Development of Protocols for Confined Extension/Creep Testing of Geosynthetics for Highway Applications

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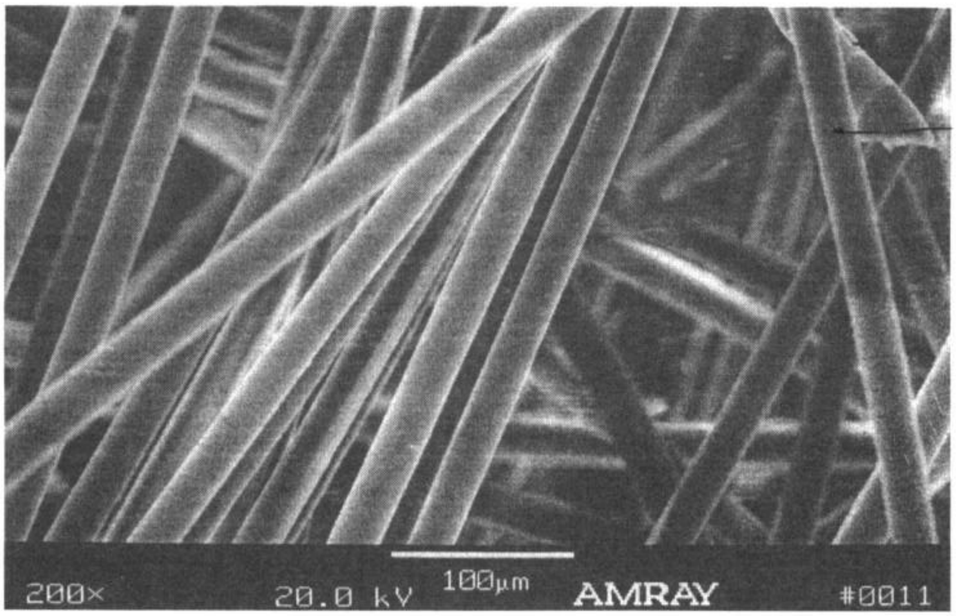

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

The report, *Development of Protocols for Confined Extension/Creept Testing of Geosynthetics for Highway Applications,* is part of a comprehensive study on the *Durability of Geosynthetic Materials for Highway Construction.* The report presents the development and verification of testing protocol and protocol equipment for confined extension testing and confined creep tests for geosynthetic reinforcement materials. The protocols are presented in ASTM format for possible ASTM consideration.

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16. Abstract

This report presents the development and verification of a testing protocol and protocol equipment for confined extension testing and confined creep testing for geosynthetic reinforcement materials.

The developed data indicate that confined response significantly improves stress strain response of geosynthetic materials, especially nonwoven geotextiles. Current use of unconfined stress-strain response appears overly conservative.

This report is part of a comprehensive study on the "Durability of Geosynthetic Materials for Highway Applications." The developed protocols in the Appendix have been developed in the ASTM format and may be forwarded for ASTM consideration.

COVER PHOTO: Nonwoven polyester geosynthetic

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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CHAPTER 1

INTRODUCTION

This report presents development and verification of the testing protocol and protocol equipment for confined extension testing and confined creep testing (Tasks C and G) for the research program titled, "*Durability of Geosynthetics for Highway Applications*" DTFH61-91-R-00054. The research was primarily conducted by GeoSyntec Consultants.

1.1 OBJECTIVE AND SCOPE

The laboratory testing program presented was developed to characterize the confined stress-strain response of geosynthetic materials in engineering design applications. The results are anticipated to improve the characterization that is currently used in engineering and analysis and to allow considerable material savings in load bearing applications.

The specific objectives of the research program were to: (i) develop the protocol test equipment for evaluating confined stress-strain properties of geosynthetics; (ii) establish protocol testing procedures for conducting confined extension and confined creep tests on geosynthetics; (iii) verify the protocol test equipment and procedures through testing of representative geosynthetics; and (iv) develop a written protocol for confined extension and creep testing. In addition, a complementary confined extension testing program was conducted at Polytechnic University (Polytechnic) to evaluate the confined response of selected geotextile materials using a modified triaxial-type test apparatus.

A scope of work was developed to achieve these objectives and to meet the stated purpose. This scope of work included the following four-phased technical approach:

- *Phase I: Initial Testing and Selection of Test Equipment* - This initial phase included extensive review of the technical literature regarding the evaluation of soil confinement effects on the stress-strain properties of geosynthetics. This phase also included the selection of testing equipment and testing materials, and preliminary confined and unconfined testing using a large pullout test device and a prototype confined extension testing device.

- *Phase II: Development of Confined Extension/Creep Test Equipment* - This phase included the design, fabrication, and calibration of the protocol test equipment for conducting confined extension/creep tests. Calibration tests were conducted to evaluate the overall performance of the protocol equipment.

- *Phase III: Verification of Confined Extension/Creep Test Equipment and Procedures* - This phase included establishment of test procedures, selection of test conditions, verification of the protocol equipment through testing of representative geosynthetics under a specific set of test conditions, and assessment of the test results using the triaxial-type test device developed by Polytechnic.

- *Phase IV: Development of Protocol for Confined Extension/Creep Testing and Equipment* - This phase included a discussion on the key factors considered in developing the written testing protocol.

1.2 TEST MATERIALS

a. Geosynthetic Materials

Seven geosynthetic materials were used in the testing program. These materials are referenced by name in this report, and include:

- a polypropylene staple fiber needle-punched nonwoven geotextile having a mass per unit area of 8 oz/yd^2 (272 g/m^2), referred to as Geosynthetic PP-10;

- a polypropylene slit-film multi-filament woven geotextile, referred to as Geosynthetic PP-11;

- a polypropylene woven mono-filament geotextile, referred to Geosynthetic PP-12;

- a uniaxial extruded polyethylene geogrid, referred to Geosynthetic PE-13;

- a polyester multi-filament woven geogrid with PVC coating, referred to as Geosynthetic PET-14;

- a polypropylene staple fiber needle-punched nonwoven geotextile having a mass per unit area of 8 oz/yd^2 (272 g/m^2), referred to as Geosynthetic PP-15; and

- a polypropylene continuous fiber spun-bond nonwoven geotextile having a mass per unit area of 9 oz/yd^2 (305 g/m^2), referred to as Geosynthetic PP-16.

The dimensional and mechanical properties of each geosynthetic material are summarized in table 1. Bulk samples of the seven geosynthetic materials were obtained directly from the respective geosynthetic manufacturers.

b. Soil Materials

A fine sand and a silty sand were used in the verification testing program. Both sand materials were obtained from project sites located in the southeastern United States and are herein referred to as beach sand and silty sand, respectively. Sufficient bulk quantities of the two soil materials were obtained to complete the entire testing program. Particle-size distribution, compaction characteristics, and internal shear strength of the two soil materials were evaluated and are summarized in table 2. The particle-size distribution curves for the two soil materials are presented in figure 1.

1.3 ORGANIZATION OF REPORT

The report is organized as follows:

- The results of *Phase I: Initial Testing and Selection of Test Equipment* are presented in chapter 2.

- The results of *Phase II: Development of Confined Extension/Creep Test Equipment* are presented in chapter 3.

- The results of *Phase III: Verification of Confined Extension Creep Test Equipment and Procedures* are presented in chapters 4, 5, and 6, as follows:

    - Results of the verification testing program using confined wide-width equipment are presented in chapter 4.

Table 1. Summary of geosynthetic material properties.[1]

Geosynthetic Materials	Type of Filament[2]	Structure or Manufacturing Process	Polymer Composition	Mass Per Unit Area[3] (oz/yd^2)	Direction of Testing[4]	Aperture Size (in)		Ultimate Tensile Strength (lb/ft)
						MD	CMD	
Geosynthetic PP-10	Staple filament	Nonwoven	Polypropylene	8.0	MD	NA	NA	1,352[5]
Geosynthetic PP-11	Slit-film multi-filament	Woven	Polypropylene	NA	CMD	NA	NA	4,800
Geosynthetic PP-12	Mono-filament	Woven	Polypropylene	NA	MD	NA	NA	2,760
Geosynthetic PE-13	NP	Extruded Punched and Drawn Sheet	Polyethylene	NA	MD	4.0[5]	0.7[5]	5,892
Geosynthetic PET-14	Multi-filament	Woven	Polyester	NA	MD	3.2[5]	0.5[5]	5,856[5]
Geosynthetic PP-15	Staple filament	Nonwoven	Polypropylene	8.0	MD	NA	N/A	1,126[5]
Geosynthetic PP-16	Continuous filament	Nonwoven	Polypropylene	9.0[5]	MD	NA	N/A	890[5]

1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 oz/yd^2 = 33.91 gr/m^2

Notes:
(1) Information presented in this table was obtained from the 1996 Specifier's Guide, Geotechnical Fabrics Report, December 1995.
(2) NP refers to the fact that the property is not applicable to the product.
(3) NA refers to the fact that the property was not reported.
(4) MD and CMD refer to the machine direction and cross-machine direction, respectively.
(5) The material properties were measured by GeoSyntec.

Table 2. Summary of soil properties and shear strength test results.

Soil Material	Particle Size ASTM D 422	Coefficient of Uniformity (C_u)	Coefficient of Curvature (C_c)	Soil Classification ASTM D 2487	Compaction Characteristics ASTM D 698		Shear Strength Parameters[1] ASTM D 3080	
					Maximum Dry Unit Weight (pcf)	Optimum Water Content (%)	Peak	Residual
Beach Sand	0% gravel 98% sand 2% fines	2.2	1.2	SP (Poorly Graded Sand)	102.6	11.5	30° and 10 psf	29° and 0 psf
Silty Sand	1% gravel 77% sand 22% fines	16.0	2.6	SM (Silty Sand)	98.0	21.5	34° and 160 psf	30° and 95 psf

1 psf = 47.88 Pa

Note: (1) Shear strength parameters were determined from direct shear testing conducted on remolded beach sand or silty sand specimens that were compacted to 95 percent of their standard Proctor maximum dry unit weight at their optimum moisture content. Each test series was conducted at normal stresses ranging from 2 to 9 psi (14 to 63 kPa).

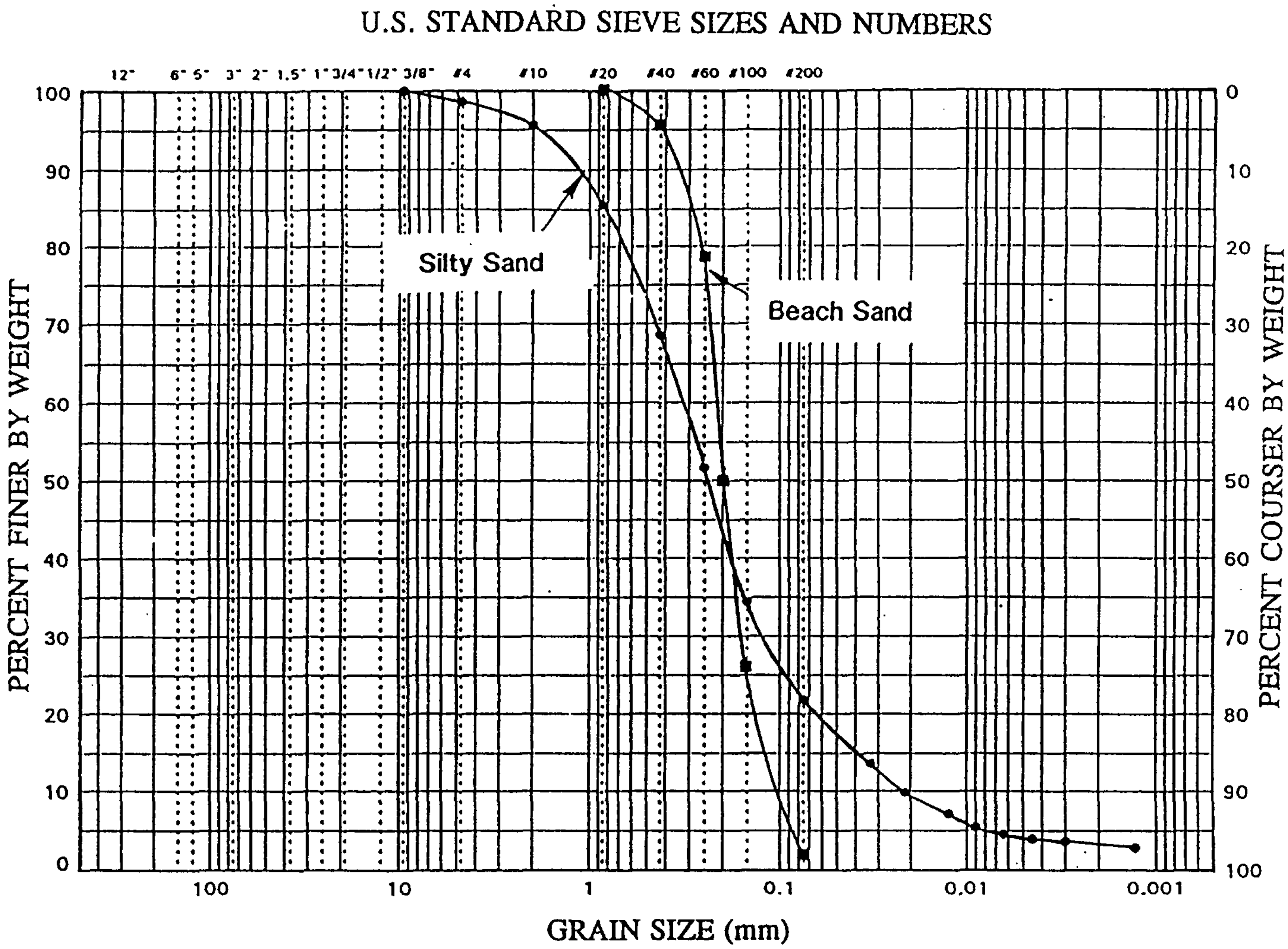


Figure 1. Particle-size distribution curves for beach sand and silty sand.

