THE DEVELOPMENT OF A NEW INEXPENSIVE APPARATUS FOR THE MEASUREMENT OF FRICTION BETWEEN SAND AND LOW STRENGTH GEOTEXTILES.

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

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

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

ABSTRACT: The Authors describe the development of a new inexpensive apparatus for the measurement of the friction coefficient between extremely weak geosynthetics and fine granular soils, which can also be used with normal geotextiles and coarser soils up to gravel size. The apparatus provides the means for studying the frictional behaviour of all kinds of geosynthetics down to strengths of 0.03 kN/m. The apparatus confirms and quantifies the presence of friction coefficients that vary with vertical loading at model scales. This is useful for model studies of reinforced soil where pullout is being investigated.

1 INTRODUCTION

The authors are undertaking a program of research into the use of nonwoven geotextiles in soil reinforcement (Rankilor et al 2002). In particular, this research involves the construction of micro-models of reinforced soil structures using very weak tissue papers (0.03 kN/m failure strength) as reinforcing element simulators. Rankilor, Sarma and Dawber (2002) have reported on the development of the especially delicate tensile apparatus used to test the strength of these very weak materials. This paper reports on the apparatus developed to test the frictional coefficients existing between sand and these very weak geosynthetic simulators. Without a special apparatus, tissue papers simply disintegrate under the stresses imposed by conventional test equipment. This paper also describes some of the test procedures undertaken to obtain the output results.

The authors extended the work to demonstrate that this apparatus can also be used to measure the friction coefficients of fine granular materials against conventional stronger geotextiles. Test results are presented.

The research work undertaken revealed three interesting aspects of the interaction of textiles with frictional fill in soil reinforcement applications. The first was that a frictional coefficient could be measured between sand and very weak materials; the second was that fine particles bed into the fibres of nonwoven textiles creating the interface frictional link, and the third was that the coefficient of friction does vary with vertical loading under model-scale loads up to 12 kN/m2.

2 THE APPARATUS

The apparatus was designed to permit the testing of extremely weak tissue papers and textiles, without damaging them. This was impossible to achieve whilst the tissues were in their normal, unsupported condition. So it was decided to spray glue the tissues onto a piece of card or other hard material. By so doing, the adhesive coated the lower side of the tissue, thus supporting it, whilst leaving the upper surface of the tissue available for friction testing. This stratagem worked well and quite heavy vertical loads could be imposed on these weak tissues whilst the sand was sheared over them. The apparatus is capable of exerting very low frictional forces suitable for model testing purposes and of measuring the material/granular coefficient of friction without, or before, destroying the test sample, at varying vertical load.

Previously published work by Palmeira and Lanz (1994) discussed the laboratory model-scale phenomenon of coefficient of friction varying with vertical loading at low stress levels. Their test work implied that the coefficient of friction in a model would differ at the base of the model from at the top of the model. It was clearly necessary to investigate this further and to assess the impact on model construction. Such variation, if true, would be a scaling factor and if confirmed and quantified, could be numerically catered for in model design and construction. Gowayed and Magahzy (1994) and Rankilor and Heiremans (1996) have also published papers studying the frictional behaviour of geotextiles.

It was evident that a shear box would destroy the very weak papers being used for the present research work. Therefore, any new apparatus would have to be capable of measuring the coefficient of friction at very low vertical loads - sufficiently low as to not cause the paper to rip when sheared laterally. Also, the shear box is a slow, cumbersome and expensive piece of apparatus, so these aspects were also borne in mind in the present development work. The apparatus developed permitted the application of surcharge loads between the equivalent of 5 cm and 50 cm of granular fill, being the model requirement. It is capable of more - although this is presently unexplored.

Fig.1 is a cross-sectional drawing of the apparatus that was developed for the purpose. Fig.2 is a photograph of the apparatus as constructed. The setup comprises a rectangular funnel-shaped container made from thin steel sheet (hopper), which stands on, and is pulled over, the top of a sample of textile clamped to a rigid base board.

3 CALIBRATION OF APPARATUS FOR VERTICAL IMPOSED WEIGHT

Before tests could begin, the actual frictional weight being experienced onto any given textile had to be determined. To do this, the hopper was first placed on a frame over an electronic balance in such a way that the gap between the hopper and top of the balance was 1mm. The reading of the balance was checked to confirm no load was being transferred from hopper.

200 g of sand was placed uniformly in the hopper with a level upper surface. The reading of the balance (the apparent weight of the sand), the vertical height of sand in hopper and the true weight of sand placed in hopper were measured and recorded. On the sand in the middle of hopper, a small plate 6 cm x 6 cm was placed, which weighed 29 grammes. Again the reading of the balance and the total weight of sand and plate were measured and noted. Then a 1.0 kg weight was placed on the plate and the balance reading and the total weight placed in the hopper were measured and recorded.

