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The testing of very weak geosynthetic layers for use in micro-models of reinforced soil

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ABSTRACT: The proposed construction of very small scale micro-models of reinforced soil structures necessitated the use of very weak reinforcing layers to simulate geotextile and geogrid layers in the models. Consideration and testing of low weight geotextiles showed these to be too strong for this purpose. The location and testing of lightweight paper materials showed these to be much more suitable and provided real-scale properties which precluded the need to apply scaling factors or surcharging to the models. The paper describes the samples selected and the new frictional and tensile laboratory equipment developed to test these very weak products. It demonstrates that these particular types of product provide physical properties that can be used for the realistic construction of small scale, low strain micro-models. Paper provided selectable strengths of between 0.03 - 0.06 kN/m width with strain failure selectable between 5% and 25%.

1 INTRODUCTION

The authors are undertaking a program of research into the use of nonwoven geotextiles in soil reinforcement. One part of this is the construction, observation and analysis of micro-models of reinforced soil structures which allow the low-cost comparison of behaviour of nonwoven geotextiles with grids and woven products. This, in turn, will contribute to a new or improved theory for the design of nonwoven extensible geotextiles in soil reinforcement.

Similarly, the development of delicate testing apparatus and a new frictional tester has permitted the testing of real nonwoven geotextiles for incorporation into real reinforced soil structures.

For micro-model purposes, the authors needed to locate and investigate suitable ‘geotextiles’ that could simulate geotextiles and geogrids.

Initially, consideration was given to low strength geotextiles, but it was found that, as could be expected, these presented a reduced strength but exhibited very high strain levels at failure. It was considered that it would be advantageous to the development of, and particularly the observation of, realistic failure modes if very low strength materials could be located which presented realistically low strain levels at failure. Further, even very weak geotextiles were not weak enough to construct self-loading failure models.

Rankilor and Heiremans (1996) have published work on the frictional values exerted between geotextiles and sand but that work involved using full strength geotextiles on apparatus that was not designed to calculate friction values varying with vertical stress.

The authors of this paper were surprised to find that in the cross machine direction, certain lightweight papers had strain levels as low as 5% at failure, with consistent test performance. This opened up the potential for creating realistic models of real-life structures which would fail at low strain levels. This creates a novel aspect to this work.

Friction and tensile testing of these very weak materials presented some practical problems which were overcome by the development of a) a lightweight friction testing apparatus, b) a method for testing the friction of very weak materials, c) a grip for a standard tensile test apparatus and d) optical measuring techniques to measure strains on specimens using a digital video and still camera. Details of test procedures developed will be described in subsequent publications.

This paper describes the generic types of paper considered and tested for the work, as well as the individual products tested. Some test results are presented, together with conclusions as to the suitability of the materials for model work.

2 SCALING FACTOR CONSIDERATIONS

The usual problem associated with the construction of small scale engineering models is the necessity to apply scaling factors to the various properties in order to obtain an interpretable behaviour. In the case of a reinforced soil model, the input parameters can be kept extremely simple. This is particularly so if the model and the laboratory conditions are kept consistent and controlled. To this end, a standard laboratory condition of temperature 20 degrees Celsius and Relative Humidity 65%, were adopted. This was adopted because it was the standard ambient environment of the Institute’s textile testing laboratory; it was also relatively easy to establish and maintain. Paper and geotextile samples were stored and model experiments were undertaken under these conditions.

It was apparent that, if realistic micro-textiles could be found and developed, then realistic models of reinforced soils structures could be constructed and failed under their own self-weight loading. This has not, to the authors’ knowledge, been done before.

The procedure that was to be followed included developing a method for tensile and frictional testing of micro-textiles and then building models using methods that would emulate real construction and permit observations on strains and failures as models increased in size.

Previous work by Palmeira and Lanz (1994) acknowledged that the internal angle of friction of a granular material varies depending upon the overburden weight. The newly developed friction apparatus in this paper permits this to be calculated.

Palmeira and Lanz (1994) had used reinforcement layers that were too strong to permit their models to fail under their own self weight. Consequently, large surcharges had to be applied to generate failure. The authors considered that the use of such large surcharges (exceeding 58 kPa on a model measuring only 0.5m high) made the results of the model tests unrealistic in terms of extrapolation to full scale constructions.

