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Factors Influencing the Selection of Woven Polypropylene Geotextiles for Earth Reinforcement

Facteurs influegant le choix des géotextiles en polypropylène tissés poive le renforcement des sols

The growth of geotextiles in the construction industry has been rapid over the last decade and many types of geotextile are now well accepted in a wide range of civil engineering tasks.

Among current new possibilities is the use of geotextiles as earth reinforcement. The paper discusses the main properties required of geotextiles in this area of application, with particular reference to woven polypropylene materials. Some suggestions as to geotextile specifications are included.

L'importance des gèotextiles dans le domaine de la construction s'est rapidement accrue pendant ces dix dernières années. diverses sortes de ge'otextiles sont de nos jours utilises dans bien des travaux divers du genie civil.

Parmi les nouvelles possibilities actuelles, l'on trouve l'usage des ge'otextiles pour le renforcement des sols.

Le présent exposé traite des principales propriétés requises des ge'otextiles dans ce domaine d'application; l'on a fait particulièrement référence aux materiaux en polypropylène tissés. L'on a inclus quelques ouggestions en ce qui concerne les spécifications du ge'otextile

1. INTRODUCTION

Textile materials are now used extensively in civil engineering applications and have properties which perform the functions of separation, filtration reinforcement, and drainage in and through the plane.

Initially in Britain carpet backing type materials in both woven and non-woven form were used in simple applications such as temporary roads. These textiles were adequate for non-critical uses having physical properties such as weight, length and width in the roll at a cost acceptable to the user. They could be regarded as "first generation" geotextiles, and no particular design of the textile specific to their application was involved.

More use was made of such textiles over the next few years and as confidence grew more critical applications were tried successfully in the construction industry. It was realised that stronger fabrics gave greater insurance against failure and that the filtration function was also becoming more important. To meet these requirements heavier fabrics were used and more discretion was exercised in their design and application. It was generally appreciated that woven fabrics, weight for weight, performed a reinforcement function better than non-wovens but equally it was thought that the thicker non-woven provided a more efficient filtration function. Such fabrics could be termed "second generation" geotextiles.

At this stage of development, agreed specification and test methods were sought by both textile and construction industries. It was recognised that a range of well-designed geotextiles would be necessary to meet the range of applications and soil types. Manufacturers began to build into their products the physical properties demanded of a particular end use as dictated by the construction industry. For example composite fabrics are now available with separate elements providing strength and filtration functions in a bonded structure. Such fabrics could be termed 'third generation' geotextiles.

The above development has taken place in the last five to ten years and there is still much debate and study being made into the effective role of a geotextile. Standards, test methods and specifications have still to be agreed but at least some standards committees have been set up to study the problems. Meanwhile research into the use of geotextiles continues and as field experience grows more use is being made of these new building materials.

At present soil reinforcement using geotextiles is widely being examined, and field experience is being gained in a number of applications. Woven geotextiles are often favoured for soil reinforcement, and various raw materials and processing techniques are adopted. Although polypropylene is a cheap and relatively inert polymer it tends to be viewed less favourably than other polymers when reinforcement geotextiles are being considered. This paper attempts to show the potential of woven polypropylene geotextiles as soil reinforcement, on the basis of experience derived from extensive laboratory testing coupled with the construction of a trial geotextile-reinforced embankment (1, 2).

In order for a geotextile to act successfully as reinforcement in soil it must satisfy a range of criteria. It should be well suited, both physically and from a cost viewpoint, to the type and height of the earth mass in which it is to be placed. It clearly must be effective as a reinforcement, and should also have sufficient in-plane permeability to prevent local high moisture content zones in the earthfill. During construction it should be sufficiently robust to withstand normal site conditions yet should be capable of being handled easily. In addition, during the design life of the reinforced soil mass the geotextile reinforcement should not be susceptible to degradation, and continuing strains (creep) should be very small. The importance of these factors with regard to the potential of woven polypropylene geotextiles as soil reinforcement is discussed below.

2. POSSIBLE AREAS OF APPLICATION

It is important to recognise that there are a range of types of earth reinforcement. Consequently it should be expected that some geotextile reinforcements may be unsuitable for some of the more demanding jobs, while others may be too expensive for some of the less demanding jobs.

