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DESIGN PARAMETERS FOR HIGH STRENGTH GEOTEXTILES

PARAMETRES POUR LE CALCUL DES GEOTEXTILES DE HAUTE RESISTANCE

PARAMETER FÜR DIE BEMESSUNG VON HOCHFESTEN GEOTEXTILIEN

This paper relates to the application of high strength geotextiles where their tensile properties are utilized in a reinforcing mode. A description is given of the type of materials available, particularly in relation to their tensile properties. A conceptual arrangement is put forward to interface these with likely creep/stress relaxation characteristics and provide permissible design parameters.

Finally, some calculation concepts are put forward illustrating some design philosophies appropriate to the application of these materials.

Dieser Beitrag behandelt die Anwendung von hachfesten Geotextilien, die aufgrund ihrer Zugeigenschaften zur Bewehrung eingesetzt werden. Die z.Zt erhaeltlichen Materialien werden kurz beschrieben, insbesondere was ihre Zugeigenschaften betrifft. Ein Konzept wird vorgestellt, das diese Zugeigenschaften mit dem wahrscheinlichen Kriech bzw. Relaxationsverhalten verknuepft, um zulaessige Bemessungsparameter zu erstellen.

Einige Entwurfskonzepte werden vorgestellt, die Besmessungsansaetze fuer die Anwendung dieser Baustoffe verdeutlichen.

1 MATERIALS

Geotextile materials have been ably described in other arenas (1) and a lengthy paper would be required to cover the proliferation of materials developed since 1970. While the range of non woven geotextiles has grown for separating and filtration purposes, lightweight woven fabrics have also become established in this commodity market, while heavier duty woven geotextiles have been developed for more rigorous end uses.

While the additional complexities of these more sophisticated applications have controlled their growth, other materials have been developed which directly address their end use requirements to provide specific tensile frictional or drainage characteristics. For example: special weaving or knitting techniques to control crimp; the use of low extension flat yarns; weaving or bonding techniques to form meshes or nets; composite materials taking advantage of combined properties of 2 (or more) different fabrics; biaxially extruded grids presenting more open structures; strips of encased single directional yarns bonded into various geometric arrangements.

These developments are intended to satisfy a range of applications, although most high strength geotextiles' functions can be broadly categorised as either robust separation/filtration or tensile reinforcement. While there is very good reason to examine the robustness of geotextiles and their site application, this paper is primarily concerned with utilizing tensile reinforcement.

The majority of high strength geotextiles are constructed from bundles of yarns. While materials such as extruded polymer grids and steel strips (3) are used to reinforce soil, producing materials from synthetic yarns is still a state of art method of achieving a high strength two directional synthetic.

The behaviour of these materials depends upon the constituent polymer properties and the way in which the fabric is constructed. Different polymer properties can manifest themselves in altering the material behaviour - in instantaneous, or creep, strain for example. The method of manufacture has a significant effect upon the geotextile's performance, and can often be adjusted to mirror quite varying property requirements, although economics may constrain their viability (See Figure 1).

Two fundamental areas of information necessary to complete a design utilizing a geotextile (over and above the normal soil parameters, geometry etc) are:

1) What real tensile characteristics can be utilized in the geotextile.
2) How this load can be transferred into the soil.

