A 94-B
DESIGN AND CHARACTERIZATION OF GEOTEXTILES FOR HIGH PERFORMANCE APPLICATIONS

Sabit Adanur (Leader), Yasser Gowayed , David Elton - Auburn University
Bhuvenesh Goswami - Clemson University, Youwang Wang - Georgia Tech
Tushar Ghosh - NC State

Graduate Students: Sumita B. Mallick, Honglian Zhai - Auburn University
S. S. Kukreja - Clemson University

Report Prepared by: Sumita B. Mallick

Goal

Performance Evaluation of Geotextiles under Different Loading Condition

Abstract

The National Textile Center has initiated an extensive study at the Auburn University from Spring 1994, to evaluate performance of geotextiles in different civil engineering applications. Two separate experimental approaches, in-situ and in-isolation, were considered to characterize the performance of a geotextile under diierent loading environments. One approach was to perform pullout tests and to evaluate the mechanical interaction between a soil and a geotextile with a numerical model using the load-deformation relationships obtained from the test results. In another approach, a tensile load was applied to a nonwoven fabric in isolation and the deformation of the fabric along with the reorientation of the fibers were investigated.

2. Characterization of the Mechanical Interaction between a Soil and a Geotextile

The study reported here is a part of the broad based research initiated by the National Textile Center to evaluate the performance of several geotextiles in different civil engineering applications. The objectives of this study are: (1) to perform pullout tests with woven geotextiles and evaluate the effect of fabric structure, normal pressure and soil types on the pullout test results, (2) to develop a critical review of finite element techniques available for analysis of pullout tests with soil and polymeric reinforcement, (3) to develop a finite element model to predict stress-strain and deformation-strain relationships of a reinforcement during pullout test and, (4) to validate results from the finite element analysis with experimentally obtained values and modify models until acceptable agreement between experimental and numerical results is obtained.

2.1 Pullout Tests with Woven Geotextiles

This study includes a total of 72 pullout tests with three woven geotextiles with different fabric structures, and 5 pullout tests with one nonwoven geotextile. These three woven fabrics have same apparent opening size, comparable grab tensile strength but different fabric geometry. Three types of sand (coarse, medium and fine) were used as embedment material for the pullout tests. Effects of fabric structure and soil properties on the pullout test results were analyzed in terms of ultimate or peak pullout load, pullout efficiency factors and the strain developed at different points of the geotextile. Pullout tests were conducted at 7, 21 35 and 49 kPa normal pressures. The tests were performed at a constant displacement rate of 1 mm/min. Statistical Analysis System (SAS) software was used to perform Analysis of Variance (ANOVA) and Duncan's test of multiple comparison. From the test result, the following observations were made:

1. Pullout load at 40 mm front end displacement increased with an increase in normal pressure levels. Between 21 to 35 kPa of normal pressure levels pullout mechanism changed from friction to a combination of friction and tension. Indentation of sand particles inside the woven structure of the geotextile increased the pullout resistance at higher normal pressure.

2. For the woven geotextiles strain at different points along the length of the fabric increased with increasing normal pressure. For the high extensibility of nonwoven geotextiles, strains at points away from the clamped end decreased with increase in normal pressure levels.

2.2 Critical Review of Finite Element Techniques

Katagiri et. al (1) conducted several pullout tests on geogrids and analyzed the test result by finite element method. From the experimental results a linear relationship between the normal pressure and the shear stiffness was obtained. A linear equation relating static friction and normal pressure was also developed. Finite element analysis was done to verify the validity of the constants in the constitutive relationships obtained from the experimental results. Joint element technique was used to connect the upper and lower surface of the geogrid with the soil particles. The results showed that the analyzed strain sufficiently covered the measured strain. Measured and analytical tensile stress at different points on the geogrid element were in good agreement.

Floss and Gold (2) conducted a finite element analysis on the efficiency of a single geotextile reinforced two-layer system. Soil continuum was modelled by a eight node isoparametric element with quadratic shape functions and for the geotextile isoparametric bar elements were used. To model the soil-geotextile interaction, thin-layer elements were used at the interface. An elastoplastic nature of analysis with Mohr-Coulomb yield criterion was adopted to limit the transfer of the load from soil to geotextile. Shear modulus and friction parameters of the interface were obtained from the pullout tests. From the analysis of the test results, it was noted that the deformation of the reinforced system was not necessarily smaller than the unreinforced system but the degree of plasticity of the reinforced system was distinctively lower than the other. Peak shear stress of the reinforced system was found to be 25% lower than the unforced system. Because of the reinforcement, the horizontal strains were also reduced significantly.

