PARTICLE INTERACTION WITH REINFORCEMENT FIBRES AND ITS IMPLICATIONS ON THE USE OF NONWOVEN GEOTEXTILES IN SOIL REINFORCEMENT

P. R. Rankilor
Consulting Engineer, Rankilor Consultants, Macclesfield, UK.

R. S. Karri
Research Fellow, Department of Civil Engineering, University of Birmingham, UK.

R. Dawber
Researcher, The Bolton Institute, Bolton, Lancashire, UK.

ABSTRACT: This paper demonstrates that current in-air tensile tests do not provide the real in-soil stress/strain response of nonwoven geotextiles in either absolute or meaningful terms. It discusses critically important aspects of the tensile strength of nonwoven geotextiles that are not catered for in the current national and international tensile testing standards. In particular, the standard 200 mm by 100 mm test sample does not take account of fibre length and orientation in relation to the 100 mm gauge length nor the effect of the fill on the textile in real field applications. A novel piece of laboratory apparatus developed to demonstrate the effect of staple fibre length on real tensile strength, is described and laboratory test results are illustrated. The paper points the way to the need to develop a new tensile testing apparatus that will provide valid tensile strength results for all textile types. The paper describes the authors' view of the particle-to-particle and particle-to-textile interaction that takes place in a reinforced soil environment as the vertical load is increasingly applied during construction. The authors submit that this mechanism is not catered for in current reinforced soil design procedures.

1 INTRODUCTION

The fundamental problems that affect the majority of the Geosynthetic Industry's standard tests stem from the fact that these tests were originally and successfully developed for use in the clothing and domestic textile industries. Many of the tests used today for geosynthetics testing - and defined as national and international standards - were not developed for use in relation to the Civil Engineering and Geosynthetics Industries.

It is this creation and definition of 'standards' that concerns the authors of this paper. The term 'International Standard' conveys not only its literal meaning, but automatically suggests that such a standard is a well thought out, properly developed and (particularly) suitable method for testing which produces appropriate, useful results.

Unfortunately, this is far from the truth. The Geosynthetics Industry has conveniently 'adopted' and slightly 'adapted' what were standard in-air textile tests. These only described the properties of textiles for completely different and diametrically dissimilar uses - not for geotechnical purposes. In the laudable urgency to try and standardise tests, this fact has been overlooked and largely forgotten. Thus it is vitally important that these 'standard geotextile tests' should be recognised as, and regarded as, only temporary holding positions on the way to the development of new and realistic geosynthetic-related test procedures.

2 PROBLEMS WITH CURRENT PROCEDURES

Jaw clamp tensile and wing-tear tests have been shown over many decades to be suitable indicators of how a textile responds to the normal or exceptional in-air stresses to which they can be subjected.

In soil reinforcement including both reinforced soil applications and temporary access road design, a geotextile is always stressed in an environment where it is fully confined within soil. It never has two grips applied to it, to be stretched in open air.

Consequently, tests that simulate two grips with an in-air stretch cannot replicate or even resemble the in-soil stress scenario to which geosynthetics are subjected in practice, How, therefore, can they be expected to produce meaningful. let alone numerically accurate, results.

The authors propose that the properties of woven fabrics and geogrids, when tested in air by current standard tests, only 'accidentally' and approximately, permit those tests to indicate their useful in-soil tensile properties. The authors use the word 'may' advisedly since no current test procedures actually confirm this, but reinforced soil design practice indicates at least, that conventional testing must produce conservative results since they can be applied to current design theory with a very low failure rate.

However, it is not the objective of testing to be conservative - it should be factual. It is design that should be conservative - to a chosen degree that is based upon reliable test information. This, of course, raises the question of whether our current design procedures can be regarded as being comprehensive. This is also doubtful. No doubt they work in a crude way, with large safety margins, but there is little doubt that there is a need for improvement - particularly in the sense of developing design equations that can cater for stress applications involving highly extensive nonwoven geotextiles as well as relatively stiff geosynthetics.