Several reinforcement applications are currently being investigated. These can be divided into two areas- those in which reinforcement is placed internally within earthfill, and those in which reinforcement is placed externally on an earthfill boundary. The former areas include reinforcement in edges of embankments to allow full compaction (3) reinforcement to allow the use of steepened sideslopes thus saving in fill volume and land area (1, 2), reinforcement in Reinforced Earth type retaining walls, (4) and reinforcement in poor quality fills. External reinforcement usually centres around reinforcement of soft foundation strata beneath embankments.

At one extreme these applications require only temporary reinforcement from the geotextile. For example edge reinforcement of embankments requires little more than local short-term strengthening of side slopes. Once construction is complete the stresses imposed on the geotextile are relatively small. Similarly the construction of embankments on soft ground can be facilitated using geotextile sheets placed on the subsoil surface beneath the fill. Once consolidation of the soft ground has occurred as a result of this loading, it may itself support the construction and the geotextile essentially becomes redundant (eg 5). In such applications the geotextile should have suitable tensile strength, stress-strain characteristics and adhesion or friction with the soil to enable it to reinforce successfully.

At the other extreme, however, the geotextile will be required to function continuously as effective reinforcement during the design life of the structure, for example, as with reinforced earth walls. In these applications not only will suitable tensile strength, stress-strain and adhesion characteristics be necessary, and with more stringent specifications, but also the long term preformance must be adequate. Creep or stress relaxation with time should be kept within certain limits, and degradation should be negligible.

3. WOVEN POLYPROPYLENE GEOTEXTILES AS EARTH REINFORCEMENT

The Lambeg Industrial Research Association (LIRA) and the Queen's University of Belfast (QUB) have for the last four years been examining the possibility of reinforcing soil with polypropylene woven tape geotextiles. Initially work was confined to the laboratory, and the basic relevant mechanical and hydraulic properties of sixteen different woven tape fabrics were examined. Laboratory research was then concentrated on the reinforcement effects obtained using polypropylene geotextile inclusions in samples of compacted clay.

It was found that significant reinforcement was possible, but was critically dependent on inclination of the fabric plane relative to shear plane direction (2) and also on other factors, notably the adhesion developed between the geotextile and the soil (1).

Since adhesion was of importance, a shearbox study was carried out using both stiff compacted clay and firm clay consolidated from a slurry. Under both drained and undrained conditions it was found that adhesion was in all cases greater than 70% of the soil control shear strength for normal stresses greater than 100 kN/m^2. For the tests each fabric sample was placed with the weft direction coinciding with the direction of shear because it had been found that adhesion resistance was greatest for this orientation.

Tests at lower normal stresses for the compacted clay revealed very variable adhesion with soil, in some cases less than 80% of the soil control strength. However tests with the much more compressible firm clay indicated much higher values. A most relevant finding (Figure 1) was that the adhesion resistance depended to some extent on the weft secant modulus* although other factors associated with geotextile manufacture are also thought to be important. Further details of the laboratory test series can be found in refs (1,2,6).

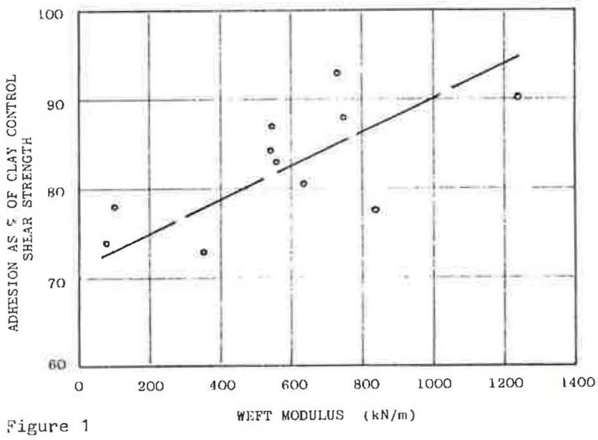

Figure 1

As the laboratory work progressed it became increasingly clear that if possible a field reinforcement trial should be attempted. This was felt necessary to investigate at full scale the viability of earthfill reinforcement with geotextiles. Consequently a full scale reinforced embankment trial was planned, and successfully constructed with the assistance of the Royal Engineers at a site within a military complex at Ballykinler, Co Down, Northern Ireland

* Footnote : The strip tensile stress-strain behaviour for the tested fabrics was linear to very good approximation. Therefore secant modulus = tensile strength ÷ breaking strain is considered a useful representation of deformation behaviour

The embankment was constructed to a height of 4m using cohesionless fill (uniform sand) available on site, and incorporated two geotextile-reinforced sections with side slopes of approximately 70° to the horizontal and two control sections with side slopes of approximately 30° to the horizontal. Laboratory testing demonstrated that the friction developed between the proposed geotextile reinforcement and the sand fill was likely to be very high (1).