- Results of the production testing program using confined wide-width equipment are presented in chapter 5.

- Results of confined extension testing using triaxial equipment are presented in chapter 6.

- The results of *Phase IV: Development of Protocol for Confined Extension/Creep Testing and Equipment* are presented in chapter 7.

- The conclusion and recommendations are presented in chapter 8.

- The following appendices are included:

  - Confined extension test results are presented in appendix A.
  - Confined creep test results are presented in appendix B.
  - The protocol for confined extension/creep testing is presented in appendix C.

1.4 REVIEWS

The research tasks reported were initially developed by a project Interdisciplinary Advisor Team and formalized on a Task A Final Report, which formed the basis of the research program.

The Task A Final Report was then reviewed by a Peer Advisory Group whose valuable suggestions were incorporated whenever possible prior to the commencement of the research. The Peer Advisory Group consisted of:

1. Dr. Robert Koerner - Geosynthetic Research Institute
2. Dr. Robert Holtz - University of Washington
3. Dr. Robert Duvall - Engineering Systems Inc.
4. Dr. Barry Christopher - Geoconsultant

Prior to finalizing the results of the research, a draft report was further reviewed by the Peer Advisory Group, which made a number of suggestions to clarify some issues and improve the final product. These suggestions have been incorporated whenever possible in this final report.

CHAPTER 2

INITIAL TESTING AND SELECTION OF TEST EQUIPMENT

2.1 OVERVIEW AND LITERATURE REVIEW

The initial component of this research program included an extensive review of the literature, an initial testing program using conventional pullout testing equipment, and an initial testing program using a prototype confined extension testing device.

The literature review was conducted to identify and evaluate the testing equipment used by various researchers to measure the confined stress-strain properties of geosynthetic materials. The literature review also identified the range and variability of the confined extension test results obtained by these researchers.

a. Test Equipment

Confined extension tests have been previously conducted using various types of testing equipment. Characteristics of the testing equipment used for the confined extension testing in the selected references are described below:

- *In-Soil Test Device by McGown et al. [1982]:* The apparatus consists of a confinement box containing two pressure bellows that are used for the application of normal stress to the test specimen as shown in figure 2. Testing with this type of equipment involves placing a geosynthetic specimen between two thin soil layers confined between the two pressure bellows. Confining pressure is applied to the test specimen by applying air pressure to the bellows. The box is then mounted vertically, and tensile loads are applied to the lower end of the geosynthetic specimen. This type of in-soil test apparatus was modified recently by Wilson-Fahmy et al. [1993]. Their modified apparatus was mounted in the horizontal direction to simplify testing; however, all of their other testing equipment conditions appear to be similar to those of the original McGown et al. [1982] device.

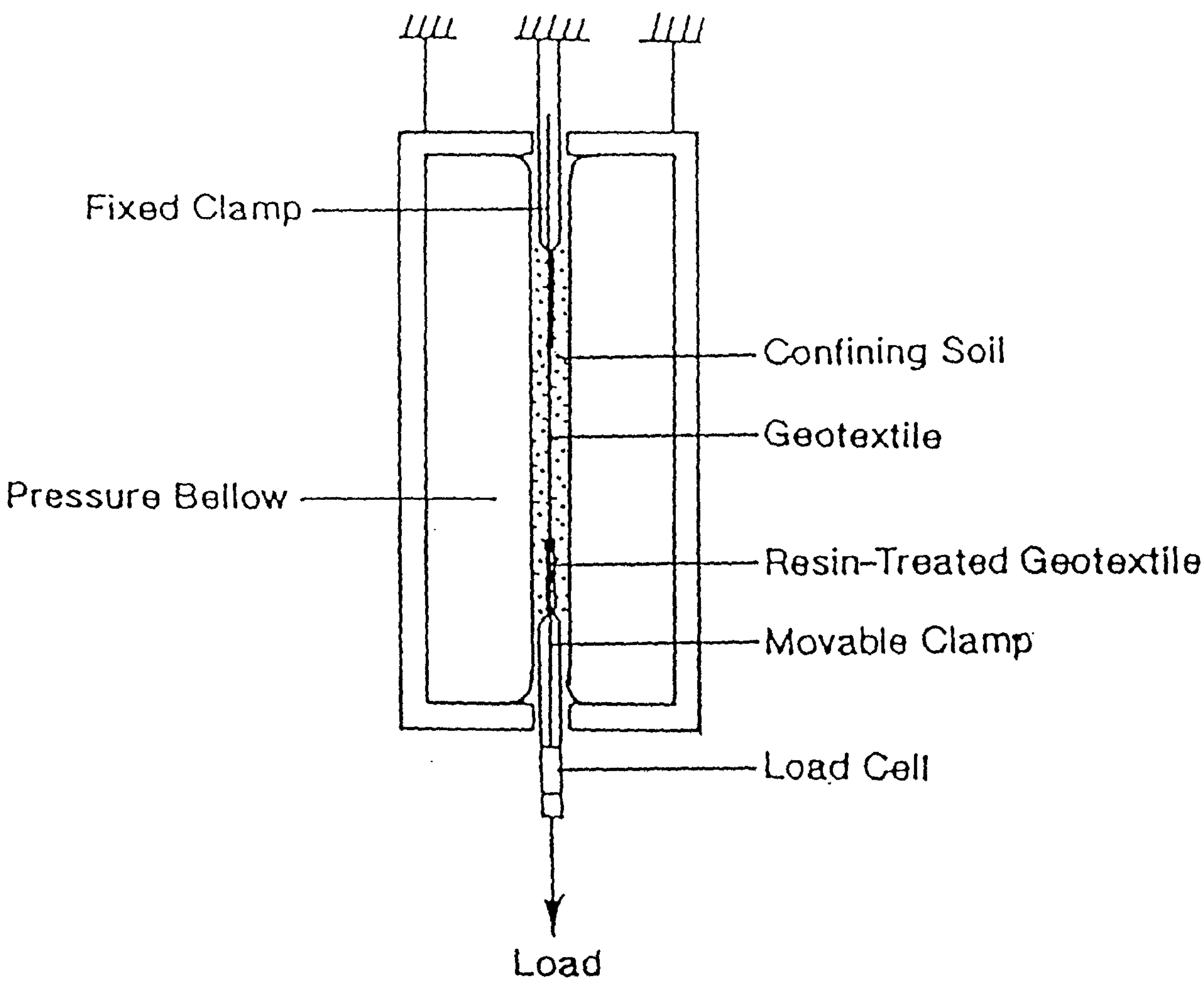


Figure 2. In-soil test apparatus (after McGown et al., 1982).

- *Zero-Span Test by Christopher et al. [1986]:* The device consists of a pair of pneumatic clamps that were used to confine the geosynthetic specimen as shown in figure 3. The two clamps are placed so that there is a zero gage length (i.e., no unconfined length of the test specimen) at the beginning of the test. Surface treatment is used on the clamp faces to reportedly simulate soil conditions. During testing, the upper clamp is designed to move apart from the lower clamp at a constant rate. Because separation between the two clamps gradually causes the central portion of the test specimen to be exposed to air (i.e., unconfined), the zero span test cannot be considered as a true confined test.

- *Pullout Test by Holtz [1977] and Juran et al. [1991]:* Testing with this type of equipment involves placing a geosynthetic specimen between two soil layers within a pullout box as shown in figures 4a and 4b. Confining pressure is then applied to the top of the upper soil layer using an air bag. During testing, tensile loads are applied to one end of the test specimen while the other end of the test specimen remains tension-free. Tell-tail wires or other deformation measuring devices may be placed along the geosynthetic specimen to monitor the development of deformation in the specimen during the test. It is noted that the pullout-type test is generally intended to measure the soil-geosynthetic interaction properties rather than the confined stress-strain properties of geosynthetic materials. However, the measured pullout response is related to the confined stress-strain properties of the geosynthetic specimen. With appropriate instrumentation and interpretation, it is expected that the confined stress-strain properties of the geosynthetic specimen can be explicitly decoupled from the pullout test results.

- *Triaxial Test by Ling et al. [1991] and Wu [1991]:* The device consists of two metal clamps, a pressure chamber, and a tension loading system as shown in figure 5. The metal clamps are fitted in the pressure chamber. The upper clamp is attached to the loading system and the lower clamp is fixed to the bottom of the pressure chamber. A typical test setup involves placing a geotextile specimen in a vertical orientation inside a cylindrical soil specimen that is encased by a rubber membrane. During testing, isotropic confining pressure is applied all around the test specimen, and a tensile load is applied to the upper end of the geosynthetic specimen. As reported by Ling et al. [1991], the confined extension testing using the modified triaxial apparatus achieves strain compatibility between the confining soil and the geosynthetic specimen. This simulates the operational conditions for many types of reinforced soil systems. Therefore, the tensile load along the geosynthetic specimen length is

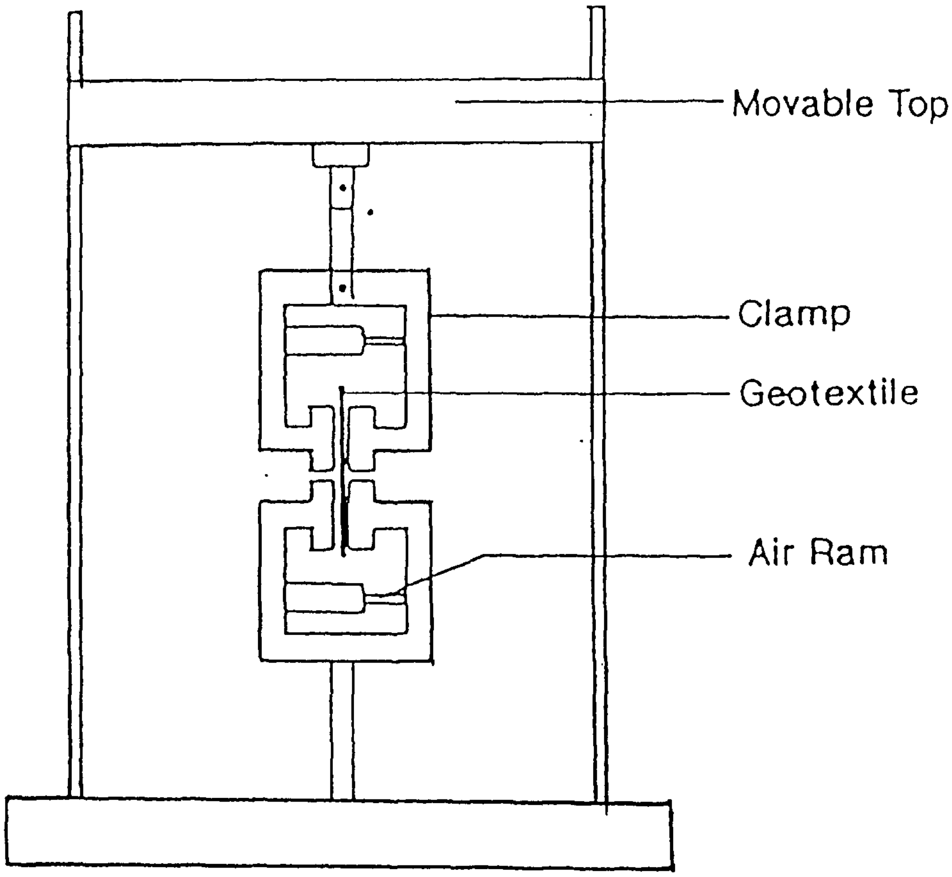


Figure 3. Zero-span test apparatus (after Christopher et al., 1986).