The authors sought to construct micro-models which would fail under their own dead weight and with proportionate strain levels. Earlier good papers by others lacked only the use of appropriate reinforcements. In order to achieve a realistic model in all respects, the authors sought to find geotextile simulators of very low strength, but with realistic strain performance.

The authors located a number of suitable paper materials to act as micro-textiles. How they were located, together with detailed descriptions will be published in subsequent papers.

3 DEVELOPMENT OF LIGHTWEIGHT JAWS FOR TENSILE TESTING OF VERY LOW STRENGTH PRODUCTS

A new type of lightweight grip was developed as described in Figure 1.

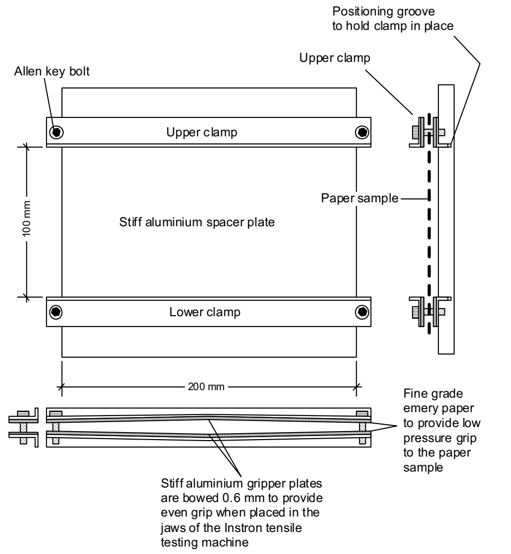

Figure 1. Diagram of special lightweight clamps developed for testing low-strength samples.

The grip was made of aluminium to reduce its weight, with a bowed centre, in order to provide uniform grip along the length of the very thin sample. The gripping surfaces were covered with a fine emery board.

The first part of the research was to use the newly developed lightweight jaws to examine a typical weak geotextile. This is the type of geotextile that has been used in previous research work. The authors conducted tensile tests and found that these textiles had the properties that made them unsuitable for real micro-scale model testing. The results illustrated in Fig. 2 show that the textiles exhibited strengths that were too high to be useful in the machine direction, when strains were satisfactory. They also showed strains that were too high to be useful in the cross direction, when stress levels might be useful.

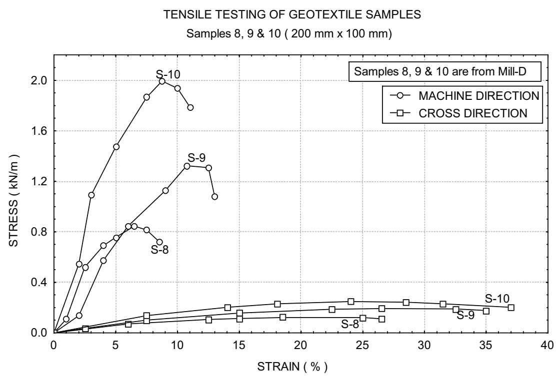

Figure 2. Graph of unsuitable results from the testing of weak geotextile samples. Either strength is too high or extension is too great at failure.

The graphs show that, for example, in the machine direction, weak geotextiles exhibit suitable strain at failure of around 10%, but at relatively high stress levels of around 1 to 2 kN/m. This is the right kind of strain to model a reinforcement geotextile, but the strength is too high to obtain gravity induced failure in a small model. Gravity induced failure models using this strength of geotextile would have to be almost full scale. Consider the results for the cross direction tests. These were less strong - around 0.2 kN/m - which were still stronger than ideal and, at the same time, these exhibited strains of the order of 30% at 'failure'. Models made of this material would strain unrealistically at failure. Even then, the level of stress at failure is relatively high at 0.2 kN/m.

It could be assessed that these weak geotextiles were not suitable for the purpose of building micro-models which would suffer self induced gravity failure. What was needed was some new material which was even weaker and yet exhibited the required low strain levels.

This is why the authors investigated the use of lightweight paper samples.

A range of very light weight papers were located and tested and it can be seen from the consistency of the test results published in Fig.3 below, that the new lightweight grip worked very well. It would have been possible to go to a narrower width of test sample, but the authors wished to maintain the exact size and aspect ratio of the standard geotextile test (200 mm width x 100 mm gauge) as used, for example, in BS 6906 Part II.