The load transfer mechanism at a soil-geogrid interface was investigated during pullout tests with single layer geogrid reinforcement and the stresses and strains along the geogrid were measured for different anchorage length (3). Numerical analysis was then carried out to simulate the operation. The CRISP finite element program was used to model the pullout test. The soil mass was modelled using quadrilateral element with a Mohr-Coulomb failure criteria. Reinforcement was modelled by a bar element with linear axial stiffness. A special type of joint element was used to model the interface region. Variable elastic modulus for different sections of the geogrid specimen was incorporated in the FEM analysis. Elastic modulus was calculated from the stresses and strains measured during the test at different points along the length of the geogrid. The residual shear modulus at the interface was selected on the basis of the assumption that the partial slippage would occur once the shear strength was reached. The results of CRISP analysis was in good agreement with the experimental results for the load and strain distributions. The technique of using varying elastic modulii was found to be effective to simulate the viscoelastic behavior of the polymeric reinforcement.

A finite element model was developed by Wu, Cho-Sen (4) to predict the stress-deformation behavior of a soil-fabric system. The model was formulated for both plane strain and axisymmetric conditions with a special provision to account for slip/separation at the soil-fabric interface. The external loading was applied to the system incrementally with large increments at the beginning of the load and smaller increments near the collapse load. The interface region was modelled by connecting the nodes with unilateral normal and tangential springs. The fabric was represented by a special element which could only withstand tension: no resistance to bending and compression was allowed in this element. A nonlinear strain-displacement relation was included in the analysis to take care of the geometric nonlinearity of the soil-fabric system. Material nonlinearity was also employed to simulate the stress-strain behavior of the soil and fabric respectively.

From the review of literature it was noted that the current trend in the modelling of a pullout test with a finite element method is to use a two-dimensional model with a truss (bar) element representing the reinforcing fabric. These types of models though comparatively less complicated than a three-dimensional model, are not very realistic in the simulation procedure. The major disadvantage of a two-dimensional model with a bar element as the geotextile is that, the surface friction (shearing load) developed between the soil and geotextile during the pullout test, is applied to the joint element (most of the cases two springs, perpendicular to each other) and not directly to the reinforcing fabric.

2.3 Development of a Finite Element Model

A linear finite element model was developed as a pilot study for phase 2 of this project. Figure 1 shows the forces considered on the fabric for the linear static analysis. For the pilot study soil particles was replaced by a shearing force at the surface of the fabric. Pullout load at the clamped end of the geotextile was estimated from the pullout load versus displacement curve and the analysis was conducted for the linear region of the load-deformation curve. A large scale general purpose computer program, MSC/NASTRAN, was used to analyze the model. NASTRAN was selected because it is a user friendly software with a built-in powerful iterative and incremental process to obtain solution for problems with material and geometric nonlinearity. Figure 2 shows the results obtained from the linear static analysis and the experimental results. As the figure shows there is a major difference between the analytical and experimental results near the clamped end. At lower front end displacement, pullout load is distributed only to the front part of the geotextile which is close to the load application point, Therefore, nonlinearity in the stress-strain relationship occurs near the clamped end of the fabric. In the next step, nonlinear-elastic analysis was adopted for the elements close to the clamped end. Figure 3 shows the element mesh for the nonlinear-elastic analysis and the parameter consideration for the analysis. Figure 4 shows the results obtained from the numerical analysis and the experimental results. From the comparison it was clear that the analytical and experimental results were in good agreement when a nonlinear stress-strain relationship was incorporated in the analysis procedure.

2.4 Future Work

The following modifications will be incorporated in the future work:

1. A three dimensional finite element model will be developed for the pullout test. Effect of surface friction and sand indentation into the fabric will be included in the model.
2. A nonlinear dynamic analysis will be conducted to model the load transfer mechanism in the pullout test.
3. Material and geometric nonlinearity will be introduced in the finite element model.