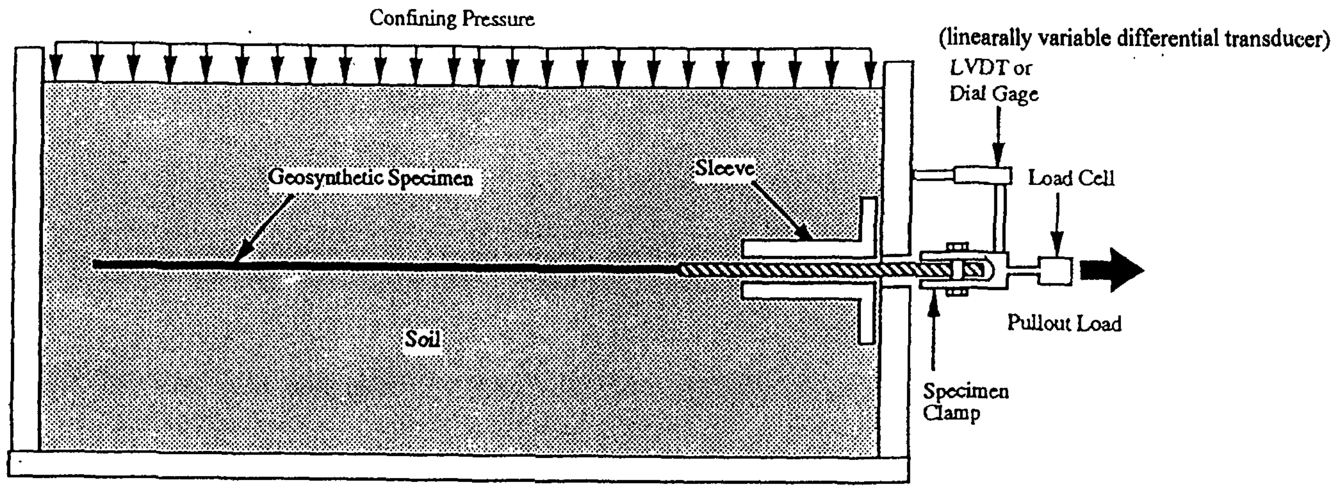


Figure 4a. Pullout test apparatus (cross-section view).

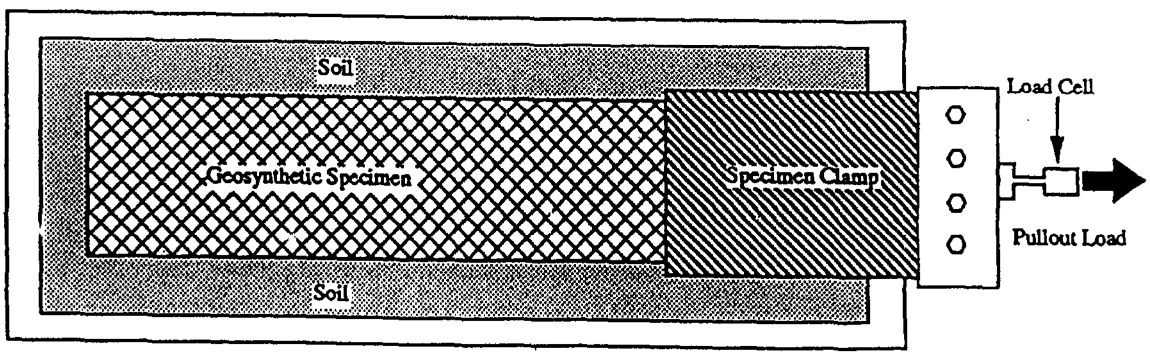


Figure 4b. Pullout test apparatus (plan view).

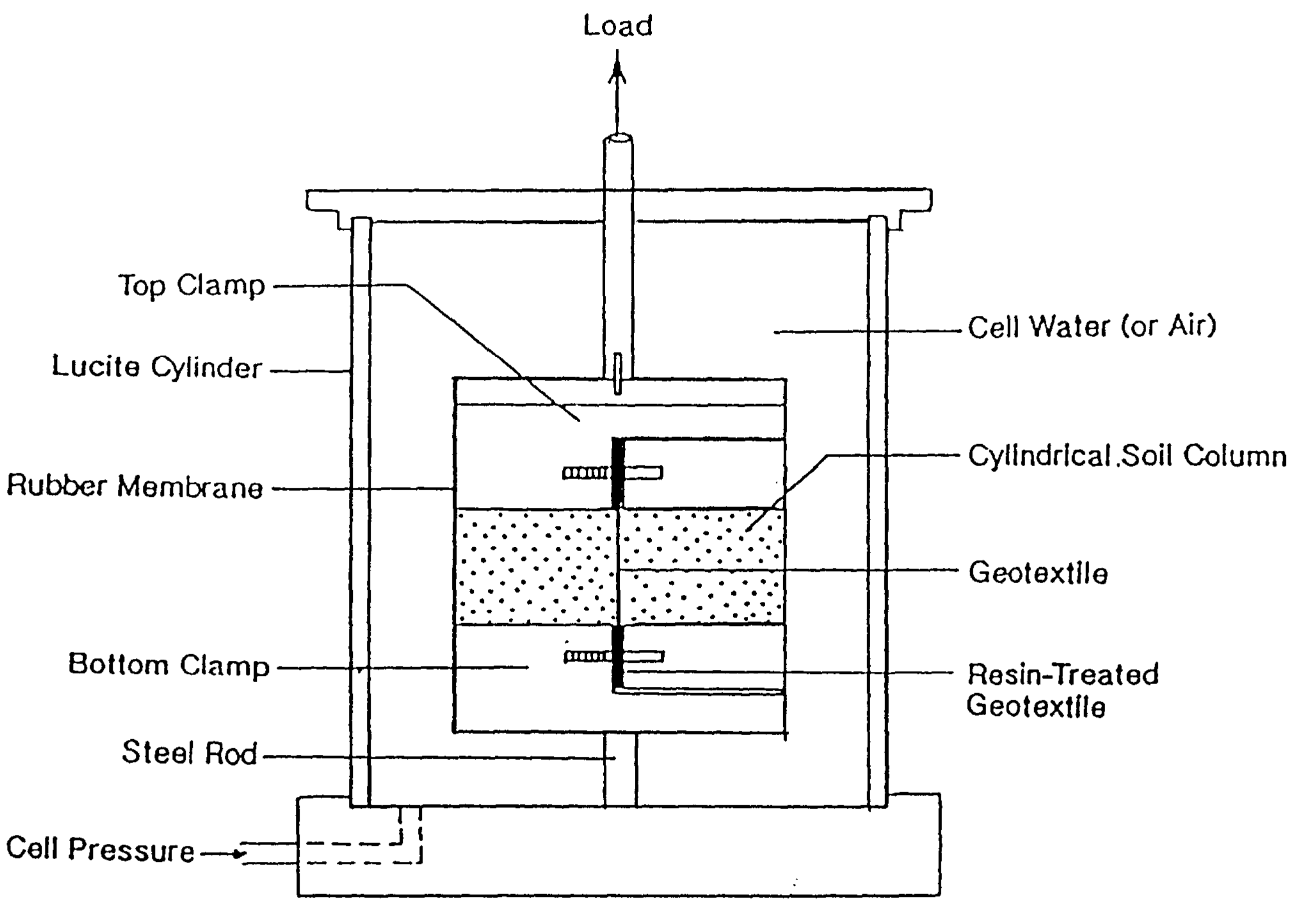


Figure 5. Modified triaxial apparatus (after Wu, 1991).

constant and a true "element" test is possible. However, since the tensile strain at failure for many geosynthetics is tens or hundreds times the failure strain of soils, the strain compatibility conditions for working stress levels are only applicable during the initial part of the testing. Additionally, placing soils in a manner that is representative of field conditions is not possible with this device.

- *The Plane Strain Unit Cell Device (UCD) by Boyle [1995]:* The UCD is a load-controlled test apparatus in which vertical pressures at the bottom and on the top of the test specimen are continuously increased until the test specimen reaches some limit state as shown in figure 6. The UCD simulates stress conditions that an element within a geosynthetic reinforced wall would likely experience during construction. The geosynthetic specimen is typically loaded at varying strain rates ranging from 0.035 to 0.25 percent/min during the actual test, although different strain rates or stress-controlled loading is possible. Boyle concluded that the effective confining pressure in the soil increased as the strain in the reinforcement increased, thus explaining the increase in reinforced soil strength relative to unreinforced soil tested at constant confining pressure. Therefore, the UCD may more closely model reinforced soil behavior, but likely will not be able to assess the geosynthetic response under constant confining pressure. Consequently, it may be difficult, if not impossible, to make a direct comparison between the unconfined stress-strain properties obtained from the wide-width tensile test and the confined stress-strain properties obtained from the UCD test. It should be noted that the UCD device was specially developed to study the interaction of soil and geosynthetics and is likely too complex for routine testing, although the device presents significant advantages to the industry for studying soil-geosynthetic interaction.

- *The Automated Plane Strain Reinforcement (APSR) Cell by Whittle et al. [1993]:* The APSR cell measures major tensile forces transferred to a planar reinforcement as the surrounding soil matrix is deformed in a plane strain compression mode as shown in figure 7. Similar to the UCD, the APSR cell simulates stress conditions that a reinforcement element in a geosynthetic-reinforced wall would experience during construction. However, the APSR cell was designed to study the load-transfer mechanism between the soil and the reinforcement and not specifically on the confined response of the reinforcement. Like the previously referenced UCD, the APSR is highly specialized and is not likely to be used for routine testing.

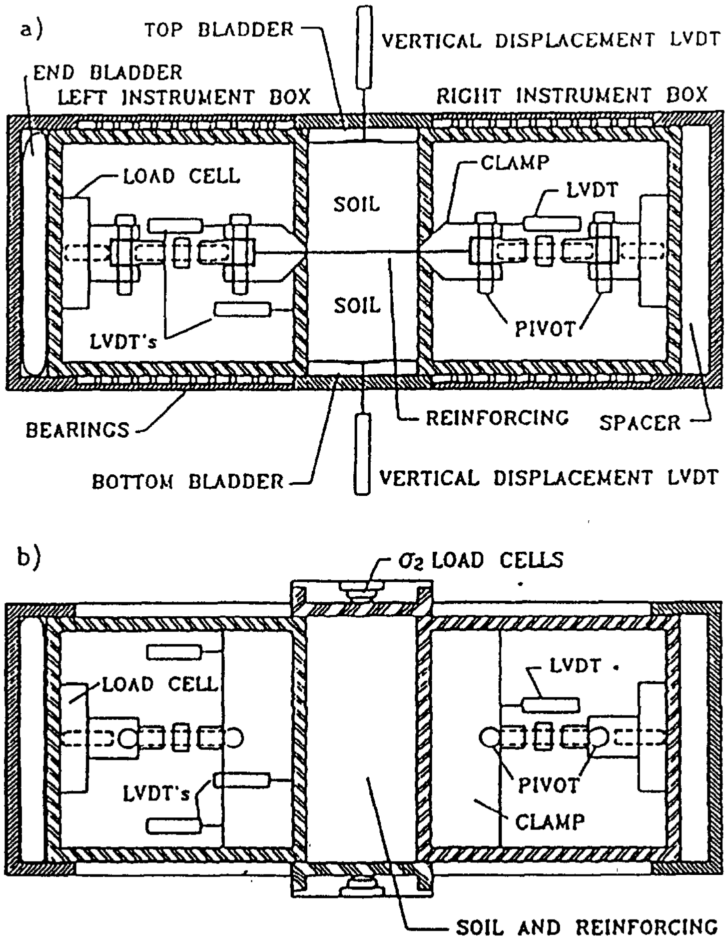


Figure 6. Plane strain unit cell device (UCD) (Boyle, 1995).

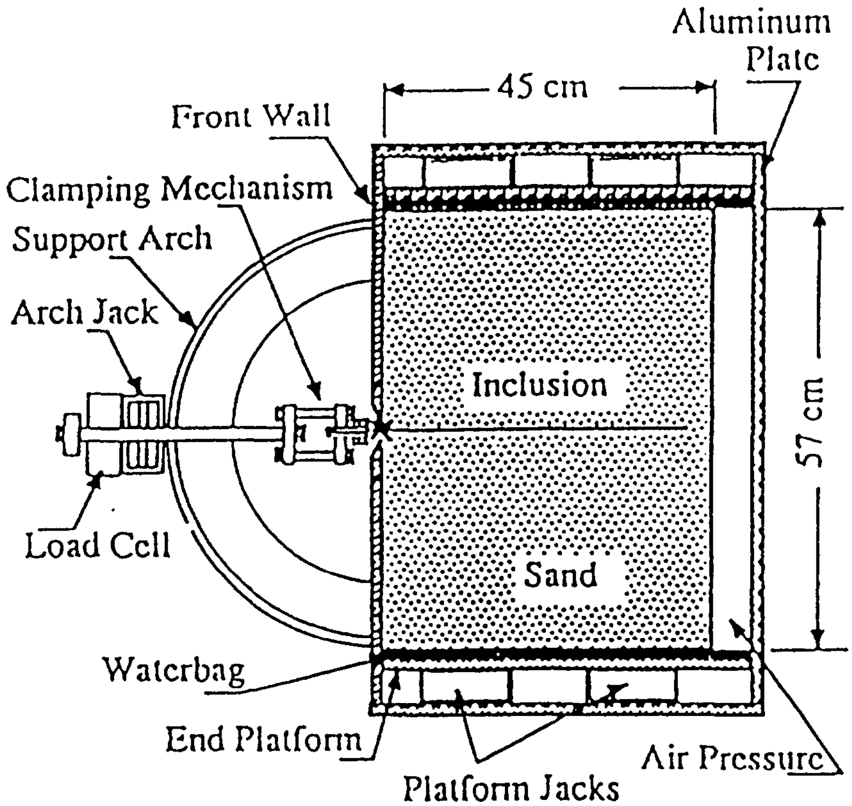


Figure 7. Automated plane strain reinforcement (APSR) cell (Whittle et al., 1993).