For model design purposes, close scatter plots that were obtained in extensive testing will allow a reliable assessment to be made of the performance of the psuedo-geotextile layers. This is particularly so in a model where the structure has numerous layers contributing to the overall performance. In models examining the behaviour of a single layer (basal embankment support for example), then an accurate assessment of the variation of performance can also be obtained from these tests.

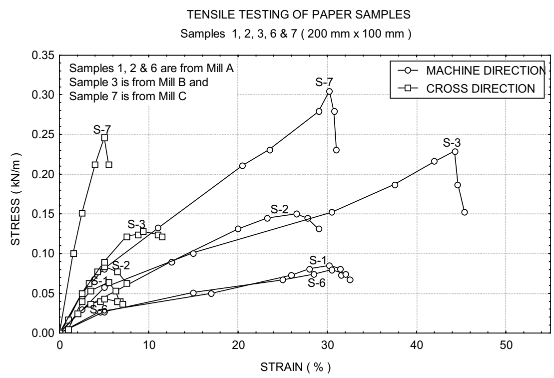

Figure. 3. Stress/Strain curves plotted for five very low-strength paper samples.

Perhaps the most exciting outcome of these tests is that the very weak paper samples can be used to represent relatively stiff woven geotextiles if incorporated into models in the cross direction and represent nonwoven extensible fabrics when incorporated into models in the machine direction. To the authors' knowledge, this is the first time that such a facility has been made available to reinforced soil modellers.

4 DEVELOPMENT OF A LIGHTWEIGHT VARIABLE-LOAD FRICTION TESTING APPARATUS SUITABLE FOR BOTH MICRO AND REAL GEOTEXTILE TESTING

Presently, the standard available apparatus for determining the frictional coefficient between a granular material and a geotextile has been the shear box. This is a slow and relatively cumbersome piece of apparatus. It is not suited for the testing of very lightweight textiles at very low vertical loads, as experienced in models less than say 500 mm high.

The authors needed a new apparatus that allowed a great range of vertical loads to be applied. The apparatus described below permits the application of loads varying between the equivalent of 0.05 m and 5 m of granular fill. The lighter loading end of the scale was necessary since it has been considered that the internal angle of friction of a sand will vary at light loads, depending upon the amount of the load. Since the object of this work was to develop testing on real geotextiles for full scale work as well as on micro-textiles for model work, this apparatus was designed to permit the confirmation of friction angles between granular fill and those materials at appropriate load values.

Fig. 4 below is a photograph of the apparatus developed for this purpose. It is essentially a rectangular funnel shaped box with a 100 mm x 100 mm aperture at the base and a larger opening at the top. The two essential parts of the apparatus are a table-mounted, levelled, specimen support plate to accommodate a small geotextile sample and a sand container. The test works with samples as small as A5 size (say 150 mm x 200 mm).

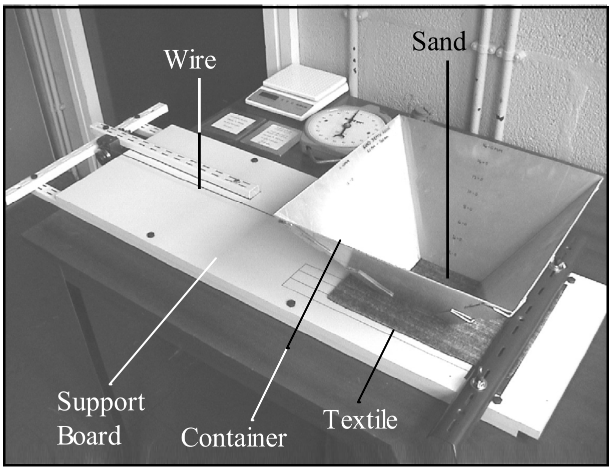

Figure 4 . Photograph of lightweight friction testing device developed for testing low-strength to high-strength samples.

5 FRICTION TESTING PROCEDURE AND RESULTS

Although the apparatus will work with smaller samples, A4 size samples were easily available and so it was decided to work with that size. Fig.4 shows a dark coloured textile placed beneath the container and held firm by the blue clamp. Sand is then placed within the container to a depth that was found to be optimal at around 30 mm. The wire is attached to the container at a low point (so that the application of lateral force does not disturb it vertically) and passes over a very low friction pulley to be loaded by weights. A bearing plate is placed on the sand surface and a given weight is placed on top of the plate. Then weights are added to the wire until the container just starts to move. This is taken as the friction point measured.