In the reinforced sections of the embankment the geotextiles were placed in horizontal layers continuously across the embankment. In order to most efficiently resist the lateral stresses, following from the laboratory shearbox tests, the weft direction was placed laterally with the warp direction therefore coinciding with the long axis of the embankment. This arrangement made site positioning simple since the warp direction is the roll direction for woven tape fabrics. Overlaps of approximately 1m were used with no bonding used between sheets. A low strength geotextile (strength of 17.5 kN/m weft and 17.1 kN/m warp) was employed in the north reinforced section with 0.5m vertical spacing. In the south reinforced section a stronger geotextile (tensile strength 42.0 kN/m weft and 56.4 kN/m warp) was used with 1m vertical spacing.

The embankment performance has been very satisfactory as a clear demonstration of the beneficial reinforcement effects derived from woven polypropylene geotextiles. It was found that tensile strains developed in the reinforcement were set up during compaction. Subsequent bank height increases modified these strains only slightly, indicating the large importance of compaction stresses relative to the overburden stresses. Further details of the trial can be found in references (1,2,7).

4. TENSILE PROPERTIES

In reinforcement applications the tensile performance of the geotextile is of obvious importance. Tensile strength, modulus, extension at break and time-dependency of the tensile stress-strain relationship for the geotextile reinforcement will all influence the behaviour of the reinforced soil mass.

McGown et al (8) have drawn attention to the possible differences in geotextile behaviour when stressed 'in-isolation' as in common laboratory tests, and 'in-soil' as in soil reinforcement applications. As a result, a new laboratory method of determining the tensile performance of geotextiles whilst subjected to normal compressive stress acting through a soil medium has been developed by McGown et al (eg (8). Tests on a polypropylene woven tape fabric indicated that the load-extension behaviour was as would be expected, influenced by the orientation of the test specimen (8). However there was no influence arising from confining pressure.

This suggests that the tensile properties in warp and weft directions, while the geotextile is buried in soil, can be determined using suitable in-isolation laboratory tests. For many reinforcement applications-plane strain conditions apply. The geotextile will be placed so that the width is required to resist high stresses and the length is relatively unstressed. As pointed out previously in this paper the width direction of a woven tape fabric will correspond to the weft direction. Consequently it seems likely that a simple in-isolation laboratory test which can be used to determine weft (and warp) tensile behaviour may be useful not only in quality control but also in the design of certain types of soil-reinforced structure. Clearly more data and field experience is required before this can be confidently accepted. Nevertheless the following discussion, which relates mainly to strip tensile laboratory testing may be of more direct relevance than previously thought.

The upper limit of warp and weft tensile strength for woven tape geotextiles is often determined by the type of loom employed during weaving. For many manufurers polypropylene tapes of up to 3000 denier can be handled, and this sets an approximate upper limit on tensile strength for the completed geotextile of approximately 60 kN/m width.

The maximum height of geotextile-reinforced soil structure which can safely be constructed using such materials can be conservatively estimated using a simple expression, as used for example by Jones (9):

$$\frac{T_{Max}}{F} = K_a \cdot \gamma \cdot H \cdot \Delta H$$

where K_a - coefficient of active earth pressure.
γ - bulk unit weight of soil (kN/m^3)
H - height of structure (m)
T_{Max} - Tensile strength of geotextile kN/m)
ΔH - vertical spacing of reinforcement
F - Factor of Safety against tensile failure of the reinforcement.

Adopting a factor of safety of 3, and conservative values for K_a and γ it is shown that for a vertical spacing of 0.5m structures of 6m to 7m in height depending on fill type can be built. For a vertical spacing of 0.33m structures of up to 10m in height can be built. Taller structures could be constructed with composite-type geotextiles employing mainly polypropylene tapes but with a percentage of tapes made from another polymer. Alternatively double thickness fabrics could be used, although other considerations such as bonding or permeability may prevent this.