- *The Modified Direct Shear Test Machine by Leshchinsky and Field [1987]:* The device is similar to the pullout test device in which the rear of a geotextile specimen is fixed while the front of the geotextile is subjected to tensile loads as shown in figure 8. This test is perhaps best characterized as a "single-sided anchored pullout" test. Due to the mobilized friction between the soil and the geotextile, the applied tensile load at the moving end of the test specimen is only partially transferred to the rear of the test specimen. The confined stress-strain properties were obtained by taking account of the soil-geotextile friction during interpretation of test results.

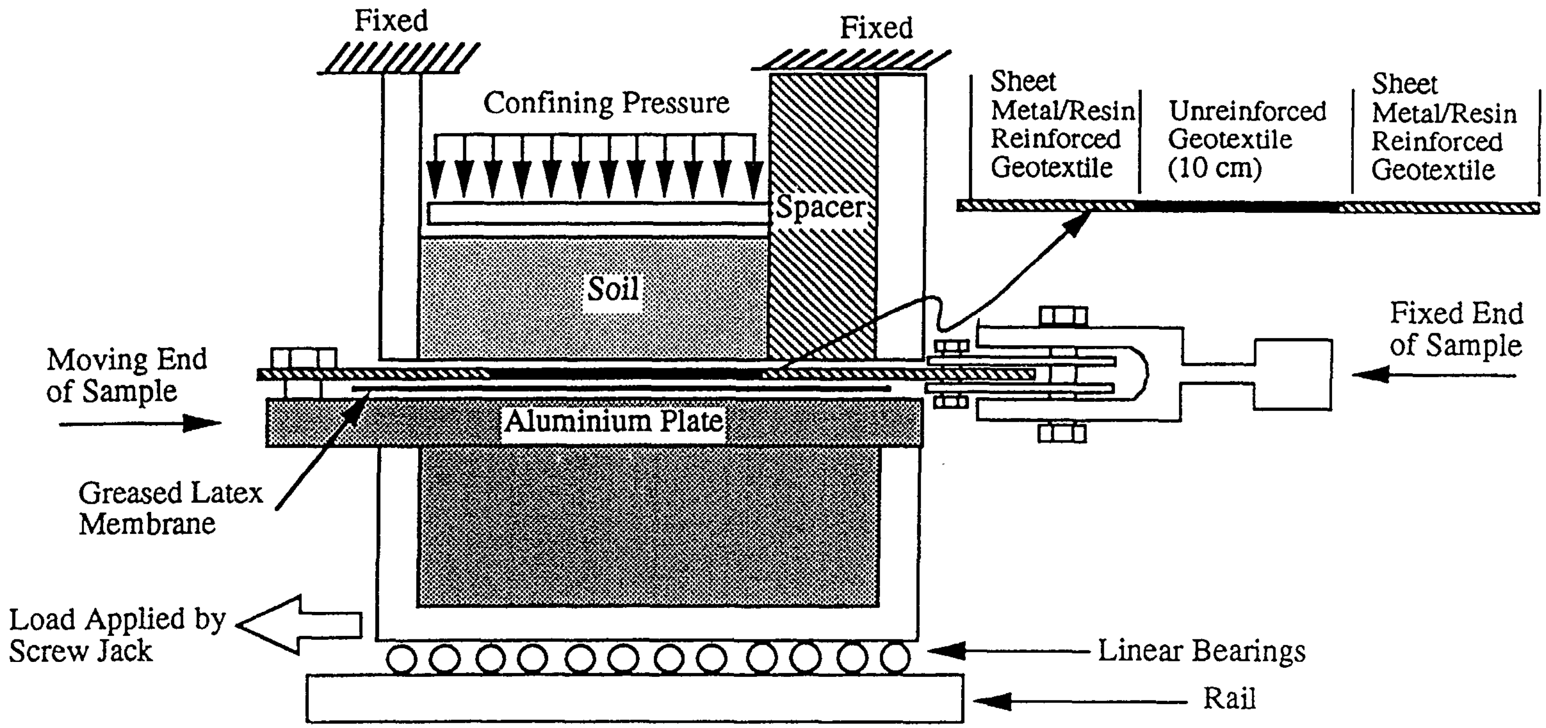
- *The In-Soil Creep Test Device by Fock and McGown [1987]:* This device is essentially the same as the in-soil extension test apparatus developed by McGown et al. [1982] as shown in figure 2. The only difference is that a lever arm system was mounted into the test frame to allow the geosynthetic specimen to be tested under constant load conditions.

A summary of the various test apparatus details that were used for reference in this research project is presented in table 3.

The confined test devices used by these researchers differ with respect to how the applied loads are transferred through the confined geosynthetic. As far as the loading method is concerned, all of the referenced testing devices can be categorized into the following two types of devices:

- *"Direct-Loading" Device:* In the direct-loading device, tension is "directly" applied to a geosynthetic specimen at a constant rate of displacement or constant rate of strain. This type of test device includes: (i) the in-soil confined extension/creep test apparatus; (ii) the zero-span test apparatus; (iii) the pullout test device; (iv) the modified triaxial test device; and (v) the modified direct shear test device.

- *"Indirect-Loading" Device:* In the indirect-loading device, pressures are applied to the boundary of the confining soil, and tension within a geosynthetic specimen is developed through the soil-geosynthetic interaction. This type of device includes: (i) the plane strain UCD and (ii) the APSR cell.



(Not to Scale)

Figure 8. Modified direct shear test machine (Leshchinsky and Field, 1987).

Table 3. Summary of selected references in confined extension and creep tests.

Investigator	Geosynthetic Types	Soil(1)	Geosynthetic Specimen Size W x L (mm)	Testing Device Description	Comments
McGown et al. [1982]	Woven and nonwoven geotextile	Sand	200x100	Two pressurized soil boxes that are clamped together and sandwich geosynthetics	Soil-geotextile interaction minimized by lubrication. Measured confined stress-strain response.
Wilson-Fahmy et al. [1993]	Woven and nonwoven geotextile, geomembrane, geonet, and geosynthetic clay liner	Sand	200x100	Two pressurized soil boxes that are clamped together and sandwich geosynthetics	Soil-geosynthetic interaction minimized by lubrication. Measured confined stress-strain response.
Christopher et al. [1986]	Woven and nonwoven geotextile	N/A	75x75	Tensile test using large pneumatic clamps with textured surfaces	No soil used. Clamps simulate soil confinement.
Holtz [1977]	Woven geotextile	Sand	150x1100	Pullout test device	Long slender specimen. Magnetic positioners used to evaluate differential strain.
Fabian and Fourie [1988]	Woven and nonwoven geotextile	Clay	500x700	Pullout test with the geosynthetic fixed at the rear	Tensile loads measured at both ends. Significant friction mobilized between soil and geotextile.
Juran et al. [1991]	Geogrids	Sand	300x900	Pullout test device	Measured pullout response of geogrids and calculated confined stress-strain properties of geogrids.
Ling et al. [1991]	Nonwoven geotextile	N/A	300x38	Modified triaxial device	Rubber membrane was in direct contact with geotextile. Measured confined stress-strain response.
Wu [1991]	Nonwoven geotextile	Sand	150x50	Modified triaxial device	Strain compatibility between soil and geotextile. Measured confined stress-strain response.

Table 3. Summary of selected references in confined extension and creep tests (continued).

Investigator	Geosynthetic Types	Soil[1]	Geosynthetic Specimen Size W x L (mm)	Testing Device Description	Comments
Boyle [1995]	Woven and nonwoven geotextile Steel sheet	Sand	200x100	Unit cell device	A load control test apparatus that increases vertical stress on a geosynthetic reinforced soil specimen until soil fails or reaches critical state. Confining stress varied during testing.
Whittle et al. [1993]	Steel Sheet	Sand	360x50	Automatic plain strain reinforcement cell	Measured loads transferred from confining soil to reinforcement as test specimen subjected to increasing vertical stress.
Leshchinsky et al. [1987]	Nonwoven geotextile	Sand	200x100	Modified direct shear device	Measured sand-geotextile interaction parameters and calculated confined stress-strain properties.
Fock et al. [1982]	Nonwoven geotextile	Sand	200x100	In-soil creep test device	Soil-geotextile interaction minimized by lubrication. Constant load applied using a lever arm system.

Note: (1) N/A refers to the fact that the geosynthetic specimen was not confined in soils.

Indirect-loading confined test devices were designed to simulate stress conditions that a geosynthetic reinforcement within a reinforced soil structure would typically experience during and/or after construction. However, relative to the unconfined response determined in accordance with ASTM D 4595 (the industry standard for assessing unconfined stress-strain characteristics of geosynthetics), the confined response measured in this type of test device reflects effects of test variables that may be difficult to quantify or isolate. It may be difficult to quantitatively separate the effect of soil confinement from the effects of other test variables. Boyle [1995] reported, that for two polypropylene woven geotextiles, the confined modulus at 5 percent strain measured in the plane strain UCD was between 50 and 80 percent of that determined from the unconfined wide-width tensile tests. The indirect loading devices likely have the highest potential for assessing the actual soil-geosynthetic interaction mechanisms, because they rely on the soil applying load to the geosynthetic. This mechanism is typically what occurs in the field. These devices are, however, highly specialized and are not applicable for routine testing. One of the goals of this research program is to assess testing equipment specifically with the potential for comparing and contrasting confined/unconfined response. This research program should logically be extended to include comparison testing using indirect-loading test equipment.

As far as the ability to provide a constant rate of strain or constant rate of displacement rate to the confined specimen is concerned, the direct-loading device appears superior to the indirect-loading device because it allows assessment of the confined material response. It is believed that the in-soil test apparatus and modified triaxial test device can provide a nearly constant strain rate over the test specimen length; the other three direct-loading devices provide a constant displacement rate to only one end of the geosynthetic specimen. The referenced authors believe that the confined response of a geosynthetic measured using the in-soil test apparatus and modified triaxial test device can be directly compared with the unconfined response (ASTM D 4595) of a geosynthetic material to assess the overall effect of soil confinement.

b. Range of Test Results

Although each of the previously introduced types of test equipment potentially influences the measured confined response of the geosynthetic specimen, each respective author discusses the potential influence resulting from the in-soil confinement. Most noteworthy is that each of the selected references reports some effect of confinement. Typically, the soil confinement effect on the stress-strain properties is realized by an increase in initial tangent modulus, secant moduli at various strain levels, and ultimate strength of the geosynthetic specimen as compared with the results from in-air tension testing. To date, there has not been an attempt by any of the authors to directly compare the results found by the various investigators. For this report, a comparison was made of the test results reported in the selected references using the secant modulus at 5 percent strain for the various types of nonwoven geotextiles reported. The results of the improvement in the secant moduli at 5 percent strain due to soil confinement for the nonwoven geotextiles reported in the selected references are shown in figure 9.

Figure 9 shows a distinct influence of soil confinement on nonwoven geotextiles, but also indicates that the results, particularly the quantitative results, are scattered. As an example, for the needle-punched nonwoven geotextiles used during these investigations, the increase of moduli at 5 percent strain under a confining pressure of approximately 15 psi (104 kPa) varies from approximately 40 to 350 percent. For other geosynthetic materials, data are limited in the literature. However, Fabian and Fourie [1988] reported that the confined modulus at 5 percent strain increased approximately 15 percent in comparison with the unconfined modulus at the same strain level for a polypropylene woven geotextile confined in a silty clay under a confining pressure of 7 psi (48 kPa). For a polyester geogrid tested under a confining pressure of 7 psi (48 kPa), the confined modulus at 5 percent strain increased approximately 210 percent as reported by Juran et al. [1991].