There have been a limited number of case histories where structures have been built which should not have stood up or performed as they did, according to current design theory. Recorded strains (and thus stresses) in nonwoven reinforced soil structures have invariably been lower than they should have been according to our current design equations. The logical reasons for this are either that our current equations do not cater correctly for the presence of weak, extensible textiles (as defined by current tensile test procedures) or else, the current test procedures are not providing accurate indications of the properties that are being inserted in the equations. Possibly, of course, both of these apply. It is the authors' view that the latter suggestion is the true case. What is needed currently, are new test procedures to provide realistic data and modified design equations to use the new data realistically.

3 THE APPLICATION OF IN-SOIL STRESS TO A TEXTILE

If stress in the ground is not a matter of applying two clamp points and stretching the textile, then how is force applied in the ground?

In reinforced fill or in subgrade/sub-base reinforcement for example, it is the fill that imparts the stresses to the textile and not the other way round as is the mechanism applied in early in-soil tensile testing. Early laboratory testing clamped soil around a geotextile sample and then stress was applied to the textile, to observe how the clamping soil affected the textile's apparent stress-strain behaviour. The authors believe that this earlier work by researchers such as McGown et al (1982), although valuable, did not reflect the true in-soil mechanisms operating in structures where geotextiles were reinforcing soil fill.

The authors believe that stress is imparted into geotextiles, whether woven or nonwoven by the relative lateral movement of individual pairs or groups of particles in response to increasing vertical loading. This is quite in contradiction to the generally held image of the particles imposing a larger scale tensile force in the textile which extends along the full length of filaments. This inappropriate image supports the idea that long filaments of woven fabrics therefore act like tension strands giving support to the ground and that logically, therefore, short fibre or random fibre geotextiles such as nonwoven fabrics cannot sustain load and support fill in reinforcement applications.

The authors propose that this image is created by and reinforced by the 200 x 100 mm in-air tensile test itself. In this test it can be clearly seen that long filaments can bridge the distance between the jaws and thus woven fabrics can sustain the imposed loads where nonwoven fabrics cannot.

This is a serious error because it overlooks the fact that this is not the physical situation in the ground. Forces are not applied by widespread grip loads; rather they are applied to the textile by millions of tiny particle grip loads. This is shown in Fig.1 which shows the general principle of particle-spreading in a vertically loaded granular fill.

This in turn leads to a new concept of maximum grip length whereby effective loads are only capable of being imparted into a geotextile when the gaps between particles are smaller than the length of individual reinforcing fibres. This is a more accurate definition of the reinforcing mechanism since it acknowledges that woven geotextiles will act as excellent reinforcements in nearly all fills, owing to the long fibre length of a woven fabric, but it also recognises that nonwoven geotextiles can act equally well where the stress-imposing particle size is of a similar order of magnitude to the fibres of the textile. In the simplest scenario, as in Fig.2, it is seen that the fibres would have to be more than the diameter of the stress-imposing particles to obtain a suitable grip.

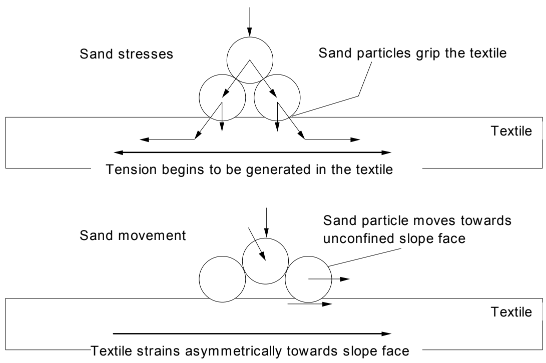

Fig. 1. Diagram showing the concept of the minimum grip length between particles and a reinforcing

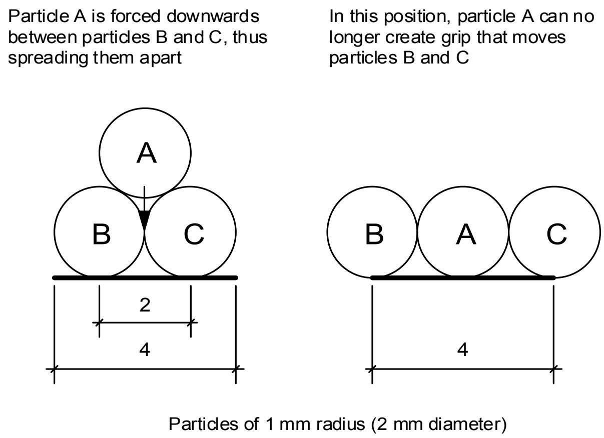

Fig. 2. Diagram showing the microscopic role of particles in the gripping and extension of a geotextile under soil reinforcement conditions with increased vertical loading.

