP tensile strength test – higher than the breaking load in the weakest direction! However, such geotextiles will break before the maximum load reach the theoretically accepted average values. They will break already when the load passes the maximum load in the weakest direction. Consequently, we need to establish a confidence-inspiring set-up of profiles, however, still practically and easy to use for the end-user.

3 SELECTION OF SPECIFICATION PROFILES

When evaluating the Nordic NorGeoSpec guideline for the selection of specification profiles, and put it side by side with the German geotextile-robustness-classification system, it can be found, that the two principles more or less agree about several of the same fundamental conditions. E.g. is the demand for tensile strengths higher the softer ground conditions we have, and the grain size of aggregates and the loads from traffic or installation stresses during construction are essential parameters.

3.1 *Discussion on the contents of the specification profiles*

In order to extract the key points from the two classification systems in question, and in order to present a simplified set-up of specification profiles easy and tangible for the end-user, at the same time valid for both woven and nonwoven products when used in road constructions, following conditions are taken into account.

However, when the site conditions are very extreme, site tests should nevertheless be required for the approval of chosen geotextile.

3.1.1 *The subsoil*

The subsoil is divided into soft or normal condition. Soft condition is, in round figures, when the CBR-value estimated on the subsoil is below 1,0 or the undrained shear strength is below 25 kPa. Which can be estimated at site with an uncomplicated field estimating procedure; as if you are able to penetrate the whole of your thumb in the ground we are talking about soft condition.

It is to be noted, that even the subsoil has been estimated to normal condition, the subsoil might change from normal to soft condition during the installation period. In case that rainy weather take place in a period, the subsoil might turn from normal to soft condition and influence in the choice of specification profile.

3.1.2 *Traffic and construction conditions*

Nowadays, most construction works takes normally place using heavy equipment in order to compact the fill layers as much as possibly. Therefore, the grouping will only be in two parts, low- and heavy traffic, and heavy traffic is defined as more than 500 heavy vehicles per day.

3.1.3 *Material conditions*

For the specification profiles is the assumption taken, that a major percentage of the fill material will be sharp edged stones, therefore, no need for adding of extra factors of safety.

3.1.4 *Determination of specification profiles*

Taken the condition of actual subsoil and traffic into account, the following Table 1 show the relevant specification profiles, that will be kept in a number of five. Counting for the specification profile 1, this may be used for roads with low temporary traffic, access roads or similar, when the subsoil is of normal condition and fill material of d_{90} < 6 cm is used.

Table 1 Determination of relevant specification profile

Subsoil	Traffic	d_{90} in cm of covering fill material			
		d_{90}< 6	6<d_{90}<20	20<d_{90}<50	d_{90}>50
Soft	Low	3	4	4	5
	Heavy	4	4	5	5
Normal	Low	2	2	3	3
	Heavy	2	3	3	4

3.1.5 *Requirements of the geotextile*

In road constructions, technical figures as mass per unit area and thickness of the geotextile are only used for identification and will not be included in following overview of standardised test methods used for determination of required characteristics.

All the required values for the following five specification profiles can be easily checked, as the technical figures given of the manufacturers on various technical product data sheets always should be within a 95% confidence interval when tested.

Table 2 Relevant test standards and acceptable tolerances

Characteristics	Test standard	Tolerances	Abbreviations
STRIP tensile strength	EN ISO 10319	- 10%	T_{fa}
STRIP tensile elongation	EN ISO 10319	± 20%	$T\varepsilon_a$
CBR puncture resistance	EN ISO 12236	- 10%	F_p
CBR elongation	EN ISO 12236	± 20%	$F\varepsilon$
Stress energy index	Test results based on the respective standards	± 20% ± 20%	W_T (STRIP) W_F (CBR)
Cone drop	EN 918	+ 20%	D_c
Permeability	EN ISO 11058	- 30%	k_n
Pore size $O_{90\%}$	EN ISO 12956	± 30%	O_{90}

All technical figures descended from the above-mentioned test standards, except the Stress energy index, are figures required at the CE marking accompanying documents for geotextiles used in road construction, and the figures are therefore always available for geotextiles delivered to European projects. For the STRIP tensile strength is the stress energy index calculated by use of the average of machine and cross machine direction, and is the strength and strains at break in machine and cross machine direction respectively.

However, when calculating the average values (T_{fa} and $T\varepsilon_a$), only average values of non-uniformities less than 1,2 can be counted in. Consequently, if the non-uniformity is larger than 1,2 the average values are calculated with the factor 1,2 times the value of the weakest direction only.

In order to present a simplified way of selecting geotextiles, the technical figures in table 3 are all nominal values easily to find in the manufacturers product data sheets. Normally used safety factors for the constructions are consequently included in the specified characteristics.

Table 3 Required nominal values for the five specification profiles

Characteristic		Specification profiles				
		1	2	3	4	5
Woven geotextiles						
T_{fa}	kN/m	15	20	25	30	35
$T\varepsilon_a$	%	15	20	25	30	35
W_T	kN/m	1,4	2,5	3,9	5,6	7,7
Nonwoven geotextiles						
F_p	kN	1,0	1,5	2,0	3,0	4,0
$F\varepsilon$	%	40	40	50	50	50
W_F	kN	0,3	0,4	0,6	0,9	1,2
All geotextiles						
D_c	mm	35	30	24	18	12
k_n	m/sec	0,05	0,04	0,04	0,03	0,03
O_{90}	µm	200	180	165	155	150

Both the stress energy indexes W_T and W_F are calculated by using the same theories as behind the equation (1) and as described in section 2.1.1. It is to be noted, that even the STRIP tensile strength and CBR puncture resistance are two totally different ways of testing geotextiles, experiences show nevertheless, than when calculating various geotextiles, an approximate relation seems to appear between the two stress energy indexes:

$$W_F = 0{,}16 \cdot W_T \qquad (2)$$

4 CONCLUSION AND RECOMMENDATION

Taking into consideration, that the German geotextile people anyhow need to substitute the CBR X-s values as basic classification values for nonwovens, and arrange their geotextile-robustness-classification GRC system to fit into the European requirements for geotextiles used in road construction, the above proposal for classification profiles, valid for both nonwovens and woven geotextiles, and with the use of a stress energy indexes, can be recommended as a suitable replacement.

5 REFERENCES

SVG, Schweizerischer Verband der Geotextilfachleute, 1985: Das Geotextil-Handbuch, Switzerland, pp. 4.15

Eiksund, G., Watn, A., Rathmayer, H., 2002: NorGeoSpec, a proposed system for specification and control of geotextiles for separation and filtration in roads in the Nordic countries. 7th International Conference on Geosynthetics, Nice, pp. 1375-1378

Wilmers, W. 2002: The revised german regulations for the use of geosynthetics in road construction. 7th International Conference on Geosynthetics, Nice, pp. 1401-1404