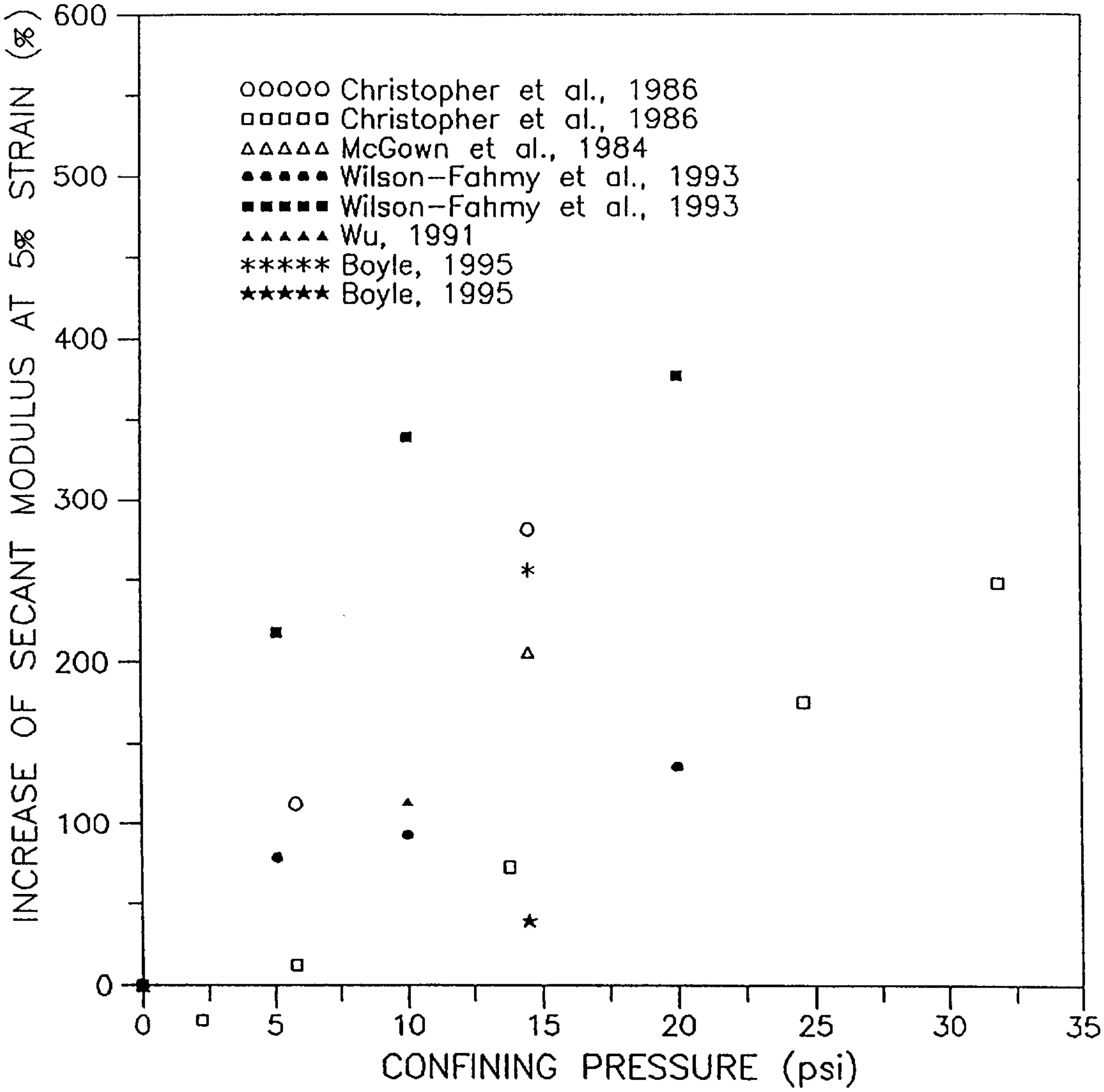
On the basis of the results of confined tests reported in the selected references, it appears that:

- There is a significant confinement effect on the modulus of nonwoven geotextiles. This is supported by the results presented in figure 9, which summarizes the increase in secant moduli at 5 percent strain due to soil confinement effects for several nonwoven geotextiles.

- There may be a confinement effect on the tensile strength of nonwoven geotextiles.

- There may (or may not) be confinement effects on the stress-strain properties of polyester geogrids and woven geotextiles; observed effects may be induced by the testing equipment.

Each of the referenced different types of test equipment offers various advantages regarding ease of testing and ability to simulate actual field conditions. There are, however, disadvantages to each test device, particularly related to the ability to uncouple the confined



1 psi = 6.89 kPa

Figure 9. Soil confinement effect on secant moduli at 5 percent strain for nonwoven geotextiles.

extension behavior of the geosynthetic specimen and the potential influence of the test equipment on the measured test results. These observations are based on the limited data presented in the selected references summarized in table 3. Furthermore, there was no reported instance where a direct comparison had been made of results from tests conducted on a common geosynthetic product using different test equipment or of a test program in which a particular test apparatus was used to conduct testing on a wide range of products.

2.2 INITIAL BASELINE TESTING - PULLOUT TESTS

The initial project goals were to: (i) select a testing device(s) that appeared to have significant promise with respect to the ability to assess the confined response of geosynthetics, and (ii) systematically evaluate the effects and influences on testing results of the equipment and the geosynthetic. Of particular importance was the ability to evaluate coupled and uncoupled material response using the selected test device(s). Two direct-loading devices were selected for this systematic study. The results of initial tests using the pullout test device are presented in this section; the results of initial tests using the confined wide-width test device are provided in section 2.3.

a. Test Equipment

The pullout testing device used for the initial baseline evaluation of confined stress-strain properties of geosynthetics consists of the following three major components: (i) a pullout box that has internal plan dimensions of 24 in by 60 in (610 mm by 1525 mm) and an overall depth of 12 in (305 mm); (ii) an air bladder system to apply confining pressure of up to 20 psi (138 kPa) to a test specimen; and (iii) two 20,000-lb- (89-kN-) capacity hydraulic cylinders to apply pullout loads to the geosynthetic specimen. This device can be used for both in-air and in-soil testing under a wide range of confining pressures. The schematic diagram of the pullout test device used for the initial baseline testing program is shown in figure 10.

b. Test Procedures

Three series of pullout tests were conducted on a needle-punched nonwoven geotextile (Geosynthetic PP-15) confined in beach sand.

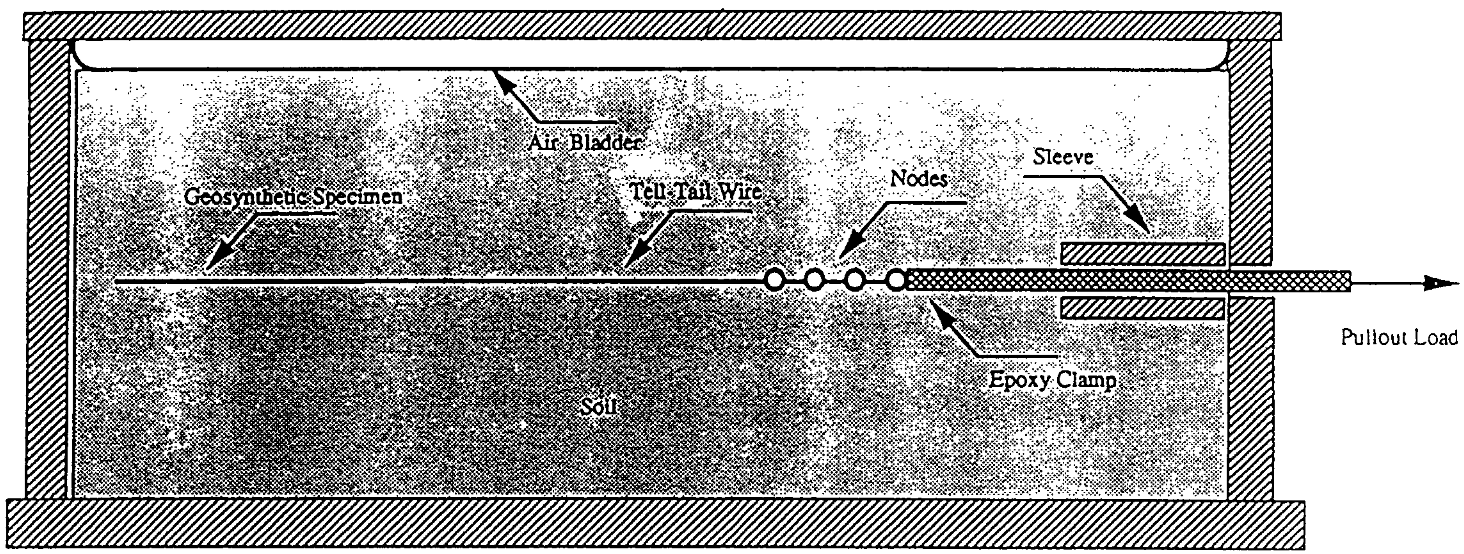


Figure 10. Schematic diagram of pullout test device.

For all the tests, the length of geosynthetic specimen was 48 in (1219 mm) while the width varied from 4 to 18 in (102 to 457 mm). The 48-in- (1219-mm) long specimen was selected with the intention to achieve a rupture failure mode for the geotextile specimen at the selected confining pressures based on experience. This would allow the full -range of stress-strain properties to be evaluated for the geotextile specimen in the pullout test.

For each pullout test series, tests were conducted in accordance with the following procedures:

- Beach sand was placed in the lower half of the pullout box and compacted by hand tamping to form a 6-in- (152-mm-) thick sand bedding layer. The sand was compacted to approximately 95 percent of its maximum dry unit weight as determined in a standard Proctor compaction test, but under dry conditions.

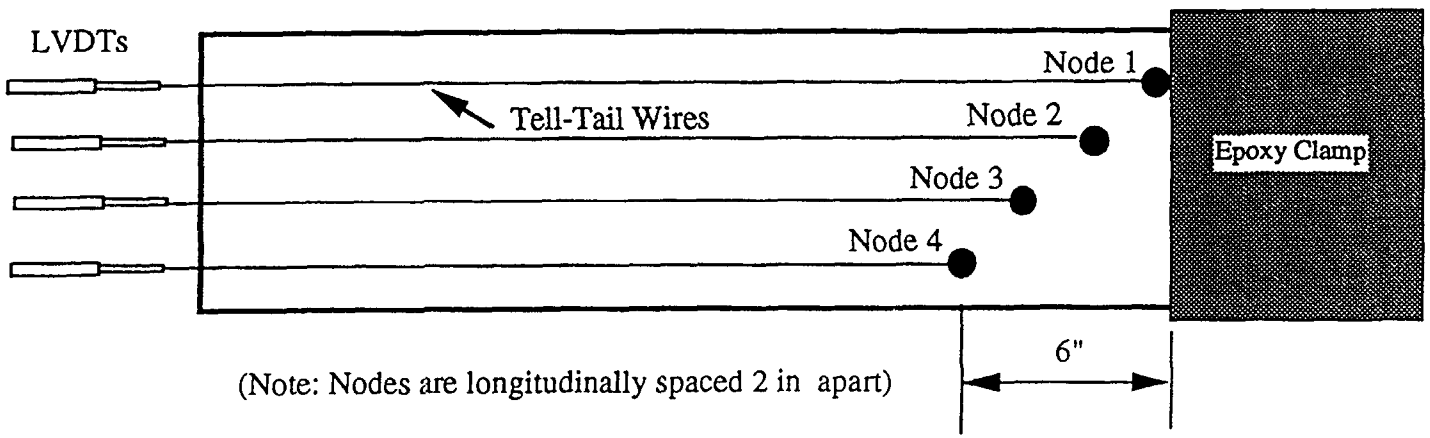
- The geosynthetic specimen was trimmed from the bulk sample and placed on top of the compacted sand bedding layer. Four tell-tail wires were connected to the selected locations on the test specimen as shown in figure 11. The front end of the geotextile specimen was cast into a low-temperature curing epoxy to form the specimen clamp.

- Additional beach sand was then placed in the upper half of the pullout box and compacted by hand tamping to form a 6-in- (152-mm-) thick layer above the geotextile specimen. The sand was compacted to approximately 95 percent of its maximum dry unit weight under dry conditions.

- A load cell was attached to the pullout loading harness that was connected to the clamping end of the test specimen.

- The normal stress was then applied to the top of the upper sand layer through the air bladder loading system.

- The geotextile specimen was then pulled out at a constant displacement rate of 0.04 in/min (1 mm/min) as measured on the specimen clamp. The specimen was loaded until a constant or decreasing pullout load was recorded. The pullout load and displacement were monitored continuously during the test.



1 in = 25.4 m

Figure 11. Schematic diagram showing tell-tail wires.

It should be noted that the four tell-tail wires were connected to the nodes located within the 6-in (152-mm) length of the geotextile specimen behind the clamp as shown in figure 11. This arrangement was intended to measure displacement variation along this short portion where the average tensile load in the geotextile was expected to be close to the applied pullout load.