This figure shows a notional fibre in relation to some equal sized particles.

Note that in the case of particles having a diameter of 2 mm, fibres ranging in length from 2 mm to 4 mm or longer can be gripped and can provide resistance to particle spreading. An individual fibre 10 mm long might, for example, be gripped along its length several times by pairs of 2 mm diameter particles. However, a two mm diameter spherical particle cannot grip a fibre shorter than 2 mm in length. Thus we elicit a general approximation that particles can ideally grip fibres of a length equal to or greater than the particle diameter.

How does this manifest itself in generating the overall absorption of energy within the reinforced soil mass? Consider Fig.3 in which arrows indicate the relative movement of many particles in the mass of a vertically faced reinforced soil wall. In this figure, it can be seen that all particles are constrained with regards to moving to the left (into the soil mass). Rather, they must all move to the right (outwards towards the free face of the wall). Thus, if there is to be horizontal strain imparted to the reinforcing geotextiles, then there must be differential movement between all particles on any horizontal plane and this is differential movement to the right at all times.

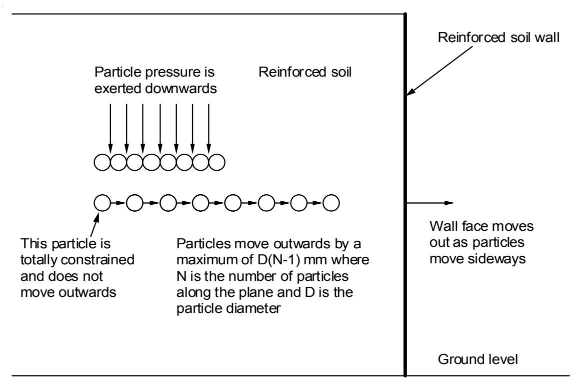

Fig. 3. Diagram showing how a compound outward movement develops as each particle is moved outwards sideways and moves its neighbour sideways also.

This explains how reinforced soil develops its internal stress absorption within reinforcing layers. Wherever the vertical or shear force is greatest along the reinforcement, that is the place where the particles are moved laterally the most.

This new concept leads to the additional conclusion that soil reinforcement will be as effectively achieved by nonwoven geotextiles as woven ones under particular conditions - which are by no means uncommon. Those particular conditions are where the soil grading and particle size are such that the soil can impose its load directly into the fibres rather than into the textile construction as in the case of woven textiles or geogrids

Fig.4 below shows how reinforcement is stretched by this micro-straining. Owing to the lack of possibility for textiles to strain inwards into a slope, any two particles that are straining apart as shown in the figure, must necessarily move outwards towards the face of the slope, with the outermost particle moving outwards more than the innermost one. Nonetheless, the mechanism allows both groups of particles to move apart, thus gripping and stretching the textile fibres, whilst creating a nett outward movement.

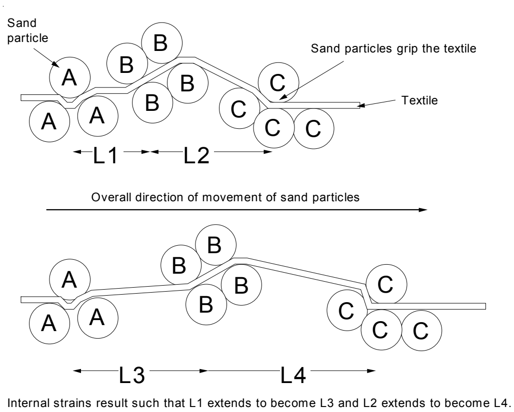

Fig. 4. Diagram showing the compound role of particles in the gripping and extension of a geotextile under soil reinforcement conditions with increased vertical loading.