The weight placed on the plate in the hopper was increased in increments of 1 kg and after every increment the balance reading and the total weight in balance were recorded. This procedure was continued until a total of 5 kg had been placed on the plate. A plot was prepared showing the relationship between the weights placed in hopper and the corresponding balance readings. Thus the vertical pressure on any textile was now known before experiments began.

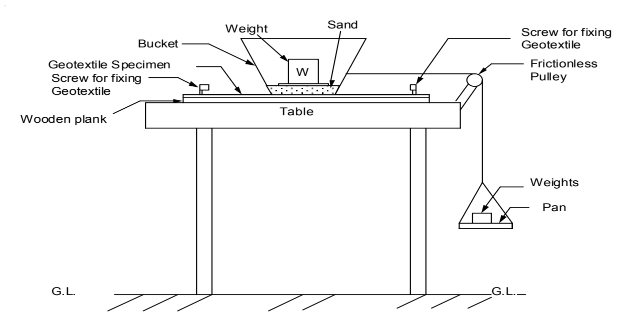

Fig.1 Diagram showing the schematic layout of the frictional apparatus developed for the test program.

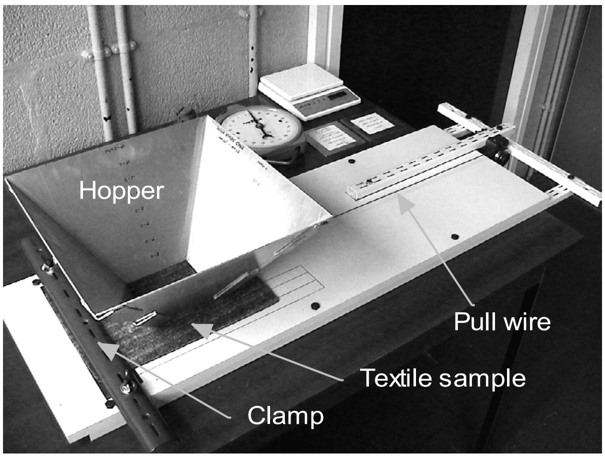

Fig.2 . Photograph of lightweight friction testing device developed for testing low-strength to high-strength samples. This apparatus has been illustrated previously in Rankilor et al (2002).

The above test is repeated with 400g, 600g and 800g of weight of sand and respective plots were prepared.

The simplicity of the apparatus is one of its advantages, but it should be noted that the configuration and method of application of the weight onto the sand through a developed load plate is the most important aspect of the apparatus. The size of the plate was designed and the thickness of the sand layer was selected such that the load placed on it would spread out downwards to exactly fill the 10 cm x 10 cm space at the bottom of the hopper. Thus, the downwards force would be distributed onto the textile and not onto the sides of the hopper. In any event, the calibration curves above informed us of the actual downwards force being experienced by the textile.

The shape and thickness of the sand also ensured that the sand did not move upwards in the hopper when being dragged over the textile. Even so, it is the starting friction that was important to us for use in reinforced soil failure models. This could be reliably determined from the applied horizontal load against the calibrated applied vertical load.

4 FRICTION TESTING PROCEDURE

The experimenting was done with A4 size specimens, but the apparatus will work with smaller sized specimens if required, down to say 15 cm long x 12 cm wide.

Fig.2 shows an A4 sized piece of geotextile placed beneath the hopper and held firm by a metal screw clamp. Sand was placed within the hopper to a depth that was found by experiment to be optimal at around 30 mm. The wire was attached to the hopper at a low point (so that the application of lateral force did not tend to lift the hopper) and passed over a low-friction pulley to be loaded by weights. The 6 cm x 6 cm bearing plate was placed on the sand surface and a given weight was placed on top of the plate. Then weights were added to the wire until the container just started to move. This was taken as the friction point and was recorded.

Previous calibration tests, measurements and calculations provided the frictional effect of the empty hopper, so this was subtracted from the lateral force applied to move the hopper when filled with sand.

By this means the frictional resistance exerted by the sand interface with the textile was measured at varying vertical constraining surcharges.

5 TEST RESULTS

Fig. 3 shows results from the apparatus for nine standard nonwoven geotextiles, a very lightweight geotextile and for two very weak paper samples - 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 differ, as might be expected when considering that the paper is smooth compared with the geotextile, giving it a lower coefficient of friction.

The graphs allowed us to observer a direct relationship between the g.s.m. property of the geotextiles and their peak coefficient of friction (See Fig.4). The test is based upon the initial movement point and thus measures the peak coefficient of friction of the sample. This is slightly higher than the continuous movement value which is not of design significance in the context of a modern design approach. Note that the rough heavier textiles, the very lightweight textile and the paper samples all exhibit a similar shape of curve rising to a peak and then flattening out, with the heavier geotextiles (See Table 1) all flattening out at about 0.4 as stress rises. Note that the lighter textiles exhibit lower values at those same stress levels and the very light textiles exhibit even lower coefficients of friction. The curve shapes were similar in form for each type of textile.

