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Design and Characterization of Geotextiles for High Performance Applications
A94-8

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Students and Tentative Thesis Topics:

S. B. Mallick - Analysis of Frictional Characteristics of Geotextile-Soil Interaction
H. Zhai - Effects of Fabric Structure on Geotextile Performance
D. Lorrimore - Frictional Characteristics of Soil/Geotextiles
M. S. Sandhu - Measurement of Lateral Contraction in Needle-punched Geotextiles Using Image Analysis
C. Potluri - Puncture Resistance of Geotextiles under Biaxial Loading Conditions

Abstract

This study included a literature review, development of a pull-out box, and observation of the effects of normal pressure and displacement rate on pull-out performance of woven and nonwoven geotextiles. Three types of woven and four types of nonwoven geotextiles were used. Three levels of normal pressure and two different displacement rates were used. An Instron machine were used together with the pull-out box to apply the pull-out force. Plots of maximum pull-out capacity and displacement values were made. Effects of different granular soils were examined. Lateral contraction of geotextiles using image analysis methods was measured. A semi-empirical model for soil-geotextile interaction was developed.

Introduction

Geotextiles are essential textile products for various civil engineering applications such as reinforcement, drainage/filtration, stabilization and separation. They are used in roads, dams, landfills and other various civil engineering applications. According to a survey by the Industrial Fabric Association International (IFAI), the geosynthetic production in the US increased from 1 million square yards in 1970 to 368 million square yards in 1991. It is expected that the environmental awareness will propel the production of some of these materials to double by the year 2000. The survey also reported that fear of product liability due to improper design and execution is one of the major reasons facing growth predictions. Textile industry needs data to take advantage of this growth area to stay ahead of the global competition.

There is a mutual industry/university need to increase the amount of instruction and research in geotextiles. Geotextile products have become major components in many civil engineering structures, including dams, pavements, slopes and drainage facilities. Due to the need to upgrade the nation's infrastructure, there will be a big demand on new geotextile materials, test methods and application principles in the near future. Currently, there is hardly any formal research or education in geotextiles at the member universities of NTC. The call for increased education and research in the engineering application of new geotextile materials comes from former students who are mostly practitioners. In fact, our graduates who are working in geotextile manufacturing or in civil engineering applications of geotextiles, have noted the shortfall of our research and education in the area of geotextiles.

Objectives

The main objective of this project is to investigate the structure-performance relationships of geotextiles for different end use applications.

The objectives for this period were 1) to do a literature review on frictional behavior of geotextiles 2) to develop a simple, practical and inexpensive laboratory pull-out testing system 3) to evaluate the potential of the apparatus in simulating pull-out effect on geotextiles , and 4) to evaluate the effect of normal pressure and displacement rate on pull-out performance of woven and nonwoven geotextiles.

1. Characterization of Geotextile-Soil Interaction

One of the important factors in the performance of a geotextile reinforced soil structure is the stress-strain behavior of the geotextile when subjected to pull-out force. For example, if a geotextile is used along the side slope of a landfill, the stability of the slope depends on the stress that the geotextile can sustain and the displacement it undergoes, as the soil tends to move downwards.

Direct shear and pull-out tests are the two most important laboratory methods of evaluating soil reinforcement interaction parameters. An extensive literature review has been completed on the frictional behavior of geosynthetics in general and geotextiles in particular. The critical review of the literature search has been submitted for publication.

Several studies [1,2] have shown that laboratory pull-out tests can be used efficiently to obtain soil reinforcement interaction parameters. Though it has been observed that unlike woven geotextiles, internal structure may be more important than constituent materials in nonwoven geotextiles, at present there is a need for more research in this area. An extensive study is required to evaluate and compare pull-out performance of different types of woven and nonwoven geotextiles under different conditions (short term and long term performance) and to determine the effect of different types of soil on frictional behavior of various types of geotextiles. Research should also be carried out to observe the effect of boundary conditions on laboratory test results.