In Fig. 2 one can see that the original grip length L1 increases to L3, whilst the grip length L2 increases to L4. Thus there is a nett movement to the right of the particle group C. In practice, particle group A will itself have moved to the right in response to vertical loads. This mechanism leads to the cumulative straining of the ground towards the open face of the reinforced soil structure.

This allows us to imagine the development of reinforced soil stresses in a completely new way, and leads us quickly to the ability to see how any new in-soil strength test must operate. It must apply and use the same principles.

In order to study and verify this concept, as part of a program of research into the construction of micro-models of reinforced soil the authors (Rankilor et al 2002) designed, created and tested a special set of clamps with variable spacers so that a textile could be tested with a jaw grip varying from say 100 mm to 2 mm or less.

Firstly the clamps had to be made with accurate grip edges that would operate very close to one another and with fillets that could be held by a spacer. Secondly, a special spacer had to be provided so that the clamps could be inserted and set to a pre-determined spacing whilst still being able to be clamped tight onto the textile sample. The spacer device was a simple block of expanded polystyrene with grooves cut into it. The clamps had fillets that fitted into the grooves. The textile was placed into the fixed spaced clamps and they were tightened up on it. The whole pre-clamped assembly was then placed into the tensile testing machine and tested to failure.

This operation was repeated for gauge lengths between 100 mm (being the standard gauge length for the BS tensile test for geotextiles) and 2 mm (being the smallest realistic gauge that we could achieve with the apparatus constructed).

By this means, one could obtain a simulation of particle size grip variation, whereby the clamp grip separation was representative of a variation in particle size grip lengths. Since this was a demonstration case, to make a scientific point, a nonwoven with well-aligned fibres was selected. The test results are shown in Fig. 5 below.

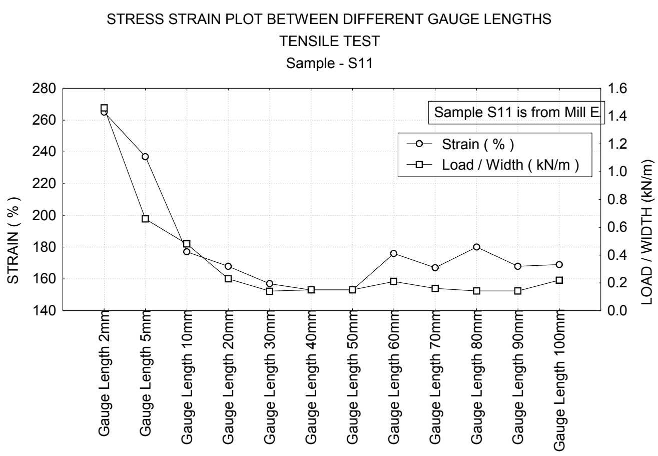

Fig. 5. Diagram using failure stress to show that the effective grip length of the tested nonwoven geotextile only starts to be exerted when gauge length is reduced below 20 mm. Note the non-linear scale of the bottom axis.

Fig. 5 shows combined stress and strain test results from the new apparatus, whereby the resistance of the fabric at failure and its extension are shown. These results are the statistically assessed values from ten individual tests at each gauge length - a total of 120 indivual tensile tests. It should be noted that the variation of results was relatively small.

Note that the right hand axis shows that as the gauge length decreases, so the necessary force to fail the textile increases substantially from about 0.2 to 1.4 kN/m width. This is an amazing increase in real in-soil tensile strength of some seven times! It is also important to notice the very rapid increase in grip strength which nearly all takes place between 10 mm and 2 mm gauge length. This demonstrates clearly that the short fibres are suddenly being gripped by both clamps and are exerting their polymer tensile resistance rather than just the entanglement frictional resistance.