3. Measurement of Fiber Orientation Inside a Nonwoven Fabric Under a Tensile Load

Global and local transverse deformation of a nonwoven fabric, strained under an Instron Tester, was measured and the results were analyzed using an Image Analysis Technique. Lateral contraction profiles of a typical needle-punched fabric is shown in Figure 5. All specimens showed a gradual necking-in effect, which caused the development of a heterogeneous strain field in the specimen. The lateral contraction, in general, varied from negligible at the clamp to maximum at the center of the specimen.

The following observations were made from the study:

1. The necking-in phenomena occurred due to the end constraints posed by the jaws of the Instron Tester. The necking-in effect of end constraints was more pronounced in the wider (3 inch) specimen than the narrow (1 inch) specimens.
2. Narrow width specimens showed more uniform deformation that the wide width specimens. This phenomena was explained by Saint Venet's principle. In practice this principle implies that the irregular distribution of stresses caused by the method of applying forces, evens out as we move away from the point of application of the load. In isotropic, linear elastic materials, the stresses become uniform a distance equivalent to the order of one lateral dimension of the sample. However, in anisotropic materials, the jaws effects have been found to persist over much longer dimension compared to those of isotropic materials. As fabrics used here are anisotropic, as far wider width samples (3"), the jaw effect would persist for at least 3", whereas the stresses would become uniform after about 1" in narrow width (1") samples. Hence the narrow width specimens show more uniform deformations.
3. Because of less "edge Curling" effect, in wider samples, the lateral contraction percentage profile was much smoother than narrower samples.

4. References

1. Katagiri, T., Haneda, H., Mamoru, M., 'Steep Reinforced Embankment Using Geogrid: Laboratory Pullout Test of Geogrid and Its Finite Element Analysis", Geotextiles, Geomembranes and Related Products, Den Hoedt (ed.), 1990 Balkema, Rotterdam, ISBN 90 6191 1192.
2. Floss, R. and Gold, G., "Use of the FEM for the Single Reinforced Two-Layer System", Geotextiles, Geomembranes and Related Products, Den Hoedt (ed.), 1990 Balkema, Rotterdam, ISBN 90 6191 1192.
3. Yogarajah, I., and Yeo, K. C., "Finite Element Modelling of Pullout Tests with Load and Strain Measurements", Geotextiles and Geomembranes 13 (1994) pp 43-54
4. Wu, Cho-Sen, "Finite Element Analysis of Fabric Reinforced Sand", Ph. D Dissertation, The University of Michigan, Ann Arbor.