Development of the Experimental Set Up

A pull-out box of 36" length x 18" width x 18" depth, made of 1" thick ply wood, was modified for this work. The schematic of the box is shown in Figure 1. The box is used in conjunction with an Instron machine for pull-out test. The box is filled with soil up to 8" height in four lifts. Geotextile is introduced in the box with the help of a clamp through a slit (8" x 0.75") in front of the box. The box is then filled with the soil up to a height of 4" in two lifts. After placing each lift, the soil is compacted with a manual compactor. A steel cable wire from the other end of the clamp is fixed to the loading cell in the Instron through a pulley. An air-bag is placed on top of the soil in the box. The box is then covered by a wooden cover. After the cover is bolted on four sides and securely fixed to the box, the air bag is inflated to the required pressure level by an air pump. The loading cell in the Instron is then moved upwards to eliminate any slackness in the cable connected to the clamp with geotextile. Then the load is applied at a prescribed constant displacement rate of the loading ram. The results are obtained through a data acquisition software in a microcomputer. The data include pull-out load and front end displacement of the geotextile. Loading is stopped if the displacement exceeds 10" or if the geotextile fails in tension.

The current pull-out box does not have the strength to withstand high lateral pressures. Therefore, a new pull-out box has been designed. The new box will be made of metal and will allow moisture in the soil. Moreover, since the maximum capacity of the current Instron is only 1,000 lbs, a new Instron with a capacity of 20,000 lbs has been ordered for the geotextile project. The expected shipment date is early September.

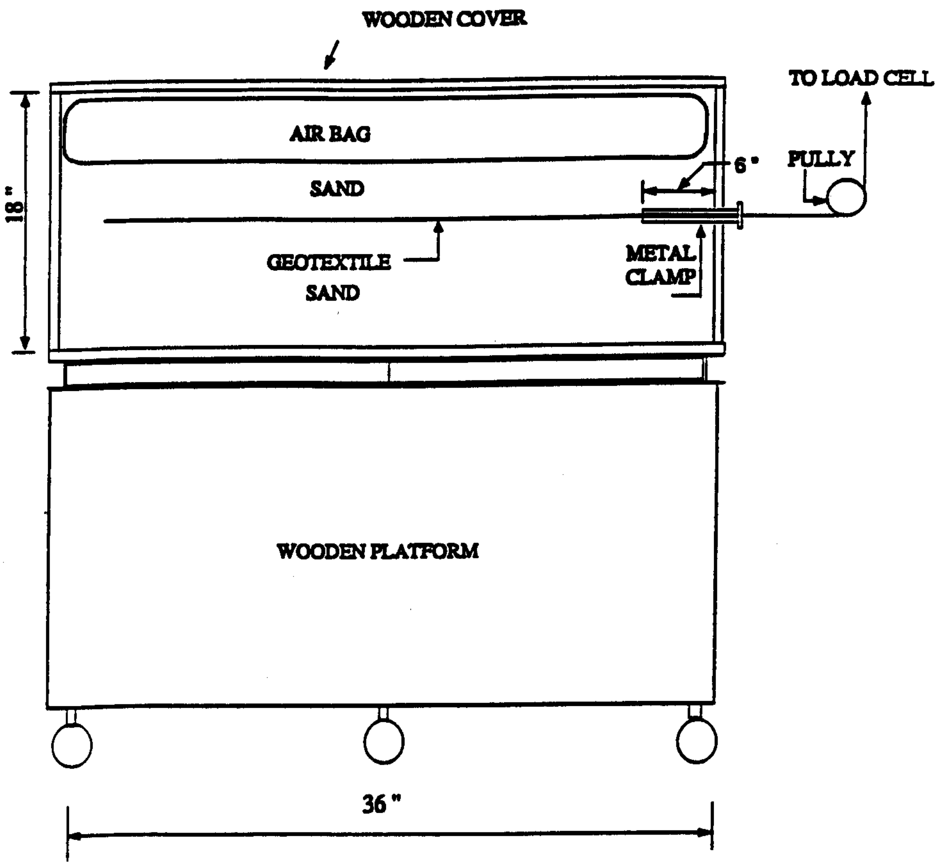

Figure 1 Schematic of the pull-out box

Geotextile Fabrics Used for the Pull-out Tests

Three types of woven and two types of nonwoven geotextiles were selected for pull-out testing. The specimens were 4" wide, and the embedment length was 28". Two types of blasting sand were used: coarse and medium. The following geotextiles were used in the tests:

- Mirafi 600X, woven, polypropylene
- Mirafi 700X, woven, polypropylene
- Woven slit film (Synthetic Industries), polypropylene
- ~~Trevira spunbond, polyester~~
- Typer 3601, spunbond, polypropylene

Test Results

Some of the test results are shown in the Figures 2-7. From the tests results, the following observations are made.