A lower limit on geotextile strength for reinforcement applications can be estimated with reference to the effect of stresses set up during compaction of earthfill placed on the reinforcement. The influence of compaction on lateral pressures behind retaining structures has been discussed, for example, by Ingold (10) and its influence has also been noted in connection with reinforced earth structures (11).

Experience gained from the geotextile reinforced embankment at Ballykinler also showed that during compaction significant tensile strains occurred in the geotextile sheets (1,2,7).

Development of geotextile extension with time allowed an estimate of the effects of compaction to be made, and at Ballykinler it seems to have been equivalent to at least 2m of fill. Factors of safety against tensile failure arising from compaction can therefore be determined by examining the performance of reinforcement placed at a level of 2m above the ground surface.

Since the laboratory strip tensile tests revealed approximately linear load-extension relationships for the woven tape fabrics used as reinforcement in the Ballykinler trial, factors of safety against tensile failure could be estimated by comparing the breaking strain from the laboratory tests with the in-situ strain recorded from the geotextile in the embankment.

For the section of embankment reinforced with the weaker fabric the min-factor of safety against tensile failure at the 2m level was 1.8. For the section reinforced with the stronger fabric the min-factor of safety was 2.3. Hence tensile stress developed in the fabrics as a result of compaction, T_c, can be estimated as follows:

(a) weaker fabric : T_{Max} = 17.5 kN/m
(weft) Breaking Strain = 1.2%
T_c = 17.5/1.8 = 10 kN/m approx.

(b) stronger fabric: T_{Max} = 42 kN/m
(weft) Breaking Strain = 6.9%
T_c = 42/2.3 = 18 kN/m approx

It can be seen that the stronger, less extensible fabric apparently develops more tensile stress during compaction than the weaker, more extensible fabric. Assuming a factor of safety of 2 against compaction stress failure suggests lower limits on tensile strength of 20 kN/m (more extensible geotextile) and 36 kN/m (less extensible geotextile).

Several factors will control compaction-induced stresses in geotextile reinforcements. These will include the type and weight of compaction plant, number of passes, type of fill and its friction or adhesion with the geotextile, and the tensile stress-strain behaviour of the geotextile. Consequently the estimates made above can only have approximate general relevance. The less extensible geotextile would be more suitable as a reinforcement material and a minimum strength of about 40 kN/m is therefore suggested.

The tensile deformation behaviour of a reinforcement geotextile is also of concern. This has been discussed by McGown et al (12) who suggests that the brittleness of the reinforced soil is to a certain extent controlled by the relative extensibility of the reinforcement. The laboratory tests conducted by the LIRA/QUB team using both sand and clay soils have shown little evidence of brittleness of soil samples reinforced with woven tape polypropylene geotextiles. These materials had weft extensions at break, measured from strip tensile tests in the range 6% to 20%. However a smaller range, perhaps 6%-12% would seen more appropriate for practical reinforcement purposes to limit extension.

As mentioned previously the weft secant modulus exerts some control over adhesion with clay, and from the laboratory tests (Figure 1) this should be in the range of 600 kN/m to 1000 kN/m. For a fabric with a weft tensile strength these imply extensions at break of 6% to 10%.

5. CREEP BEHAVIOUR

It should be noted that when a fabric is subjected to a load the deformation within the fabric has two forms -

(a) an immediate extension
(b) a slow time-dependent extension or 'creep'.

The creep component of extension is obviously an important parameter where reinforcement is of prime concern. Yet remarkably little has been published in connection with the creep behaviour of geotextiles in general and polypropylene geotextiles in particular.

In a well-conducted experimental study Finnigan (13) examined the creep behaviour of polyester and polyamide yarns and a woven polyester fabric. Van Leeuwen (14) also reports on the results of creep tests on woven fabrics made from polyester and polyamide. Table 1 summarises creep coefficients obtained from data produced from static tests in these studies.