Previous calibration tests, measurements and calculations have provided the frictional effect of the container alone. This can be subtracted from the applied lateral force to measure the force necessary to just move the sand in contact with the textile.

By this means, we can measure the frictional resistance exerted by the sand interface with the textile at varying vertical constraining surcharges. Fig. 5 shows some results from the apparatus for a particular nonwoven geotextile, and for a very weak paper sample - illustrating that there is a non-linear behaviour with regard to coefficient of friction with increasing surcharge. This graph varies through relatively light loading to full model values. Note that the curves are similar in shape, but vary in magnitude as might be expected when considering that the paper is smooth compared with the geotextile, giving it a lower coefficient of friction.

The program tested 9 nonwoven needlepunched textiles, a weak geotextile and two very weak paper samples. A detailed report will be published later.

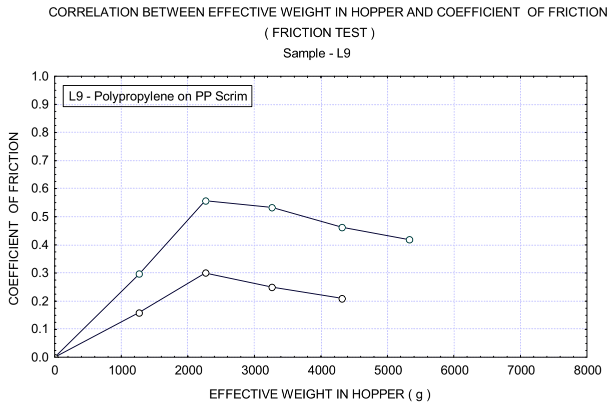

Figure 5. Graph showing variation in coefficient of friction for a polypropylene geotextile L9 (upper curve) and a very weak paper sample S6 (lower curve).

As might be expected, the coefficient of friction for the thicker, rougher nonwoven needlepunched geotextile was, overall, greater than that of the smoother paper product. It was interesting to observe that both illustrated a similar shape of curve.

The shapes of curve shown in Fig.5 are typical of the greater majority of results obtained from either paper or textile. This raises the question of whether the curve shape is reflecting the material or the fundamental geometry and stress imposition of the apparatus. This is presently under investigation. In stating this, the authors wish to be cautious, despite careful efforts to ensure that the frictional stress imposition onto the textile is understood and catered for in the geometry of the apparatus. Calibration tests were also undertaken to establish the influence of the apparatus on the test results.

Taking the results of the testing at face value, the coefficient of friction does not increase steadily from zero to a plateau level, as was expected, but exhibits a peak value which then falls away to an exponentially flat value.

The general level at which the coefficient of friction appears to stabilise is at a load of around 6,000 grammes effective weight in the hopper. This represents a real scale loading of about 0.30 m of soil surcharge. This is the upper level of height expected to be needed in the scale models. The friction test apparatus is capable of imposing vertical loads considerably greater than this, thus exhibiting a useful versatility of performance.

The value of measuring the coefficient of friction in this way is that it can be applied directly to model construction, in allocating appropriate coefficients of friction to different layers in a model.

Perhaps the most important result was that the apparatus gave different curves for different materials, thus showing that the results in principal reflected the nature of the surface being tested. This gave support to the hope that the curve shape itself was an intrinsic property of interfaces rather than an influence of the equipment.

6 CONCLUSIONS

The authors have developed two new pieces of apparatus for the tensile and friction texting of geotextiles and paper geotextile simulants. They have developed testing techniques that permit the evaluation of tensile strength properties and frictional properties for a range of weaker materials than has heretofore been possible. The frictional apparatus permits the testing of very weak materials with a wide range of vertical loading conditions.

The stress/strain ranges for located paper simulants lay between 0.03 - 0.3 kN/m width and 5% - 45% strain. This range of properties provides a useful source of material for different simulations varying between stiff grids, woven geotextiles and extensible nonwoven geotextiles.

Current research work by the authors has been made possible by the identification of tissue paper for model construction. This work includes the rapid construction of inexpensive micro-models in which low-strain failure is induced through natural gravity loading of the model without the necessity for additional surcharge.

The authors believe that the development of these new geotextile simulants, together with their use in gravity induced failure models will allow the realistic construction of models simulating real-scale constructions.

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