1. For the woven geotextiles, peak pull-out load for slow tests occurred at larger displacement with only one exception.

2. Woven fabrics showed an increase in both ultimate strength and displacement at failure with a decrease

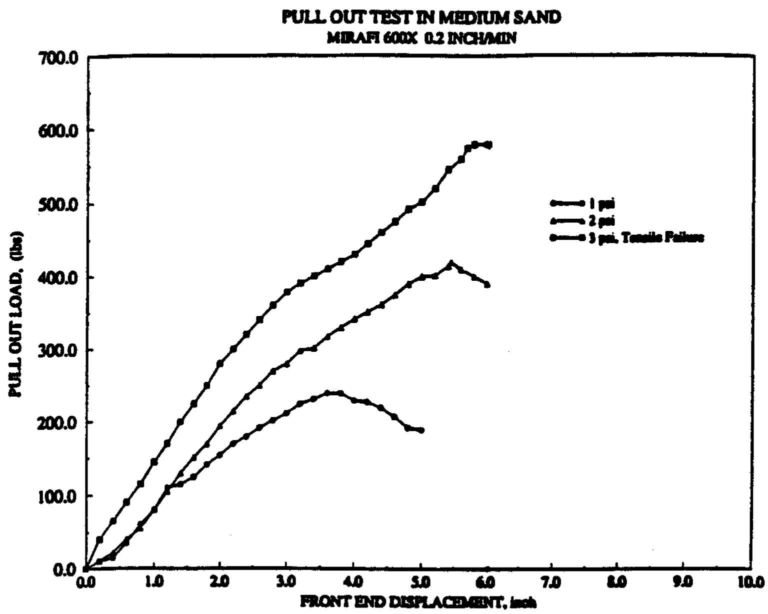

Figure 2 Pull-out load versus elongation for Mirafi 600x

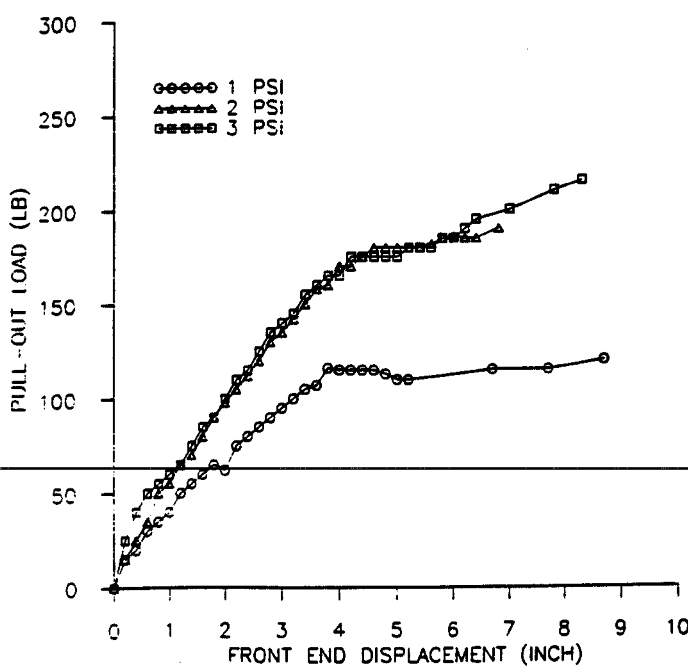

Figure 3 Pull-out load versus elongation for Trevira Spunbond (1"/min)