TABLE 1

Polymer	Creep Coefficient (% extension per log 10t)	% Breaking load (approx)	Reference
Polyamide	0.4 (woven fabric)	50	Van Leeuwen
"	0.22 (yarn)	48	Finnigan
"	0.14 (yarn)	27	"
Polyester	0.2 (woven fabric)	50	Van Leeuven
"	0.28(woven fabric-warp)	50	Finnigan
"	0.17(yarn)	41	Finnigan
"	0.14(yarn)	23	Finnigan

Although not included in his original paper Van Leeuwen's creep data was later supplemented (ref 15) by information on a polypropylene fabric which suggested a creep coefficient of about 2.0 was relevant, in comparison with the much lower values recorded for the polyamide and polyester materials.

This data is frequently employed to argue against the use of woven polypropylene fabrics as soil reinforcement, particularly for permanent structures. However, as pointed out by Finnigan (13) and Klobbie (15) heat stretching can improve the creep properties of polymers.

More recently investigations into the creep characteristics of polypropylene yarns and fabrics have been conducted at the Lambeg Industrial Research Association (LIRA) and at the Queen's University of Belfast (QUB).

The work at LIRA (16,17) compared typical polyester and polyamide yarns used in geotextiles with polypropylene tape yarns. It was shown that by correct choice of raw materials and processing conditions it was possible to significantly improve the creep characteristics of polypropylene yarns, see Table 2.

Initial studies, using static load testing have been conducted at QUB, using a strong woven tape polypropylene geotextile which was selected off the shelf and which had not been processed specially to reduce creep. As can be seen from Table 2 the creep coefficients in both warp and weft directions are much lower than might be expected on the basis of yarn creep.

That for the weft direction, which is often more relevant in reinforcement applications, shows good comparison with the reported values from other polymers, see Table 1, although it should be noted that it was stressed at only 20% of its normal (strip tensile) breaking load.

TABLE 2

Polymer	Creep Coefficient (% extension per log 10t)	Material	% Breaking load
Polyamide	0.29	Yarn	40
Polyester	0.15	Yarn	40
Polypropylene	1.50	Yarn (untreated)	40
"	0.40	Yarn (treated)	40
"	0.73	woven geotextile (warp)	20
"	0.41	woven geotextile (weft)	20

Another factor which should be considered in relation to creep performance of reinforcement geotextiles is their in-soil behaviour. The tests mentioned were all done in isolation from the soil environment. There seems little doubt that creep behaviour will be modified by the confining influence of the soil, which itself is time dependent for fine-grained soils. Although creep rates might be expected to be lower in soil than in-isolation there is almost no relevant data currently available and research in this area is needed. Experience with the Ballykinler embankment trial has been less definite than hoped for owing to the very large percentage of geotextile strain gauges which failed to function both during and subsequent to construction. However for periods up to 50 days after construction increases in tensile strain with time were very small or, as in many cases, were non-existent. It is presently almost two years since construction was complete and there is certainly no visual evidence of movement in the embankment which could be related to fabric creep.

6 OTHER RELEVANT FACTORS

6.1 Degradation of Polypropylene

Degradation of textile materials can be classified into the following areas.

(a) Chemical Degradation
(b) Thermal Degradation
(c) Degradation due to exposure to ultra-violet visible radiation
(d) Other Environmental Degradation

The following notes summarise the current state of the art in the above areas.

(a) Chemical Degradation

It is well known that polypropylene has a high resistance to chemical attack. The effects of many chemicals on polypropylene have been investigated in both laboratory and field trials. The results of such experiments are well documented elsewhere (18). For civil engineering applications chemical attack save in the case of accidents would not normally be a problem. Generally polypropylene is only attacked by solvents such as Xylene, trichloroethylene (dry cleaning solvent), turpentine, gasoline and aviation fuel etc. Such chemicals are known to cause swelling of polypropylene at low temperatures, but for extensive damage to occur temperatures in excess of 100°C are required.