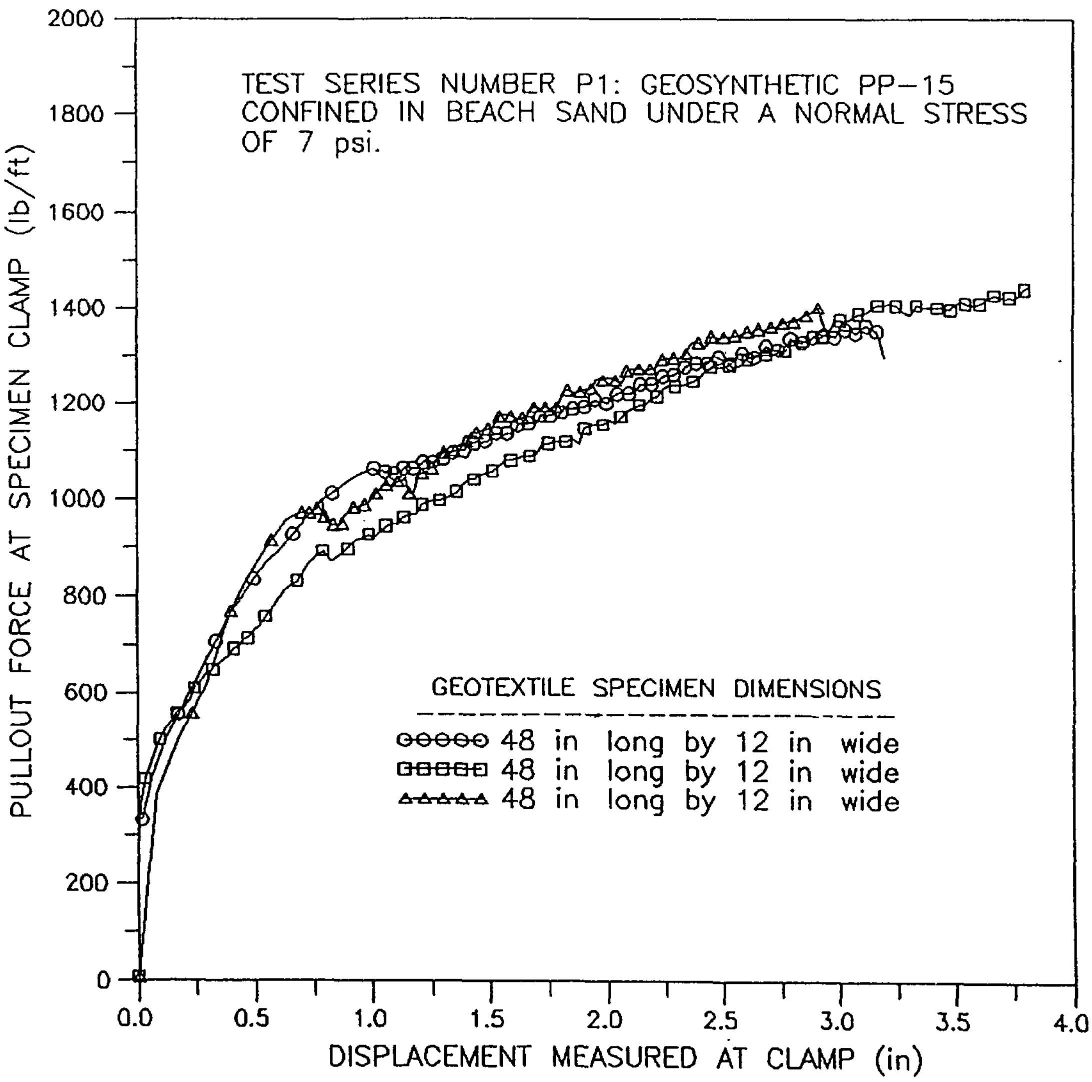
c. Test Results and Observation

Three pullout test series were performed on Geosynthetic PP-15 using the procedures described in the previous section. For each test, the pullout load and displacement at the specimen clamp and in-soil displacements of the geotextile at the four selected points were measured via the tell-tail wires. The pullout force versus displacement curves for the three test series are presented in figures 12 through 14. Following is a discussion of the test results:

- Test Series P1 was conducted to evaluate the precision of the test device and confirm the reproducibility of the test results. Each of the three tests in the test series was conducted under identical conditions as described in figure 12. Results of the tests plotted in terms of pullout force versus displacement are shown in figure 12. These data indicate excellent reproducibility. It was found that variation of the pullout forces at any displacement was generally within 5 percent of the mean value.

- Test Series P2 was conducted to evaluate the effect of specimen width on the pullout response. Tests were conducted on specimens that were all 48 -in (1,219 -mm) long but were 4, 8, 12, and 18 -in (102, 203, 305, and 457 -mm) wide, respectively; and specimens were tested under a normal stress of 7 psi (48 kPa). The test results presented in figure 13 indicate that the pullout stiffness, defined as the slope of the pullout force versus displacement curve, as well as the pullout resistance, generally increase as the specimen width increases.

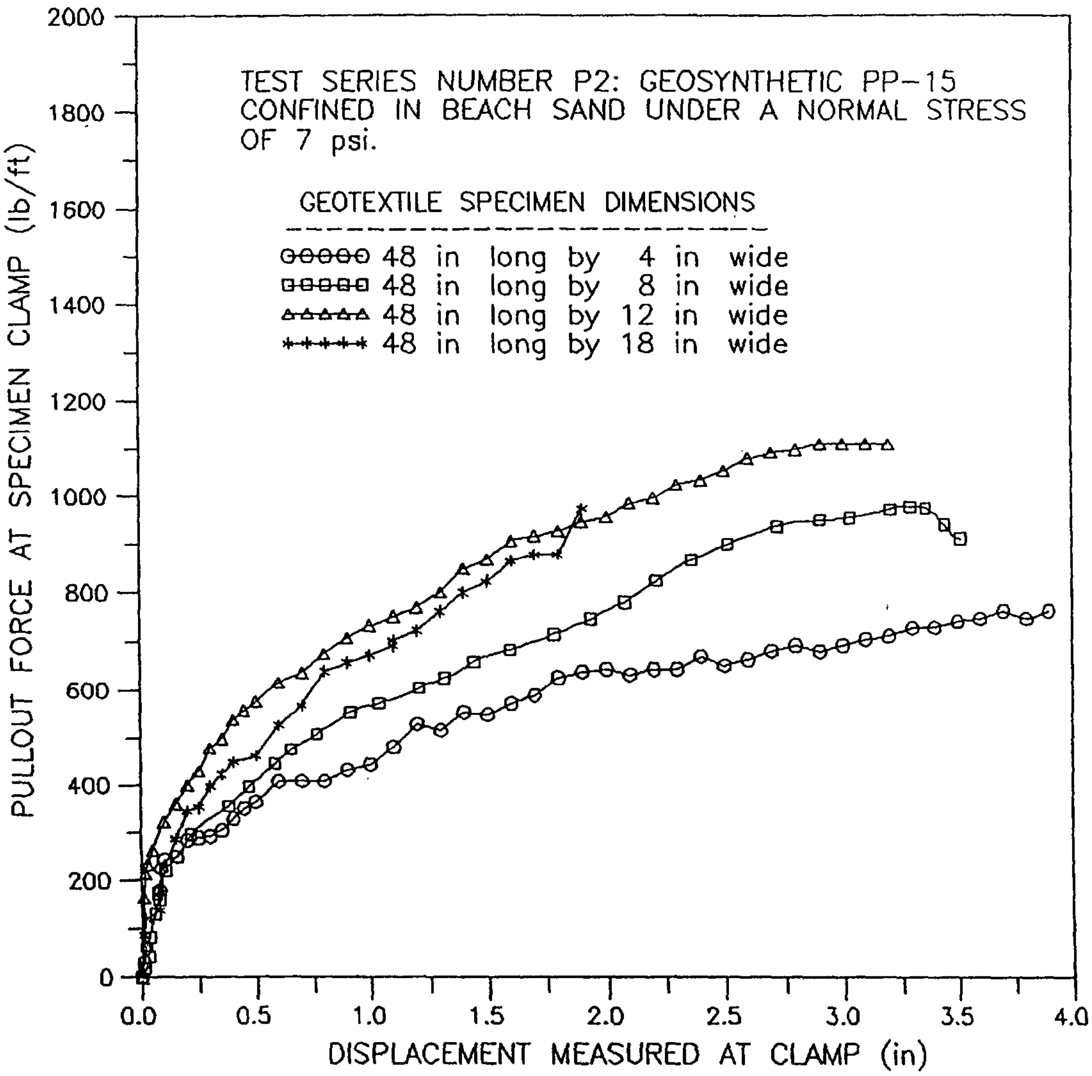
- Test Series P3 was conducted on the same size specimens as those used for Test Series P2, but at a different normal stress. The results are presented in figure 14. A consistent increase was observed of the pullout stiffness and the pullout resistance as the width of the specimen increased.



NOTE: Each test specimen failed due to rupture.

1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

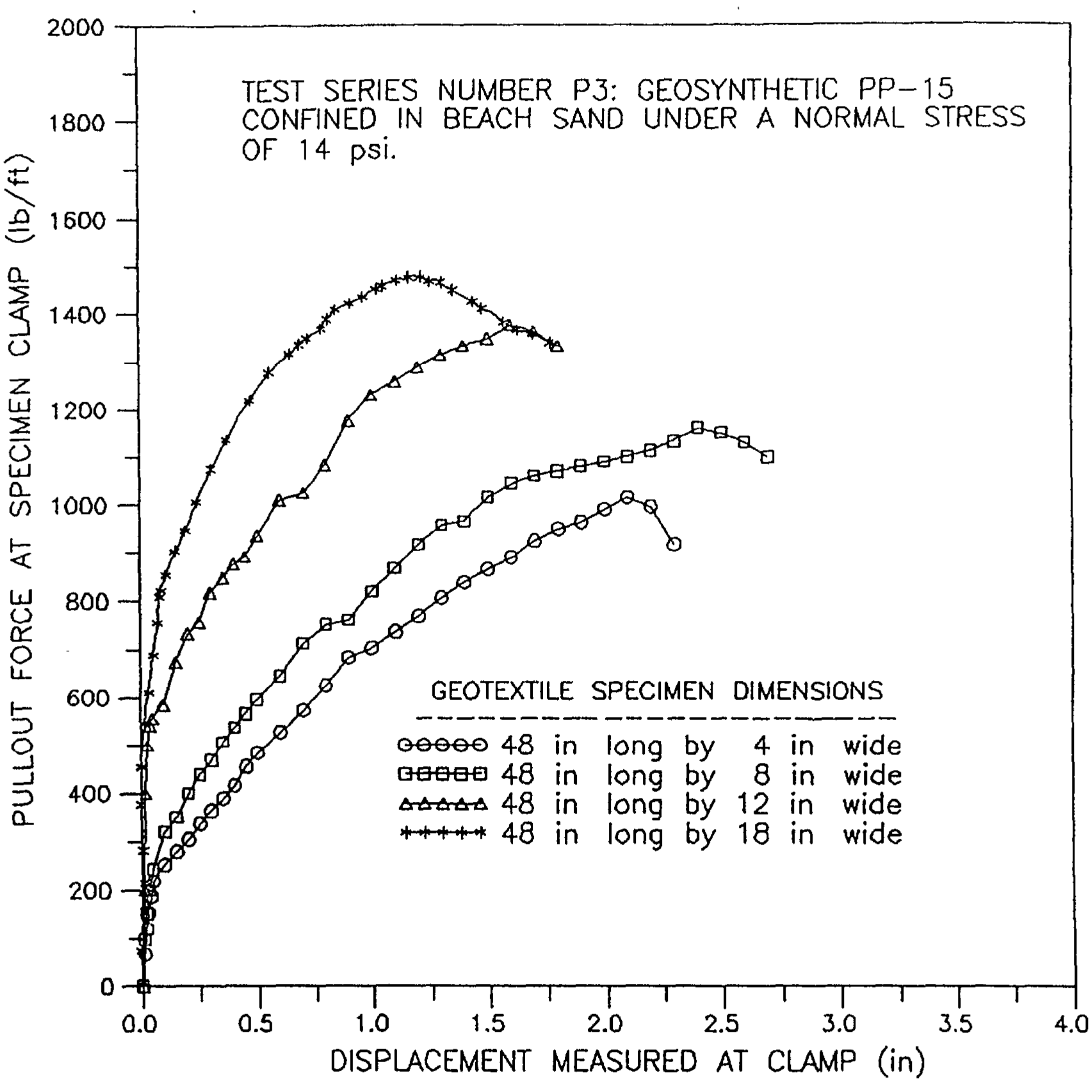
Figure 12. Baseline pullout testing - test reproducibility.



NOTE: Each test specimen failed due to rupture.

1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 13. Baseline pullout testing - effect of specimen width at a normal stress of 7 psi.



NOTE: Each test specimen failed due to rupture.