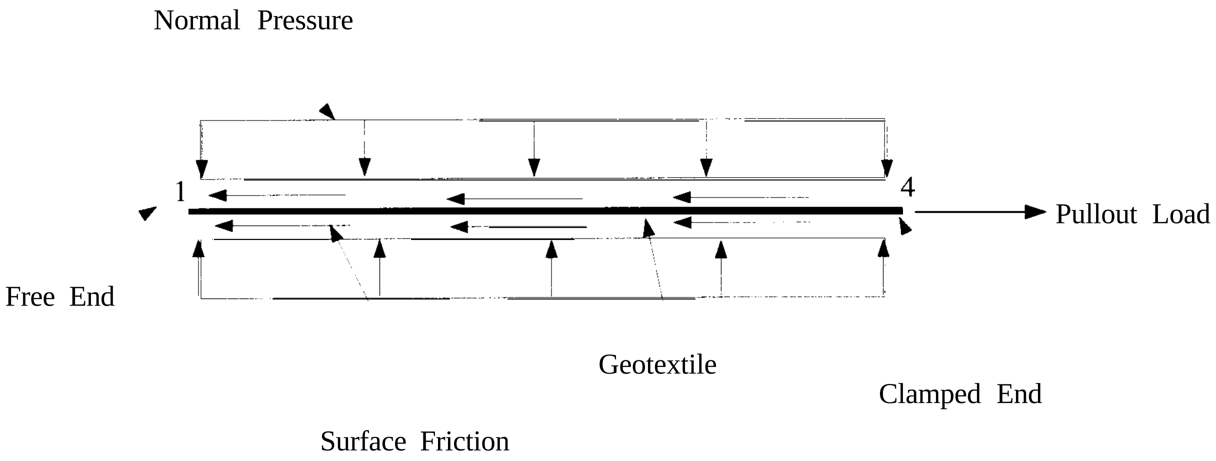


FIGURE 1 Forces Acting on a Geotextile Sample

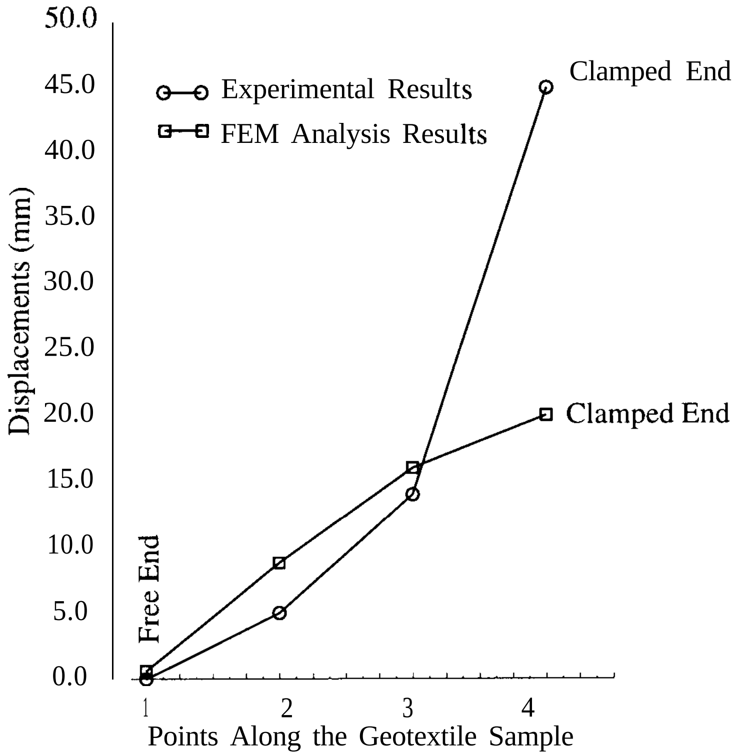
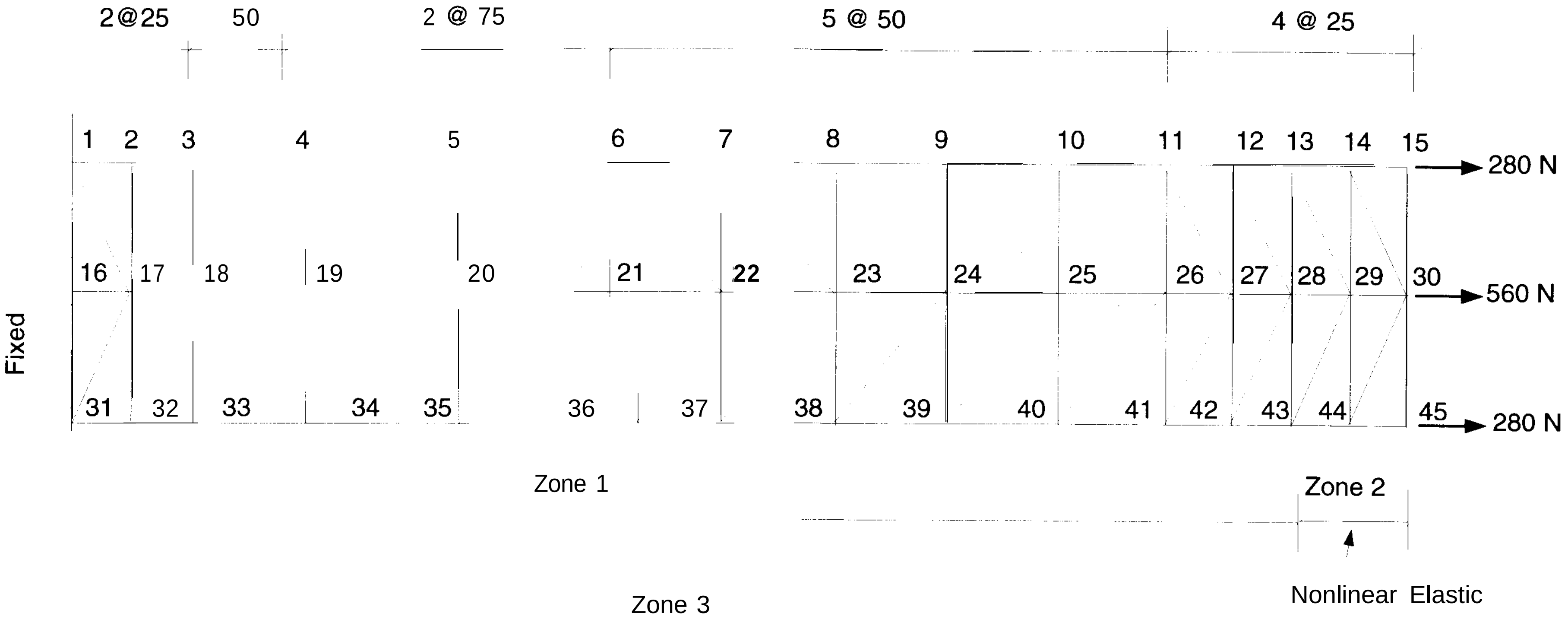