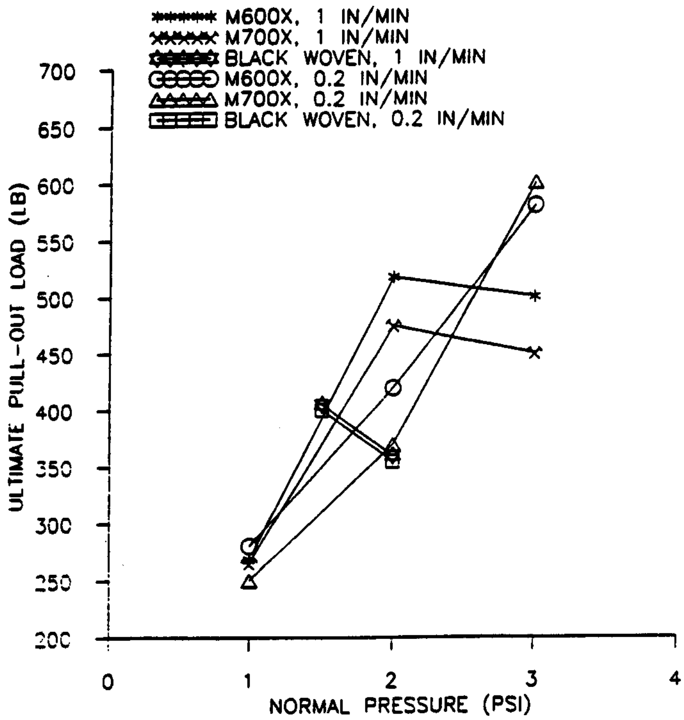

Figure 4 Ultimate pull-out load versus normal pressure for woven geotextiles

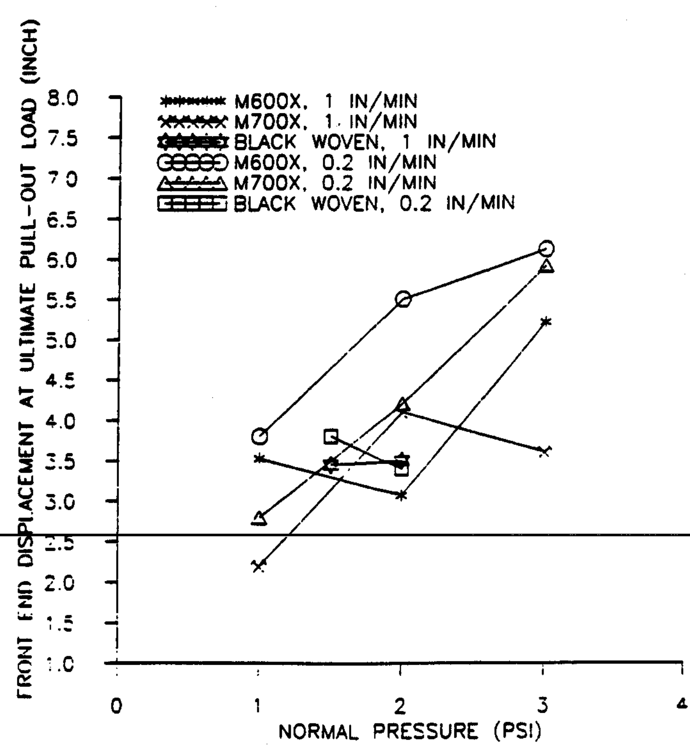

Figure 5 Elongation at ultimate pull-out load versus normal pressure for woven geotextiles

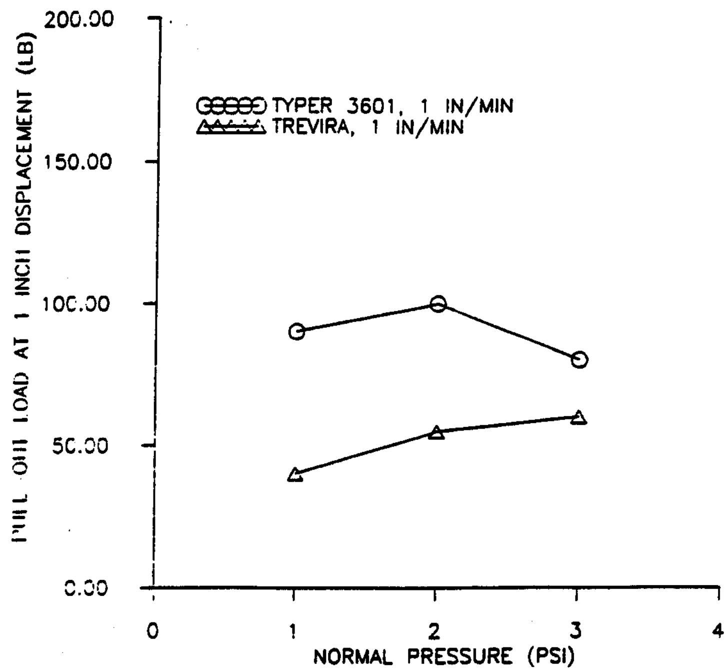

Figure 6 Pull-out load at 1 inch displacement versus normal pressure for nonwoven geotextiles