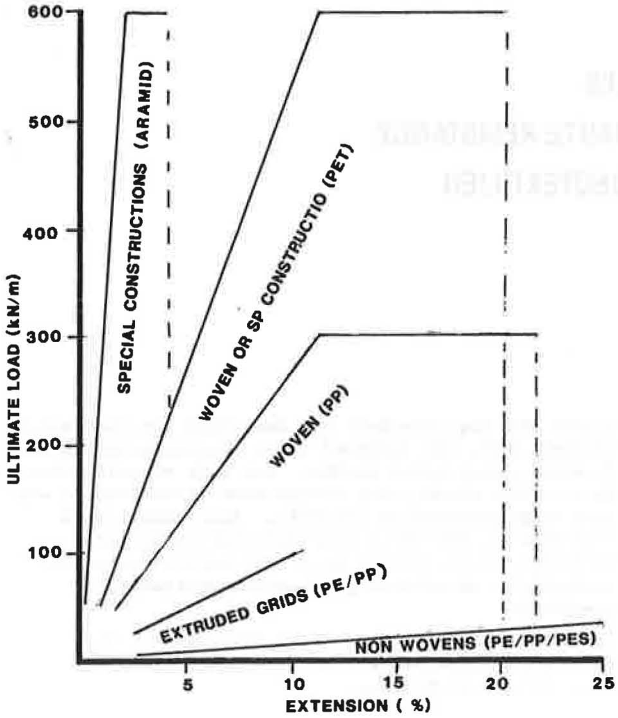

Fig 1. TYPICAL GEOTEXTILE CONSTRUCTIONS

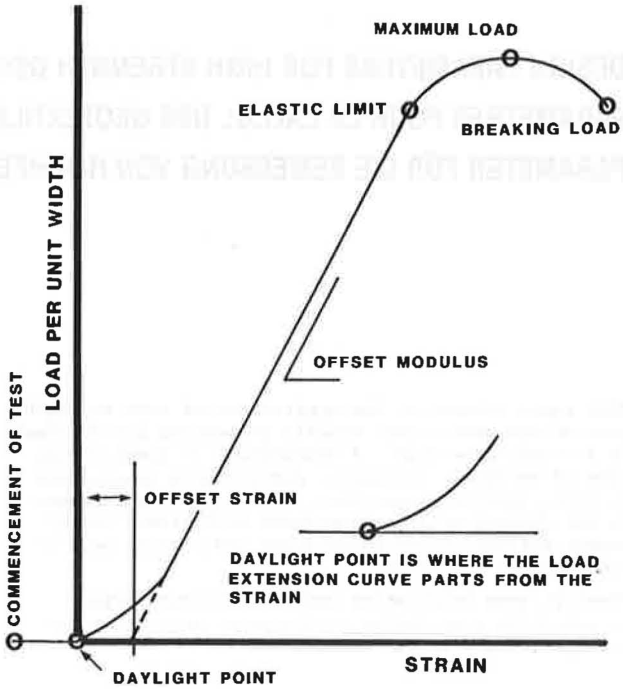

Fig 2. TYPICAL GEOTEXTILE LOAD STRAIN GRAPH (4)

2 TENSILE CHARACTERISTICS

Testing high strength fabrics at wide width (100 - 1000mm) is not easy, even in isolation, and both gripping and strain measurement require careful consideration (4). Generally, the results of such a test are presented graphically although particular figures are often tabulated.

Nominated breaking loads, or characteristic or ultimate strengths are often quoted and a partial safety factor used for design purposes, eg:

Working Load (WL) x A $\ngtr$ Ultimate Strength (NBL)

Where A = 1.5 to 2.5 (2.5 typical)

However, as geotextiles generally have to extend considerably to achieve these values, the designer must examine the tensile properties within the strain range which the soil structure is likely to tolerate. A convenient means of doing this is to identify a linear modulus within the working zone of the tensile plot, and some drafting specifications (5) are moving towards this format (See Figure 2).
(NB: values quoted per cross sectional area should be treated with caution as a fibrous cross sectional area is rarely homogenous.)

Where such a line meets the strain axis an offset strain may be identified, usually a function of the crimp in a geotextile, although this may appear reduced where a preload is used in the test method.

Test variations such as temperature, rates of strain, sample geometry, preload conditions, and means of presentation may each effect the tensile result and, until national specifications are finalised, the designer should be aware that these differing nuances may be encountered.

Furthermore testing in soil can give different results (6) for lightweight high deformation geotextiles, although probably less so for higher strength zero-offset modulus geotextiles. Not only is there a necessity to interpret available stress strain data for use when confined in soil, but also to validate the durability of the geotextile's tensile performance.

Factors likely to affect the durability of a geotextile's tensile performance include its resistance to chemical and biological degradation and the effect of temperature variations.

While there is good evidence on the behaviour of basic synthetic compositions in various regimes (7), a more comprehensive presentation of a geotextile's environmental stability is increasingly being required. Presently, however, the designer has to take the information available and build in sufficient factors of safety to account for the effect of any adverse environment considered likely.