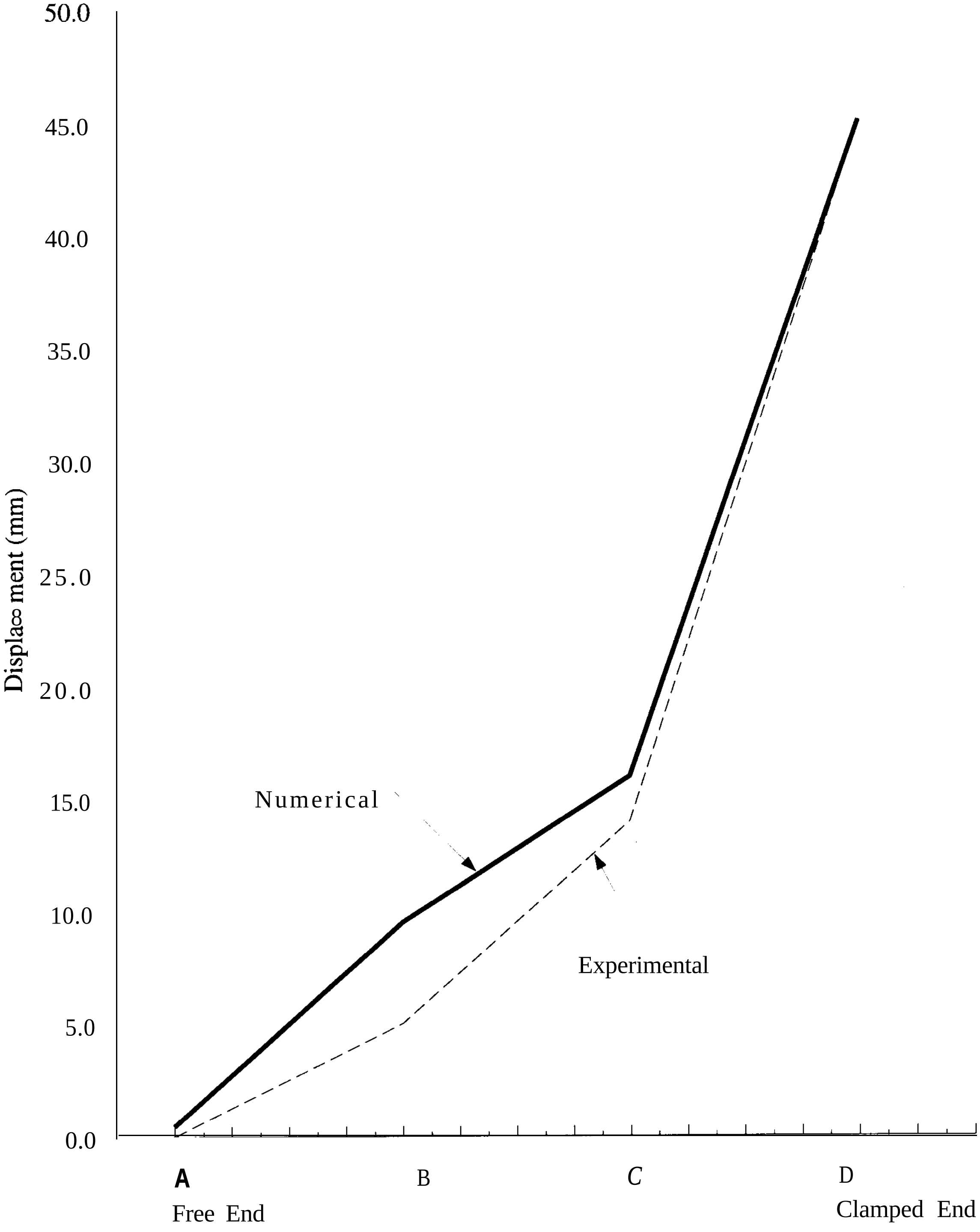
FIGURE 2 Results from Linear Static Finite Element Analysis