1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

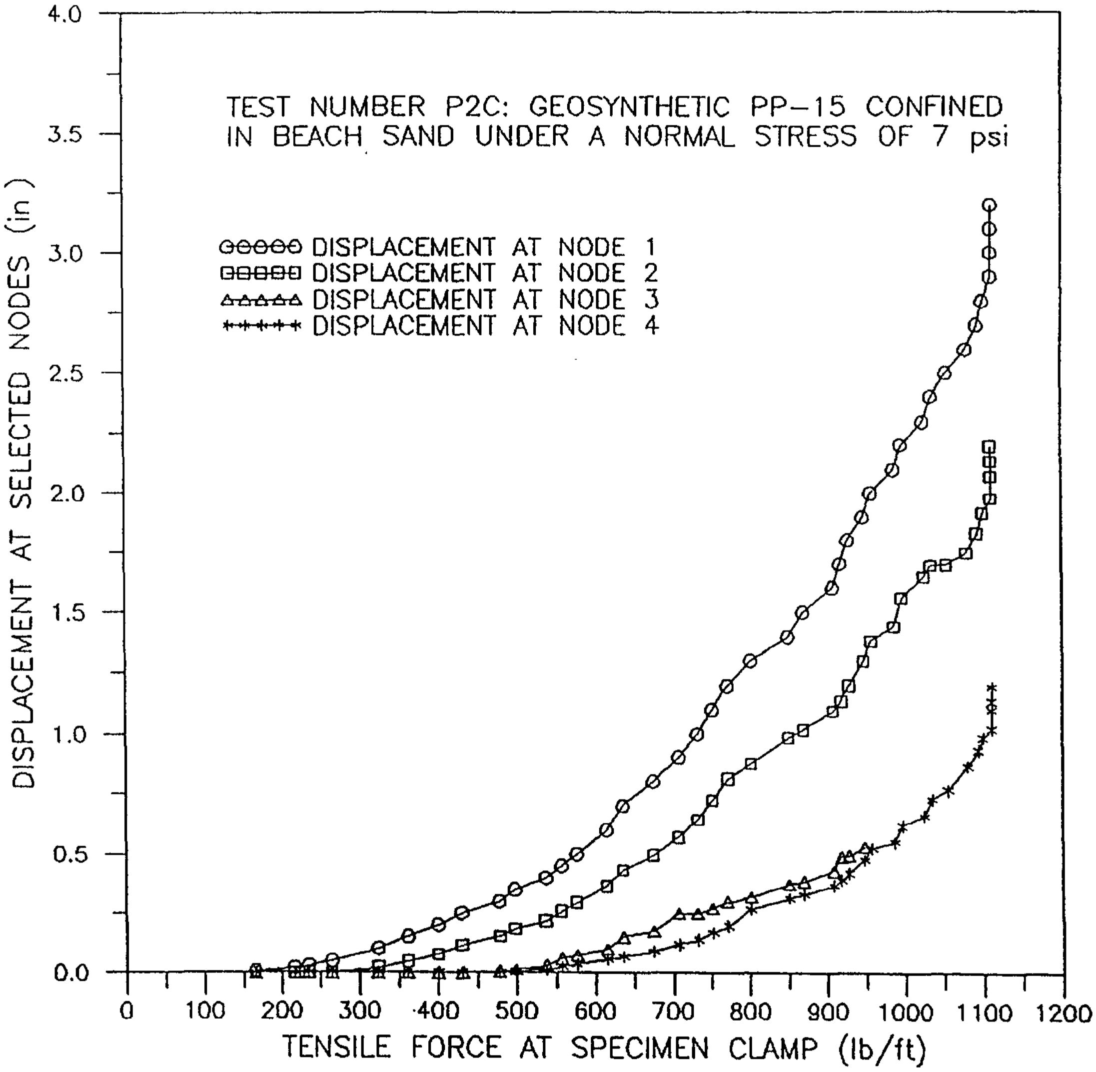
Figure 14. Baseline pullout testing - effect of specimen width at a normal stress of 14 psi.

The in-soil displacement data at each selected node on a geosynthetic specimen obtained from a typical pullout test during Test Series P2 are shown in figure 15. For all three test series, each geosynthetic specimen was inspected at the conclusion of the test. It was observed that each geosynthetic specimen deformed nonuniformly immediately behind the clamp as shown in figure 16. The maximum reduction of the specimen width occurred approximately 2 to 4 in (51 to 102 mm) away from the clamp and was the location where the rupture occurred. This nonuniform deformation is herein referred to as necking.

d. Interpretation of Test Results

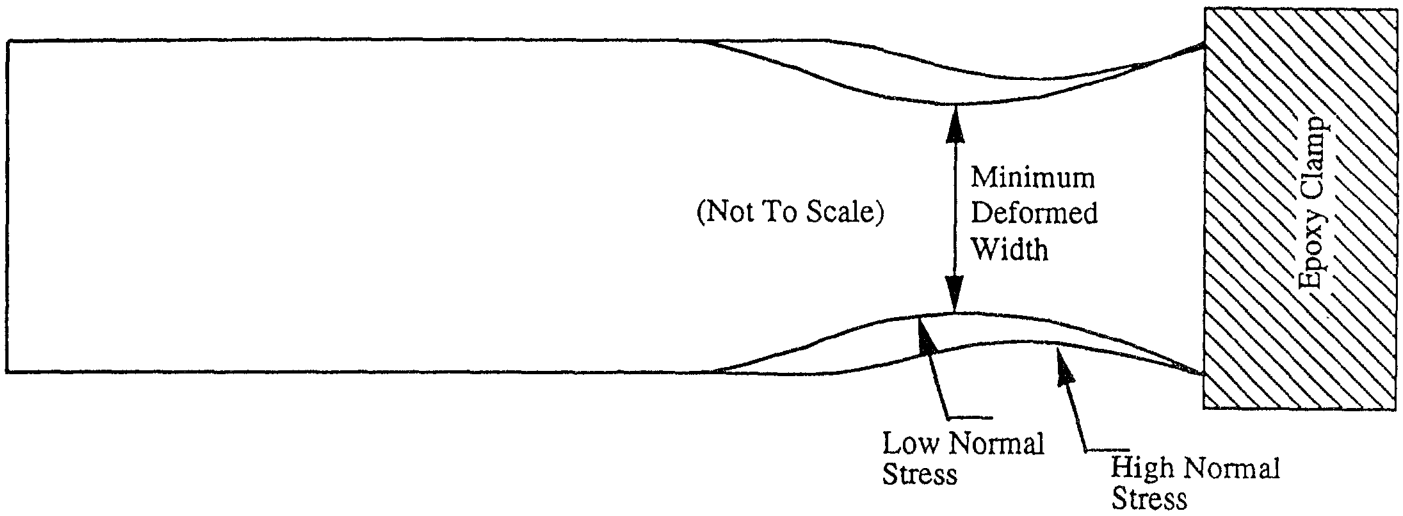
An interpretation procedure was developed to obtain the uncoupled confined stress-strain properties of a geotextile specimen subjected to pullout. The procedure involves the analysis of a pullout test in which a very short element (i.e., a short portion of the test specimen immediately behind the clamp) is used, and it is assumed that the tensile force in the short element is essentially constant across its length, herein referred to as "constant load" approach. Accordingly, the tensile force is assumed to be equal to the applied pullout force across this element. The confined tensile force versus strain curve can be readily obtained by plotting the pullout force versus the average strain over the first element. It is noted that the confined stress-strain properties obtained using this procedure vary with the first element length as shown in figure 17. Figure 17 indicates that, as the length of the first element increased from an assumed base length, the confined stress-strain properties of geosynthetics were overestimated (i.e., the calculated response indicates a progressively stiffer response as the element length increases). To use progressively shorter specimens introduces excessive calibration influence effects due to the clamping system.

An alternative interpretation procedure was used in which it was assumed that the force was distributed linearly across the element, herein referred to as "linearly -distributed load" approach. This procedure involves the estimation of the friction force mobilized along the element. On the basis of an internal friction angle of 30 degrees for the beach sand and an assumed sand-geotextile interaction coefficient of 0.8, it was estimated that the maximum friction force on the upper or lower surface of the 2-in- (51-mm-) long element at a normal stress of 7 psi (48 kPa) would be approximately 155 lb/ft (2.3 kN/m). The average force along the 2-in- (51-mm-) long element would be 78 lb/ft (1.1 kN/m) less than the maximum force. Furthermore, the average tensile force versus strain curve over a 2-in- (51-mm-) long element is shown in figure 18. For comparison, an average tensile force versus strain curve over a 6-in- (152-mm-) long element is also shown in figure 18. The comparison indicates that change in the first element's length can also influence the confined response of the geotextile.



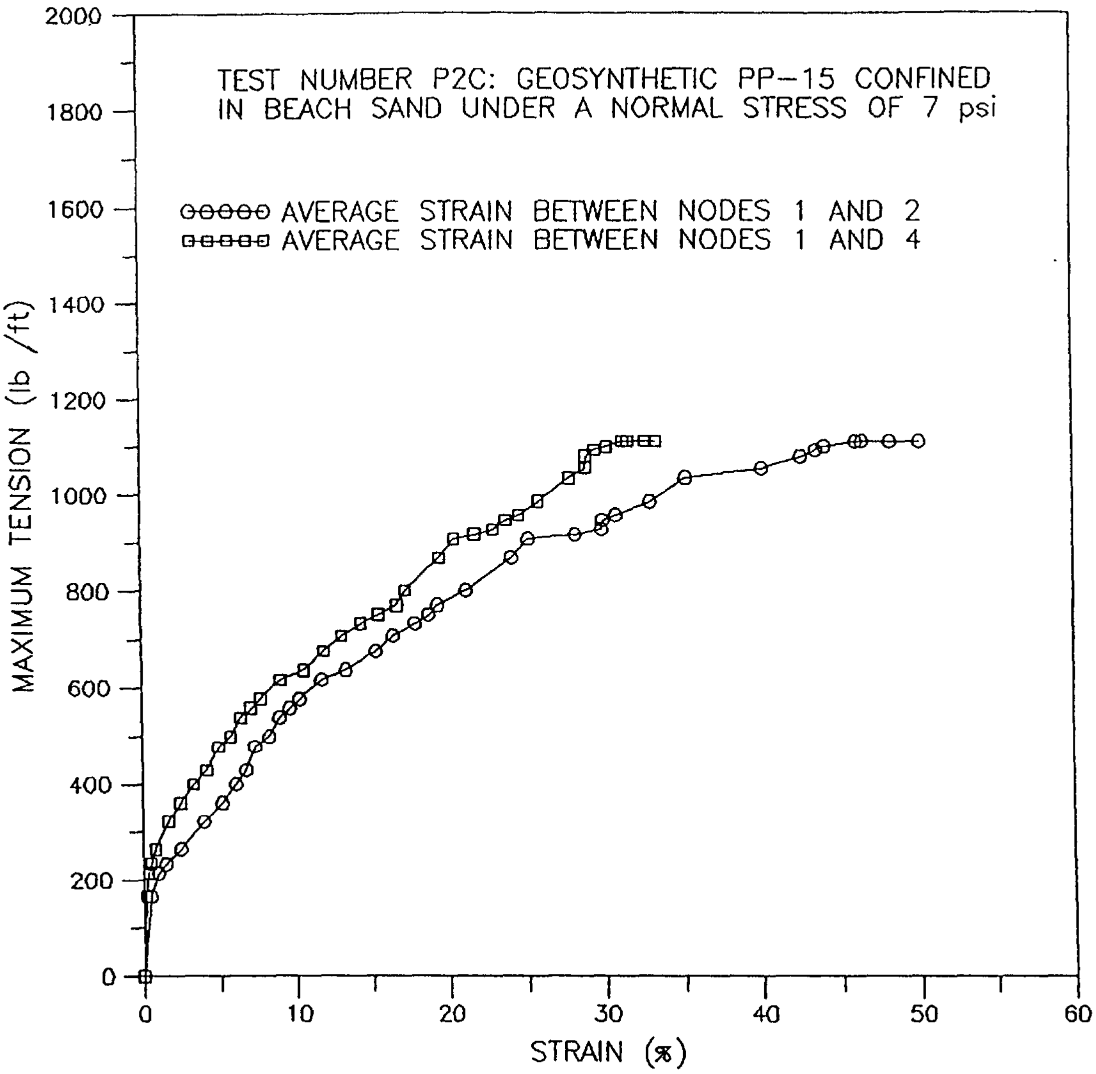
1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 15. Displacements at select nodes along a test specimen using tell-tail wires.