One of the known characteristics of polymer constructions is their tendency to creep under sustained load and consideration of the load-strain-time behaviour together has already been advocated (9) to ensure working load can be achieved throughout the design life of the structure with sufficient factor of safety.

Several studies have been carried out on geotextiles and their constituent yarns (8) to examine this aspect (See Figure 3). Further work will identify how these results are effected when the yarns are in woven or formed structures and installed in a soil environment.

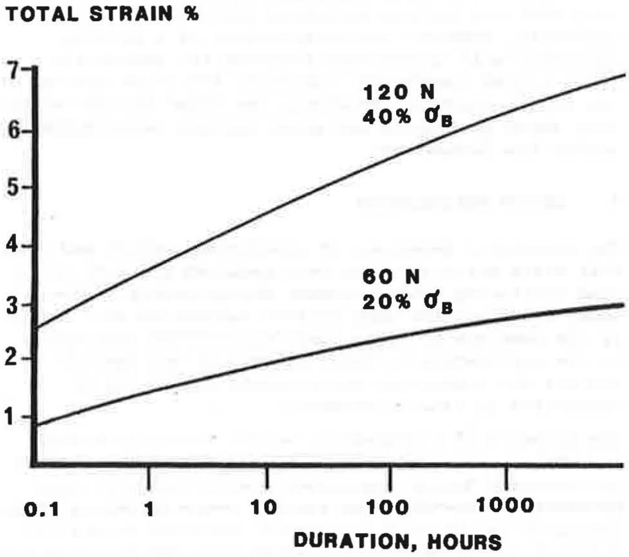

Fig 3. CREEP OF ICI POLYPROPYLENE (8)

However, there is now sufficient yarn creep data available that it should not be ignored and an alternative means of estimating the likely load/strain performance over a required design life may be to overlay the appropriate creep/strain relaxation graph directly onto the stress/strain plot (See Figure 4).

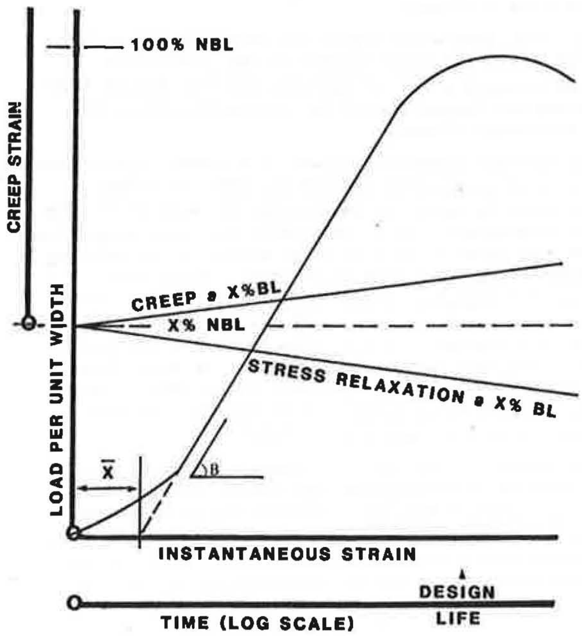

Fig 4. CONCEPTUAL LOAD STRAIN TIME GRAPH

3 LOAD TRANSFER

Having determined a material's tensile properties, it is necessary to establish how the design load can be transferred into the soil environment. A point of major importance to bear in mind is the extensible nature of geotextiles by comparison with steel or concrete, so that the strain behaviour of the structure becomes an important consideration. Generally, load is transmitted by a resistance to movement between the geotextile and soil by way of shear or, in the case of gridlike structures, by shear and passive resistance of transverse members.

Testsusing shear box apparati have been undertaken by a number of researchers using various geotextiles and soils and results of fabric/soil friction (10) have generally approached the soil's residual angle of shearing resistance (See Figure 5), eg:

Design Shear (ϕ_{SF}) $\not>$ B x Residual Shear (ϕ)

Where B = 1 to 0.5 (0.75 typical)

More conservative values are required for less free draining materials and it is recommended these are measured.