Note: All dimensions are in mm

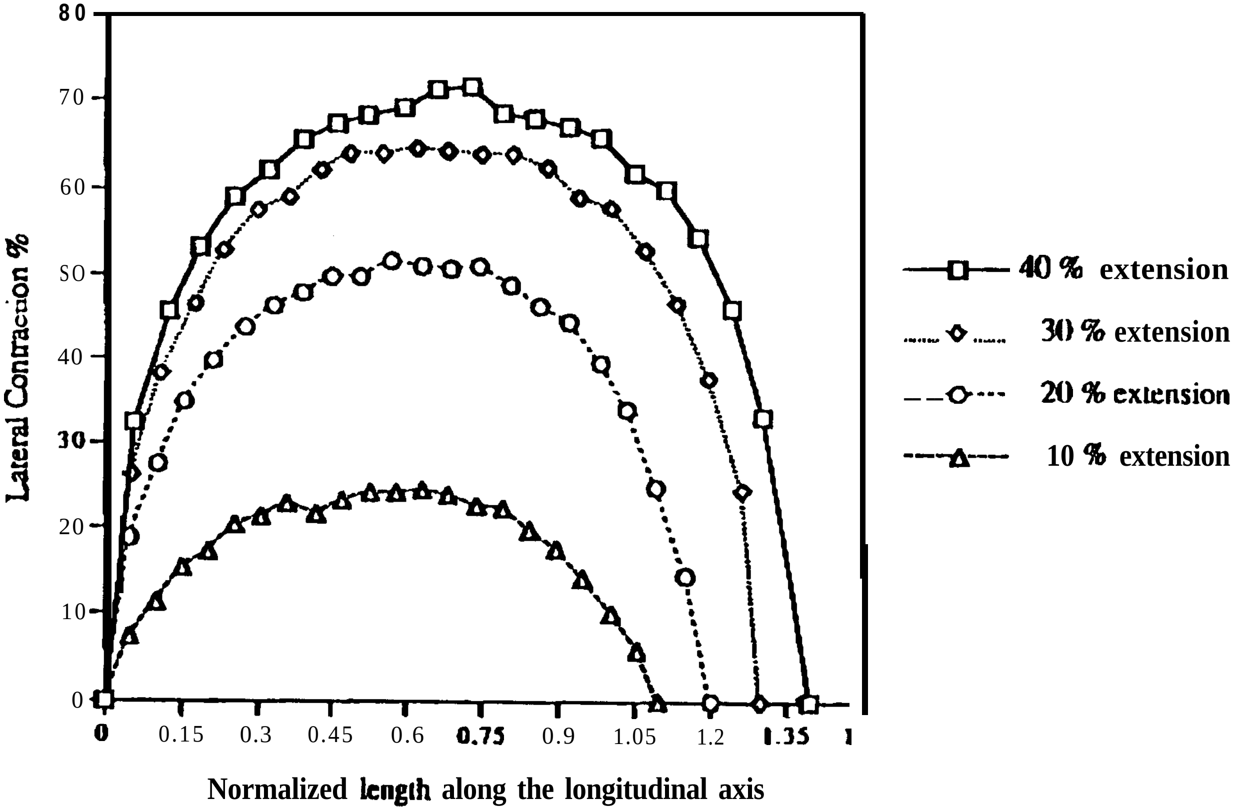
Parameters Used	**Values**
Elastic Modulus for Zone 1	**250** N/mm^2
Reference Elastic Modulus for Zone 2	20 N/mm^3
Normal Pressure for Zone 3	7 kPa
Coefficient of Friction for Zone 3	1.57

FIGURE 3 Finite Element Mesh for NonLinear-Elastic Analysis and Selected Parameters



Points Along the Length of the Geotextile

FIGURE 4 Results from NonLinear-Elastic Finite Element Analysis



Direction: MD; Sample Size: 8"X3"; Fabric Weight 12oz/sq.yd.

Figure 5. Lateral Contraction Profiles of a Needle-Punched Sample