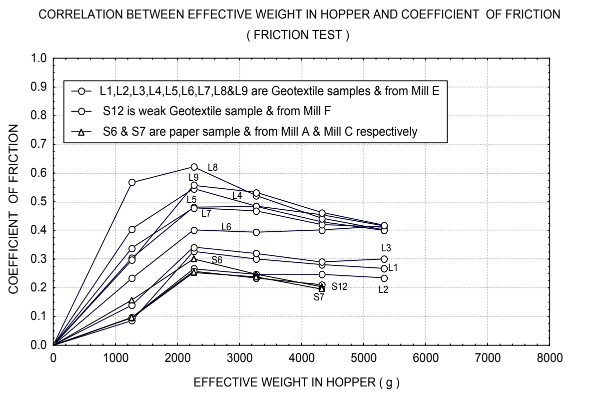

Fig. 3. Graph showing variation in coefficient of friction for 11 different samples Note the similarity between the weak geotextile and two very weak paper samples.

It was noted that the highest peak coefficient samples were those from a heavier range of nonwoven fabric weights - around the 350 - 600 g.s.m. level of weight. It is interesting to note that sample 6, which could have been expected to have a high coefficient of friction, in fact exhibited relatively low frictional behaviour before settling out at 0.4. This is probably attributed to geotextile surface structure as discussed below.

The general level at which the coefficient of friction appears to stabilise is at a load of around 5 kg to 6 kg effective weight through the hopper. This represents a real scale loading of about 0.40 m of model uncompacted sand surcharge. This is the mid-to-upper order of height expected to be needed in the scale models. The friction test apparatus is capable of imposing vertical loads greater than this, thus exhibiting a useful versatility of performance. If suitably modified, this apparatus lends itself to testing friction coefficients at real-scale stress levels both dry and under water with only a modest cost increase.

The apparatus gave different curves for different materials, thus showing that the results in principal reflected the nature of the surface being tested.

The purpose of this testing and 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. This is, to the authors' knowledge, the first time that this has been successfully achieved - especially with ultra-weak tissue paper materials. The results permit the design of models with known frictional grip at each height of the model for each reinforced element interface.

Table 1. shows the types and measured weights of the textiles.

Sample Notation	Type	Weight per Unit area (g.s.m.)
L1	PP	219
L2	PSP	152
L3	PP	163
L4	LPP	364
L5	LPP	356
L6	LPP	1456
L7	SPP	565
L8	Warp Reinforced PET	509
L9	PP on PP Scrim	567

Fig. 4 shows a close scatter and a significant trend of higher peak friction with higher g.s.m. weight. This work would benefit from more extensive testing to confirm and study this recorded trend.

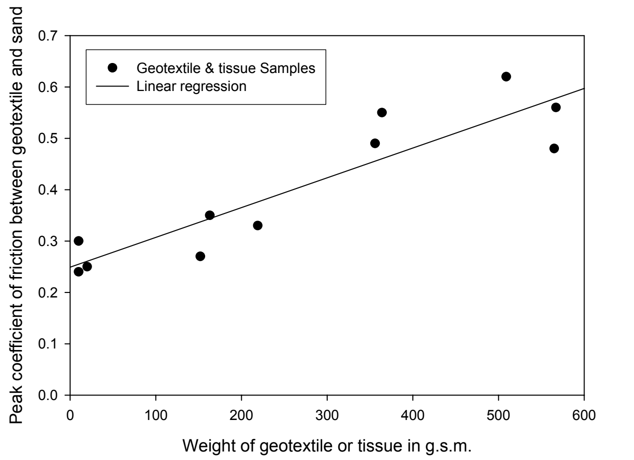

Fig. 4. Graph showing that peak friction coefficient increases with increasing fabric g.s.m.

6 EMBEDMENT OF PARTICLES IN FIBRES.

As the frictional testing progressed on the heavier textiles, it was observed that the finer sand particles became substantially embedded within the fibres of the textile.

This embedment was clearly going to contribute to the effectiveness of the grip of nonwoven geotextiles in soil reinforcement applications. No published papers, looking at this aspect, have been located so far in the literature study. The reason for this appears to be that the majority of works in the field of soil reinforcement have been done using geogrids or woven fabrics which do not have the same facility to form a three-dimensional soil/textile zone.

The iobservation made was that the friction interface between the sand and the textile, in the case of a nonwoven, became a composite layer in which both fibres and sand were intermixed. A regular pattern of embedment could be observed, relating probably to the needling characteristics of the geotextile concerned.