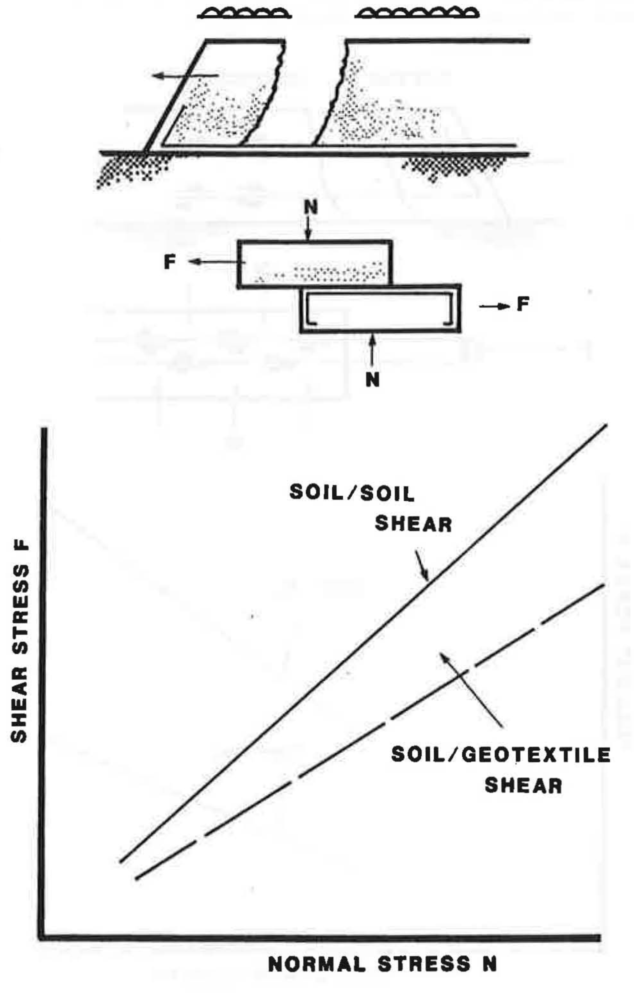

Fig 5. LOAD TRANSFER SHEAR (10)

While reinforced earth techniques generally utilize non cohesive (C=0) soils, the use of geotextiles in cohesive soils should be considered. Care must be taken to examine the worst case with particular regard to moisture content, and designs checked using undrained parameters. For design purposes with $\emptyset \to 0$ fabric soil adhesion values may require consideration, eg (2):

Adhesion $\neq$ D x Undrained Cohesion

Typically D $\backsim$ 0.5 to 0.7 but testing is recommended.

There is a further view (11) that in certain application: the less conservative pullout test is of more value and this argument finds more ready acceptance where non planar structures, such as strips and grids, are used to nail slopes or restrain facing units (See Figure 6). Several projects are currently in hand developing pull-out evaluation techniques for these applications.

Clearly a geotextile below a high embankment is subject to a high overburden pressure so that a small area of fabric - typically 2 to 5m - will give sufficient area to transfer load between soil and fabric. (It is of course, imperative that the soil has sufficient shear strength to achieve the design load at transfer).

Nearer the surface, perhaps of a steep slope, this will not be so and the additional restraint of the transverse ribs in a grid may be required to provide similarly short anchorage length to resist pullout.