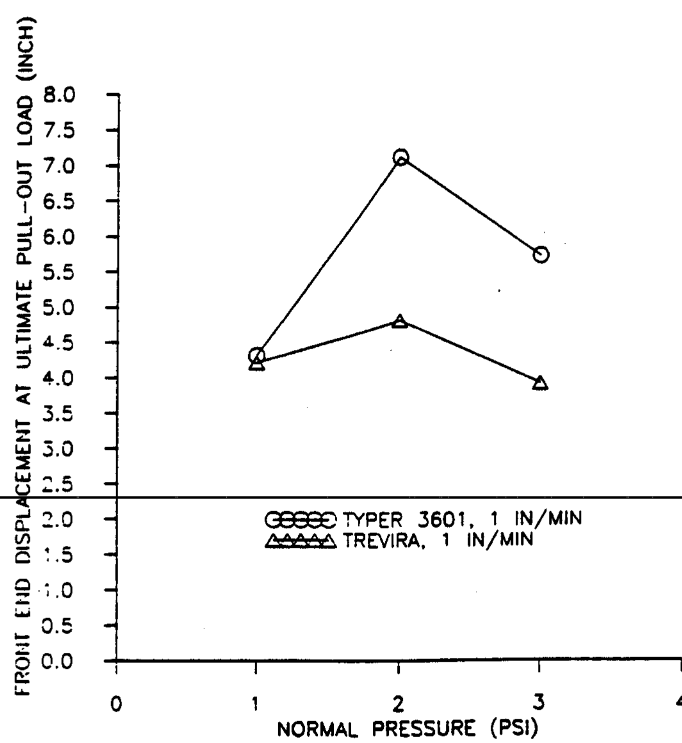

Figure 7 Elongation at ultimate pull-out load versus normal pressure for nonwoven geotextiles

in test displacement rate. For example, in the case of Mirafi 700X, ultimate strength increased from 450 lbs to 600 lbs and displacement at failure increased from 3.6" to 5.9" with a decrease in displacement rate from 1 inch/min to 0.2 inch/min.

3. In the case of nonwoven Typer 3601, the fabric failed in tension at 2 and 3 psi. At 3 psi ultimate strength and displacement at failure were less than those at 2 psi.

4. Though Trevira spunbond had larger apparent opening size than Typer 3601, pull-out capacity at 1" displacement for Trevira spunbond was less than that of Typer at 1, 2 and 3 psi. Post failure observation of Trevira spunbond and Typer 3601 showed that Trevira spunbond had undergone severe necking while no severe necking was observed in the case of Typer. It was concluded that due to severe necking, effective frictional area in case of Trevira spunbond was much smaller than that of Typer 3601, which resulted in less resistance against pull-out load.

5. From the test results it can be seen that there are marked differences between ultimate pull-out capacities of woven and nonwoven fabrics. This proves that the pull-out box used in the test program was able to show the difference between woven and nonwoven fabrics.

From the test results it was observed that the necking of nonwoven fabric had a significant effect on mobilized pull-out capacity of the fabric at a certain displacement. To prevent or decrease the amount of necking of the nonwoven fabric, it must remain embedded in cover soil throughout the test. Pull-out resistance obtained in the test is a combination of various mechanisms which can occur during pull-out of the fabric. The mechanisms for geotextiles may be one or more of the following: plane friction, three dimensional friction, tension of fabric fiber and passive resistance developed inside the thick fabric due to indentation of soil particle. Information related to the in-soil stress-strain response of a geotextile is very important for pull-out test.

A new pull-out box complete with a data acquisition system was designed to be built for future work. Strain gages and LVDTs will be used to measure local strains and displacements at different points of geotextiles. Actual vertical stress in the vicinity of geotextiles will be measured by earth pressure cells. Dilation of sand under high normal stress has a significant effect on pull-out capacity mobilized by the fabric. Information related to the vertical deformation of cover soil is required to measure the soil dilatancy during pull-out test. Larger depth of new pull-out box will help to measure vertical displacement of soil under normal pressure during pull-out test.

2. The Frictional Behavior of Nonwoven Geotextiles in Granular Soils

The nature of granular soil/nonwoven geotextiles was investigated. Tests were performed for two nonwoven geotextile fabrics and three granular soils under various vertical pressures (i.e. normal stress). A mathematical nonlinear model was used to rationalize the soil/geotextile behavior. This model takes into consideration three basic factors: i) soil/geotextile cohesion, ii) deformation of soil/geotextile contact junctions and iii) surface roughness. Normal stress versus shear stress results exhibited a nonlinear behavior. Analytical investigation of experimental results indicated that fine particle soils have higher soil/fabric cohesion component and lower frictional component than coarse particle soils.