Fig. 5 shows the retention of particles on a nonwoven geotextile, within the composite sand/textile zone.

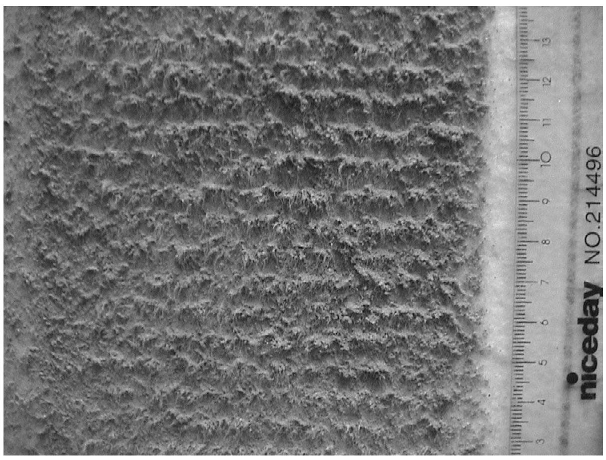

Fig. 5 Photograph showing the phased integration of sand into a nonwoven textile, reflecting the construction mode of the textile.

The photograph shows that after only a single pass of the apparatus, a deep in-textile compound friction surface had formed which very effectively transmits the frictional properties of the sand to the textile. This feature is likely to be not present on smooth woven textiles and most particularly not on grids or geomembranes which are unlikely to be able to form a composite layer upon minimal sample movements. Geogrids provide their excellent grip through having to drag their cross-structures through the fill.

However, there is clearly some relationship with the weight of the textile providing a sufficient thickness to create this zone, since the graph at Fig. 4 shows the clear correlation in this regard, and the outcome maximum coefficient of friction obtainable with each fabric. Note that the papers, having virtually no weight still exhibit a meaningful coefficient of friction. This demonstrates the reliability of the new apparatus.

7 COMPARISON WITH A STANDARD SHEAR BOX

Firstly, the natural angle of repose of the sand was measured using a simple cone test at 36 degrees. Then, a small shear box was used to check this and the findings of the new apparatus with regard to textile/sand shear values.

The new apparatus gave a uniform final coefficient of friction of around 0.4 between sand and textiles for most of the standard nonwoven geotextiles having shown different values at peak. This behaviour is significant for model testing and further conformational research would be useful.

Table 2. Comparison of coefficients of friction between textile samples and the sand fill used in the experimental work - from the new friction testing device and from the traditional small shear box.

Textile No.	Coefficient of friction (peak) from new device	Coefficient of friction (effective) from new device	Coefficient of friction from shear box
L1	0.33	0.26	0.42
L2	0.27	0.23	0.40
L3	0.35	0.30	0.47
L4	0.54	0.42	0.49
L5	0.48	0.41	0.62
L6	0.40	0.41	0.50
L7	0.48	0.41	0.55
L8	0.63	0.41	0.45
L9	0.56	0.41	0.51

8 CONCLUSIONS

The authors have developed a new apparatus for the friction testing of geosynthetics ranging from very weak tissue papers to heavy weight needlepunched nonwovens at relatively low vertical stress levels for the purposes of model construction. The apparatus has been used so far to measure the friction coefficient between these textiles and a sand. There is considerable scope for additional testing work to be undertaken using a wider range of geotextiles and different granular materials and using higher vertical stress values.

Test results obtained so far show that the peak of friction coefficients of different materials vary in direct relationship to the materials g.s.m weight, but as load stress increases, these values tend towards lower steady figures.

The apparatus confirms the concepts of Palmeira, and Lanz and quantifies them. It now permits researchers, building models of geosynthetic structures, to test and find the coefficient of friction between the chosen model fill material and very weak geosynthetic model reinforcement at different model fill heights. This eliminates estimation or guesswork and will improve the reliability of model construction analysis.

9 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.

10 REFERENCES

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, ICG7 - 7th International Geosynthetic Society Conference on Geosynthetics, Nice, France.

Palmeira, E.M., and Lanz, D., 1994, “Stresses and Deformations in Geotextile Reinforced Model walls”, Geotextiles and Geomembranes, Vol.13, pp 331-348.

Gowayed, Y.A., and El Magahzy, Y., “The Frictional Behavior of Nonwoven Geotextiles in Granular Soils”, 1994, International Nonwoven Journal, Vol.6. No.4, pp 66-71.

Rankilor, P.R., and Heiremans, F., 1996, “New Understanding of Frictional Properties at Geosynthetic/Geosynthetic and Geosynthetic/Sand Interfaces”, EuroGeo 1 Conference on Geosynthetics, Maastricht, Holland, Europe.