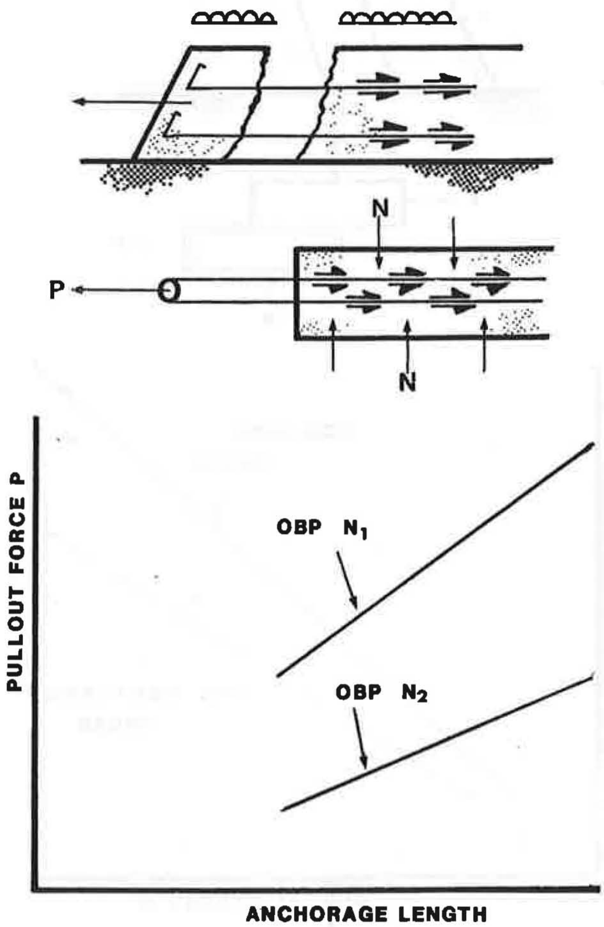

Fig 6. LOAD TRANSFER PULLOUT

Clearly the procedure for checking load transfer will vary with the failure mechanism being analysed. Generally, however, the introduction of a tensile inclusion will necessitate checking the geotextile pullout bond length/soil adhesion; the block sliding at the soil/geotextile interface; the shear failure within fill above geotextile and shear failure below geotextile within the foundation.

4 DESIGN PHILOSOPHIES

The structural behaviour of reinforced models and some full scale structures has been examined and work is in hand developing finite element design models. Nevertheless, the basis for many current reinforced soil design is the adaption of basic limit equilibrium principles to the application in hand, mindful of the special factors and conditions which relate to the use of synthetics as tensile elements.

The presence of a geotextile within a structure does not obviate the need for an overall external stability geotechnical design requirement using the basic soil parameters. However, the tensile characteristics of an inclusion can be used to enhance internal stability. A design requirement can be found from the analysis and the geotextile/soil properties for the application reviewed, and appropriate checks made.

For example, the concept of strain must be considered and while values of up to 10% have been quoted it is suggested materials will generally be expected to operate at 2-6% strain level.

One may consider whether the offset modulus is reduced when in soil (due to the confining pressure) or increased (due to installation). Correlating theoretical strain data with the site condition is difficult, unless the geotextile is uniformly stressed on site, and it is probably reasonable to reduce the in-isolation offset modulus as an estimate of in soil performance. Nevertheless any remaining strain at zero stress must be taken up before the modulus response can in theory be utilized.

However, the geotextile extension will theoretically fade out along the bond length of the geotextile from the assumed point of failure, and the design load and anchorage length should be reviewed against the total estimated strain.

Designs are not generally based on ultimate load conditions and, as previously intimated, partial safety factors must be given to materials, as well as to the overall mechanism. Such partially factored properties include the geotextile's tensile property (to account for general unknowns such as thermal variations, construction damage, environmental durability, non uniform straining) and its load transfer efficiency (to account for unknown contact efficiency and the soil strain being retained below the value at peak shear stress). Clearly the actual factors of safety used - whether overall or partial - will depend upon the application and the geotextile function.

Each application has its own construction problems which must be considered at the design stage. For example, reinforcement in 2 directions is normally achieved by cross laying. However, where only nominal transverse reinforcement is required, 2 directional strength geotextiles can be provided and the edges joined - usually by sewing. (NB: For high strength geotextiles (>50kN/m) it is usually difficult to achieve seam strength > 0.5 base fabric strength).

Other installation details such as anchoring or treatment at the face of a batter, should also be thought out in a practical manner.

5 RESTRAINING CONCEPTS

The concept of reinforcing earth is well known. Several systems and design methods have been proven while other concepts, such as anchored systems, are also becoming established (12).

The design methods which are well documented elsewhere (3), generally analyse the external and internal stabilities in turn.

Base sliding, overturning, rotational slip failure and bearing capacity should be repeated for total and effective stress conditions to examine long and short term stability. Empirical rules may apply and factors of safety determined on account of the permissible movements.

Internally, reinforcement tension and extension must be considered together with normal checks.