3. Measurement of Lateral Contraction Using Image Analysis

With the advent of digital image analysis equipment, it has now become possible to convert analog images to digital form. The dynamic measurement of Poisson's ratio effect can be done by taking high resolution analog images of fabric deformation process using a high resolution video equipment and then processing these images on digital image analysis equipment. A high resolution telescopic lens attached to the camera and a high resolution video tape player compatible with high resolution monitor of image analysis equipment are used as supplement.

Such instrumental set-up has been successfully assembled and studies have been conducted to dynamically characterize the longitudinal and transverse deformation in fabrics [3]. The non-woven specimen is first imprinted with a 0.20" x 0.20" grid on a printing machine. The specimen is then mounted on an Instron testing machine and is illuminated with halogen bulbs. The background is covered with a dark cloth so that reflection of light can be minimized. A digital clock is placed in the view to record the whole process of deformation on a video recorder. The images, so obtained, are digitized using a commercial image analysis system. During image analysis, the previously imprinted grid marks are used to characterize the deformation.

Figure 8 shows the shape of a typical spunbond nonwoven fabric undergoing tensile deformation on Instron Tensile Tester. The lateral contraction is zero at the jaws and increases gradually to the maximum at the center of the specimen. The lateral contraction increases with increasing strain levels. For tracing the contracting boundary, markers are placed on several points along the boundary and their (x,y) coordinates are recorded. Coordinates of a reference point 'P', (x_p, y_p) are also recorded. Lateral contraction is calculated as follows:

$$\% \text{ Lateral Contraction} = (x_p - x) * 100 / \text{original half width of the specimen}$$

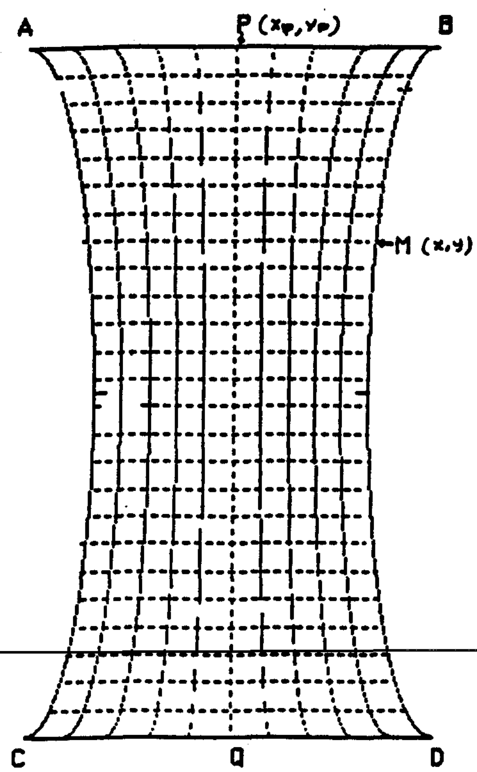

Figure 8 Lateral contraction of nonwoven geotextile

Percentage lateral contraction can be plotted against the relative position along the axis (i.e., $y - y_p$) to get the profile of contracting specimen at different strain levels. It is felt that this technique will be very effective in studying the deformation behavior of geotextile structures.

4. Puncture Resistance of Geotextiles under Biaxial Loading Conditions

Most geotextile materials, during installation or use, come under concentrated local forces normal to the fabric plane that may cause puncture failure in the material. The forces causing puncture are generally accompanied by moderate to high levels of biaxial in-plane stresses. The interaction of these forces and the resultant deformation is of particular importance for geotextile materials used in reinforcement and separation applications. In a typical case of puncture failure the geotextile material comes in contact with sharp or rounded aggregates under static or dynamic conditions while the geotextile material is under biaxial loading due to boundary constraints.

A literature review on the subject research shows lack of information in this critical area. In light of the present state of knowledge in this area, work has begun on developing the principles of a biaxial load-frame with a subassembly for puncture resistance measurement.

References:

[1] Cowell, M. J., and Sprague, C. J., "Comparison of Pull-out Performance of Geogrids and Geotextiles", Geosynthetics Conference-93, Vancouver, Canada.

[2] Richards, E. A., et al., "Shear Resistance Between Cohesive Soil and Geogrids", Geosynthetics Conference-89, San Diego, USA.

[3] Goswami, B. C., Anandjwala, R. D., and Bais, S., Heterogeneous Strain Development in Non-woven Fabrics, Project Reports submitted to NSF-NCRC Consortium.