(b) Thermal Degradation

Polypropylene is generally regarded as being thermally stable for long periods at ambient temperatures. Work has shown that commercially produced polypropylene material (with no surface lubrications) exposed at 80°C for periods up to one year show no appreciable loss in tensile properties. On the other hand application of lubricants (to assist with further processing ie weaving) can accelerate the thermal oxidation of the materials, with resultant loss in tensile properties. Results show that such materials exposed for a one year period at 80°C can lose up to 50% of their original strength (19)

(c) Degradation due to exposure to ultra-violet and visible radiation

Unstabilised polypropylene is very susceptible to attack particularly by ultra-violet (UV) radiation,which causes rapid breakdown and loss in tensile properties. However this problem can be easily overcome by the correct use of stabilisation systems. Research work carried out over a long period of time has shown that even under extreme conditions of outdoor exposure (in Australia) it is still possible to stabilise the material in order that its lifetime is satisfactory. It was shown that samples exposed to these extreme conditions still retained in excess of 50% of their original tensile properties after a two year period of exposure (20). Thus for civil engineering applications long term UV stability should not be a problem. If care is taken with on-site storage and use, UV degradation should not be a problem with adequately stabilised fabrics.

(d) Other Environmental Degradation

Studies have shown that polypropylene is not attacked by chemicals or micro organisms commonly found in the environment. A detailed study of the effect of normal seawater and modified high alkaline seawater on woven polypropylene fabrics has been carried out (21). Results from this work show that, in the main, all fabrics retained more than 90% of their original strength after a one year period.

The above studies have shown that as far as woven polypropylene in civil engineering fabrics is concerned any environmental problems can be relatively easily overcome by a suitable choice of stabilisation system. However it must be remembered that such systems will add to the cost of the material.

6.2 Permeability

In general this will have little direct relevance to reinforcement and all that will normally be required of the geotextile is that it should not prevent the free passage of water while embedded in the fill. The woven geotextiles tested as part of the LIRA/QUB programme of research were adequate from this viewpoint. The minimum measured cross-plane permeability for these materials, using a simple 100 mm static head test, was 5 litres/m^2/sec.

6.3 Site Handling

Consideration should be given to the packaging and means of transport of geotextile rolls to the construction site. Once on-site the geotextile fabric should be given adequate storage since continuous exposure to the elements may cause weakening of the material as indicated elsewhere. Geotextile rolls are supplied with protective covers and these should not be discarded until the fabric is to be used.

Physical damage to the geotextile may be caused by the use of paper core tubes on which the geotextile is wrapped in the factory. If such paper cores are exposed to continuous wetting and drying they will degrade and possibly collapse if poorly stacked on-site. In particular, heavy rolls containing, say, 200 or more meters of geotextile should be provided with plastic cores which will allow mechanical handling methods to be used. It has been found that roll sizes greater than 100 m cannot be easily handled by site labour.

The geotextile manufacturers literature should be carefully studied with regard to storage conditions since reported damage may be subject to debate if poor site storage and handling methods are practiced.

For example during placement plant should not run directly on the geotextile. If cohesive fill is being used not less than 150 mm should be placed on the fabric before the passage of plant.

All geotextiles for reinforcement should be tough enough to withstand the rigours of site handling and placement. For example this includes the possibility of being torn by large angular stones occurring in the earthfill. Unfortunately it is difficult to devise a single test which would equate with this robustness requirement. Burst tests, grab tensile tests, wing tear tests, cone drop tests and wear tests have all been suggested. As in several other areas there is a need for generally agreed relevant tests for'robustness'.

7 CONCLUSIONS

Laboratory tests have shown, that woven polypropylene geotextiles have considerable potential as soil reinforcement. Fabric inclination was shown to be critically important.

A field trial has shown that the encouraging laboratory results could be reproduced at full scale. In addition the important influence of field compaction in initially stressing the fabric was shown to be important. This modifies to some extent the laboratory conclusions concerning inclination.

Application areas for woven polypropylene geotextile reinforcement (suggested specification below) which are currently feasible include edge strengthening and slope steepening of road and railway embankments, in waste or tailings embankments, and as 'load spreaders' beneath low embankments on soft ground.

A suggested specification for woven polypropylene tape geotextiles is as follows:

		Weft	Warp
Tensile Strength	≮ :	40 kN/m	Similar
Tensile Modulus	:	600-1000 kN/m	Similar
Extension at Break (%)		6-12	Similar
Creep Coefficient (% log 10t)	≯	0.4	0.6
Cross Plane Permeability (litres/m^2/sec)	≮	5	
roll width	≮	5m	
roll length	≯	100m (if labour only)	

Notes concerning site handling and placing should be carefully followed and in particular the warp direction should be placed in the long axis of the embankment, thus ensuring that the weft is placed in the load-carrying direction.

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