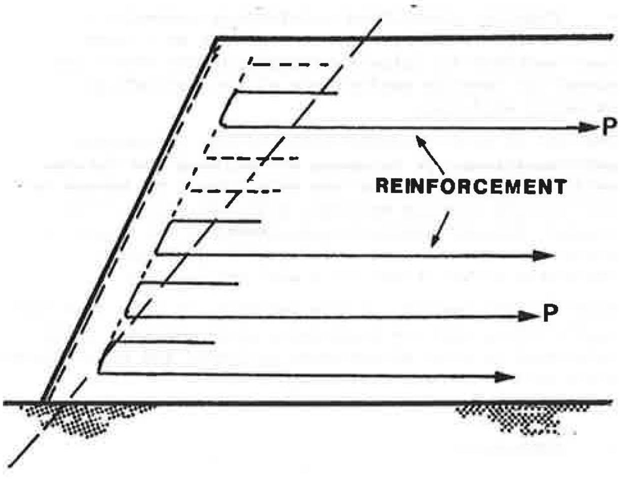

Fig 7. SLOPE REINFORCEMENT

Similar concepts can be used to reinforce steeply sloping embankments using geotextiles, and a method using charts has been put forward (13) for use under certain sets of conditions.

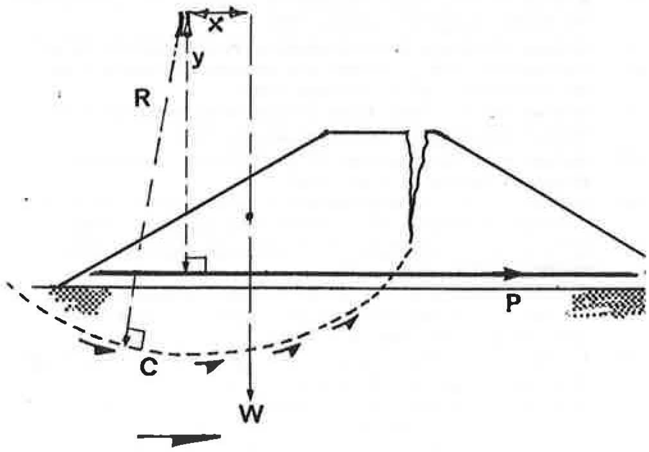

Fig 8. EMBANKMENT REINFORCEMENT

6 SUPPORTING CONCEPT

Similarly, geotextiles have been used for some time below embankments as reinforcing elements to enhance ease of construction, to even out settlement and to improve the factors of safety against shear failure (2).

Although geotextile mattresses have been employed, the application of a single reinforcing layer appears not to influence the bearing capacity of the subsoil directly

In a typical application the overall factor of safety for foundation stability and internal stability will reach unity without a geotextile. However, in order to increase the FOS (eg: to 1.5) an additional restraint is considered due to the fabric in which the required force is calculated using conventional circular or wedge analysis (See Figure 8), eg: conceptually summing the moments:

$$P \nless \frac{W x \times FOS - C.R.\,arc}{Y} \quad *$$

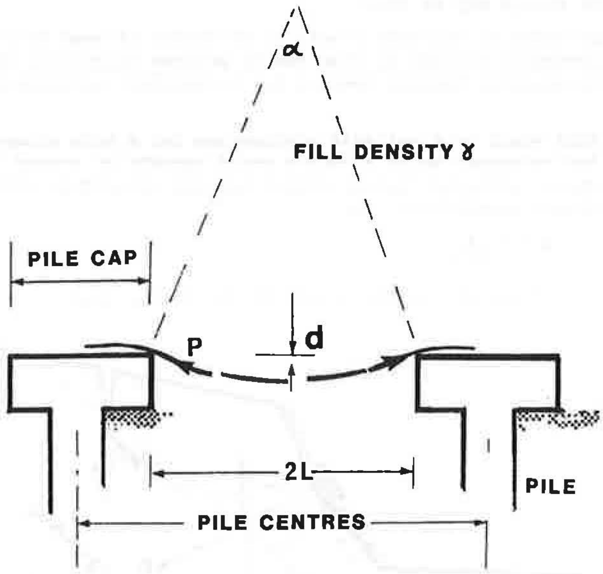

Fig 9. EMBANKMENT SUPPORT

Another idea gaining increasing interest is that of using a geotextile below an embankment to 'span' voids (14) or the caps of a piled foundation (15). For example, where a high strength membrane is required below an embankment supported on piles driven into a soft foundation, a design could be based on conventional piled embankment design methodology (16) adapted to include a geotextile.