The left hand side of Fig. 5 has to be interpreted with some care. The left hand axis is the strain at failure. In the case of this nonwoven fabric, the failure strain was around 160% increasing quite significantly to 270%, an increase of about one and a half times. Given the mechanism proposed by the authors (increasing grip on the fibres as the gauge length decreases) one would intutitively expect the extension at failure to decrease with decreasing gauge length. However, extension was recorded as increasing. The authors have recognised this as a point requiring further investigation and suggest in the first instance that the increase in strain percentage as the gauge length reduces, may reflect the nature of the fibre redistribution during application of tension across a small gauge length. Note that the actual strain induced was increasingly small with decreasing jaw gauge; strain at 100 mm was 160 mm (160% of 100 mm) whilst strain at 2 mm was only 5 mm (260% of 2 mm). It also is possible that the detailed mechanism of grip at shorter gauge lengths is different from longer gauge grip, leading to a slight increase in inter-fibre slippage. It is further possible that the method of recording the initial gauge is insufficiently accurate for strain measurements and consequently a consistent apparent increase in percentage is being recorded.

The experimental results as far as tensile strain is concerned are additionally interesting in that the experiment produced a slight fall in failure extension between 80 mm and 60 mm. The authors intend to investigate more nonwoven fabrics at different gauge lengths and different thicknesses to assess the grip implications in relation to tensile failure further.

4 CONCLUSIONS

This research work has demonstrated that when the grip gauge of the in-air tensile test was wide (greater than 20 mm apart) the clamps gripped individual fibres that depended for their resistance upon their entanglement. Thus, as stress was applied, a consistent value of stress around 0.2 kN/m at failure is recorded. This general failure value was recorded approximately between the standard gauge length of 100 mm and 20 mm. Once the jaw gauge reduced below 20 mm an increasing number of whole fibres were gripped by the jaws resulting in an increase in the failure strength. This rapidly increased until when the jaws were only 2 mm apart, the failure strength of the fabric was then 1.4 kN/m width - 7 times that of the standard geotextile test! It is possible that, given the appropriate technology, the strength of the nonwoven geotextile could increase further with an even smaller gauge length.

This simple experiment showed that the international standard geotextile test, in the case of this textile, would have underestimated its true in-soil stress reinforcement behaviour by seven times or more. It also explains why the standard in-air tensile test consistently under-estimates the real in-soil tensile strength of nonwoven geotextiles. Woven textiles and grids can transmit tensile forces along extended lengths by virtue of their mechanical construction; nonwoven textiles do this in a different way, utilising instead inter-particle grip on individual fibres or fibre clusters to impart tensile stress to the fabric.

It might well be expected that in-soil grip created by the intimate contact of small particles would obtain an even more effective grip on the textile fibres than in our experiment and would, in reality, produce an even more marked increase in tensile strength below the critical gauge length.

So far as the authors are aware, no publications by others have tried to relate particle size to the grip potential of a textile. Work was done about twenty years ago on the more obvious aspect of particle size in relation to large-opening grids, but not on textiles. The work on grids confirmed that there are optimum sizes of fill in relation to the grid interstitial dimension. However, this is a different concept entirely from a fibre length or orientation having a fundamental effect on grip in the context of a nonwoven geotextile

The experiment clearly demonstrates that the proposed mechanism for force transfer, being a logical one, accounts for the recognised but previously unrealistically tested higher strength of geotextiles in soil - particularly nonwoven geotextiles.

The paper introduces the first steps towards a new concept of particle diameter to fibre length in the use of nonwoven geotextiles in soil reinforcement.

5 ACKNOWLEDGMENTS

The authors would like to acknowledge with thanks, the support in the preparation of this paper of Polyfelt g.m.b.h., of Linz, Austria and Bidim S.A. of Paris, France.

6 REFERENCES

Mc.Gown, A., Andrawes, K. Z. and Kabir, M. H. (1982). Load-Extension Testing of Geotextiles Confined in Soil, Proceedings of the 2nd International Conference on Geotextiles, Las Vegas, 3, PP. 793 - 798.

Rankilor, P. R., Sarma, K. R., and Dawber, R. (2002). The Testing of Very Weak Geosynthetic Layers for Use in Micro-models of Reinforced Soil, 2002, 7th International Conference on Geosynthetics, Nice, France.