With pile layout and caps defined, a preliminary design requirement due to the dead load can be derived using an assumed loading and deformation profile as illustrated in Figure 9, eg: conceptually for a catenary:

$$P \sim \frac{w.L^2}{2d} \sqrt{\frac{1+4d^2}{L^2}} \times FOS \quad *$$

$$\text{Where } w = \frac{L.\gamma}{3.\tan\left(\frac{\alpha}{2}\right)}$$

Raking piles are often installed below the batter to accommodate the horizontal thrust but the geotextile may also be required to take this load. The tensile requirement for dead load and horizontal thrust are then summed to determine required working load and a series of checks are applied.

*Such concepts are considerable simplifications. For example, the soil is usually less likely to suddenly shift the load onto the geotextile than it is to strain together with the reinforcement during construction. The engineer will advance his analysis from the conceptual towards a more realistic such design model and must carefully explore each possible scenario within the structure, mindful of the geotextile's likely modulus response.

7 STRESSING CONCEPTS

Geotextiles can be installed in a pre-stretched manner below embankments to rid any offset strain and could be used as prestressed elements to impart active load into a structure. The use of a tieback gives an ideal example, particularly where specially constructed rods or strips may be used.

In order to tie back a wall to an anchor of some kind a synthetic tie may be required to provide durability or to minimise bending tension due to backfill settlement.

This would be a suitable application for a zero crimp, low extension material which could operate at around 1% strain achieved through staged jacking coinciding with staged backfilling, eg:

$$\Delta L = \frac{L}{100}$$

Where ΔL is the strain at the design load.

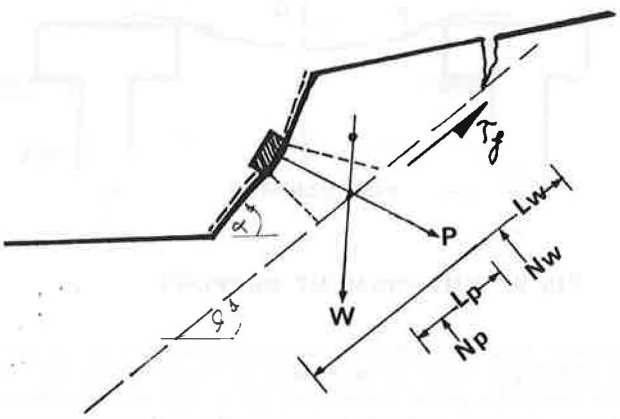

Fig 11. STRESSED SLOPE TIE BACK

The stressing of anchored ties is also appropriate to the nailing of slopes in cutting or "spidernetting". Using a simple analysis of the polygon of forces a preliminary stress requirement can be estimated, eg:

$$\text{If } \tau_{fw} = \tau_f(p+w)$$

$$P = \frac{W.\sin\theta - \tau_f}{\sin(\alpha - \theta)}$$

From that the capacity of the tie, the proof load (usually P x 1.5), the estimated strain and the block size (from the bearing capacity of the soil) is determined. Again, in practise, a more rigorous analysis will follow.

8 CONCLUSIONS

There are many existing uses of geotextiles in a reinforcing mode and still more under development. Often, their design and practise has already been well documented, and much authoritative work has been published on the behaviour of geotextiles in tension.

This paper discusses the general interface between geotextile properties and reinforced soil design parameters:

- A conceptual method of assessing long term tensile performance has been put forward.
- Load transfer mechanisms and the concept of strain, have been given as examples of other considerations which require attention at the design stage.
- Finally, simplified reinforcing concepts - some well established, others less so - have been sketched to illustrate applications where the potential tensile performance of the geotextile requires analysis.

The use of high strength geotextiles, in various configurations, is becoming established and further national specifications are soon likely to emerge on appropriate testing methods, although there still remain further research requirements, not least in pursuing the behaviour and durability of these materials under stress in a soil environment.

However, the demand of the industry is such that new applications and new techniques will continue to be developed as more adventurous end uses and sophisticated materials continue to be sought.

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