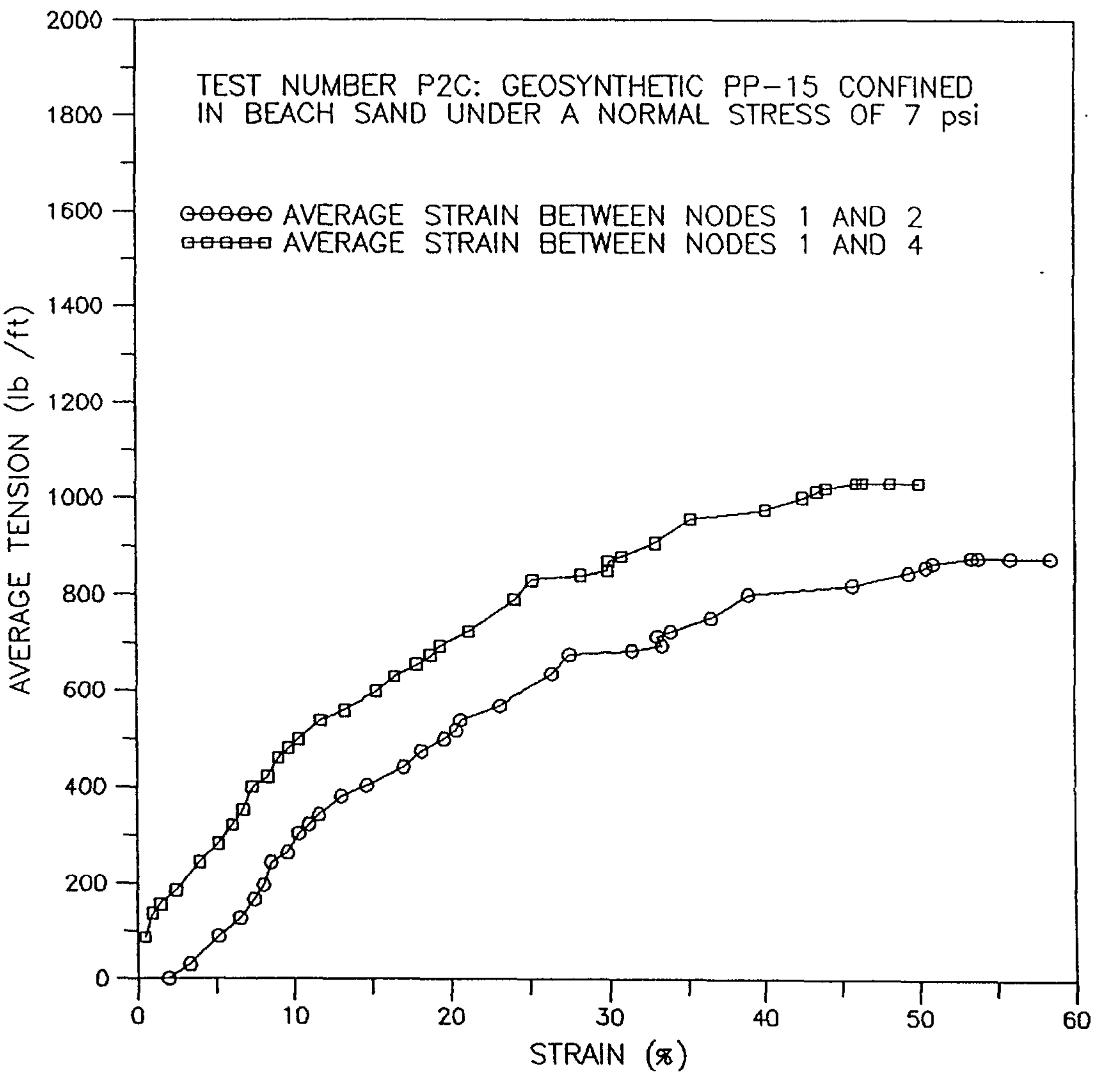
(Note: Typical response of Geosynthetic PP-15 specimen observed at the completion of pullout test)

Figure 16. Schematic diagram of deformed Geosynthetic PP-15 after pullout test.



1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 17. Tension versus strain curves using the "constant load" approach.



1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 18. Tension versus strain curves using the "linearly -distributed load" approach.

As described in the previous section, each geotextile specimen deformed nonuniformly immediately behind the clamp, resulting in the narrowing of the specimen width (i.e., necking). The effect of necking on the strain distribution was investigated by measuring displacements at four locations (i.e., nodes) on a 6-in- (152-mm-) long portion of the test specimen behind the specimen clamp as schematically shown in figure 11. It was anticipated that the tensile force and strain would decrease along the 6-in- (152-mm-) long portion. However, the actual strain distribution along the 6-in (152-mm) length immediately behind the specimen clamp obtained from a typical pullout test indicated that the maximum strain occurred in the center element at high tensile loads as shown in figure 19. This unexpected strain distribution is likely a result of the necking along the front portion of the geotextile specimen and a restraining effect of the reinforced clamped end.

e. Conclusions

Confined testing in a pullout device is convenient because the equipment is readily available in many laboratories throughout the United States. Tests conducted using the pullout device during this and other testing programs show that there is an effect of soil confinement on the pullout response of geosynthetic specimens. However, the pullout test results and laboratory observations indicate that there are four major problems in evaluating the confining stress-strain properties of a nonwoven geotextile using the pullout test method. The problems are: (i) the necking of the geotextile, which affects the response of the geotextile; (ii) the actual "mobilized" aspect-ratio (i.e., ratio of the mobilized specimen width to length), which varies during the pullout test and thus makes stress distribution difficult to quantify; (iii) the actual strain rate, which varies along the geosynthetic specimen during the pullout test; and (iv) the arbitrary selection of the size of the first element length for interpretation. Because of these observations associated with the pullout test, it was warranted to consider other alternative tests that could be used to assess the confined behavior of geosynthetics.

2.3 INITIAL BASELINE TESTING - CONFINED WIDE-WIDTH TEST

a. Equipment

Since unconfined stress-strain properties of geosynthetics are obtained from the wide-width tensile test conducted at a constant strain rate, it is logical to consider a similar testing approach for evaluating the confined response of the geosynthetic materials. A prototype confined extension test device was designed and fabricated as part of this initial testing program. The schematic diagram is shown in figure 20. The device was designed to operate

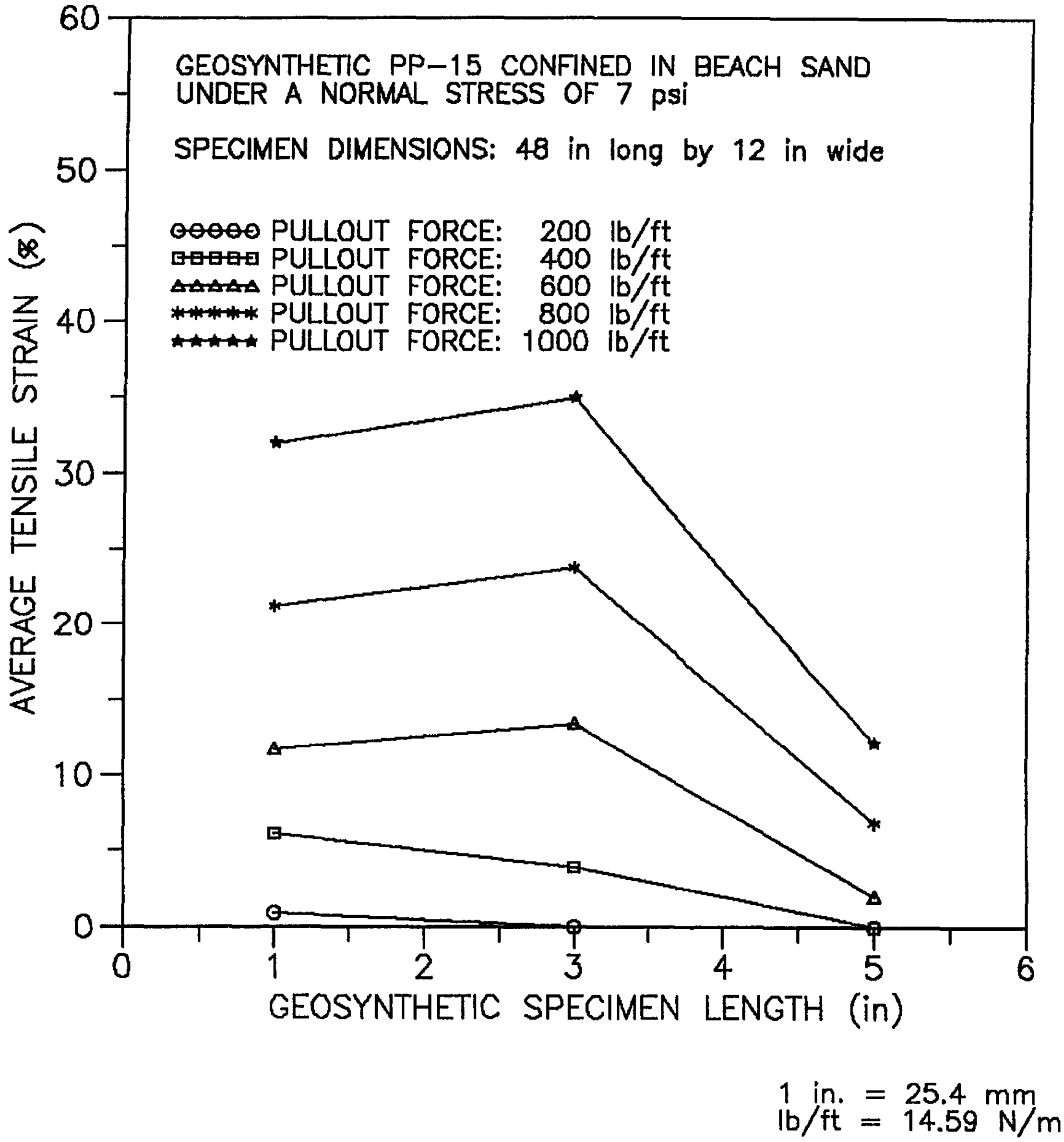


Figure 19. **Strain distribution along 6-in-long front portion of pullout specimen at various pullout forces.**

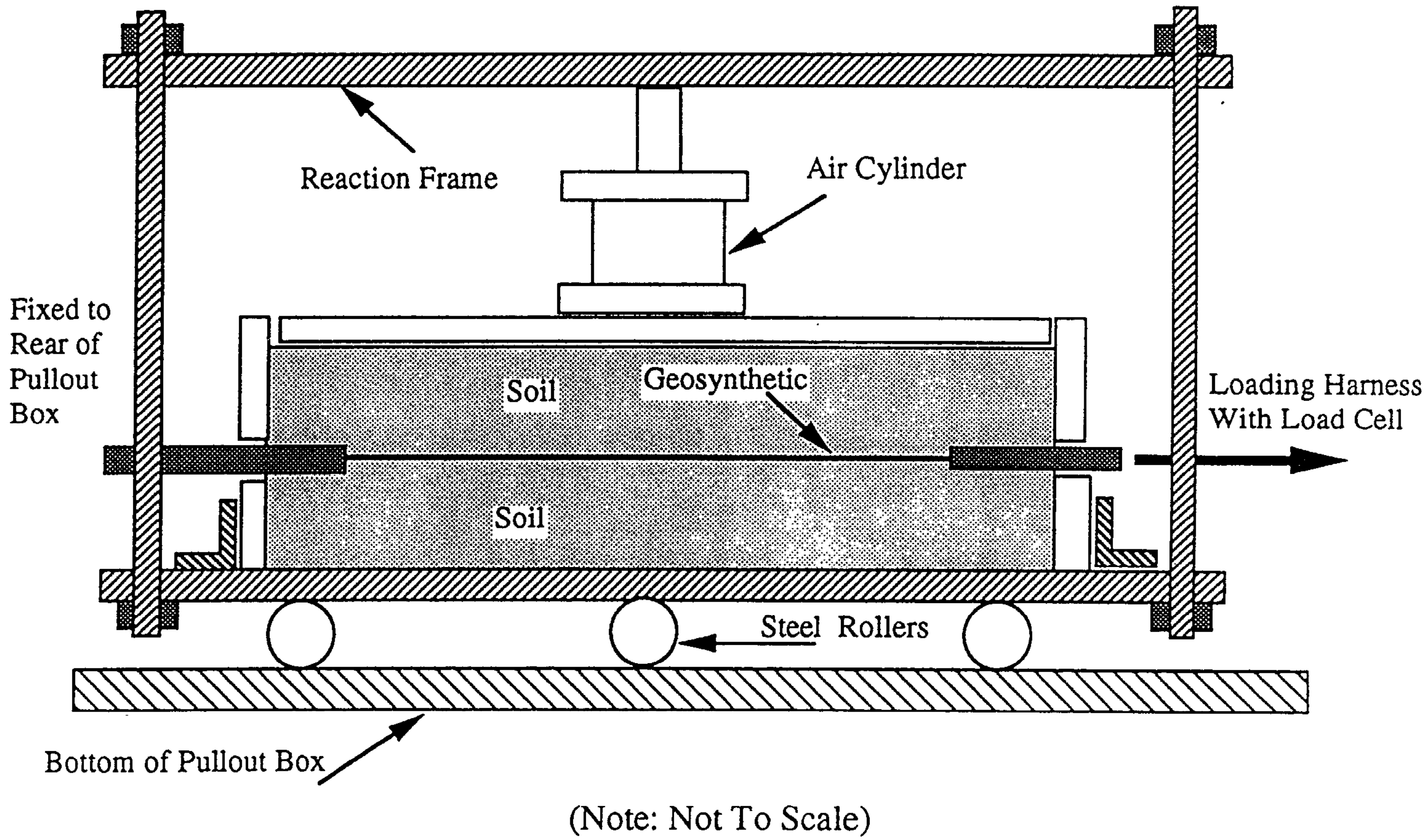


Figure 20. Schematic diagram of prototype confined wide-width test device.

within the pullout box. Confining pressures were applied to the test specimen using an air cylinder, and tensile loads were applied to the front clamp of the test specimen using the two hydraulic cylinders of the pullout box at a constant rate of strain.

b. Testing Procedures

Two confined extension test series were conducted on two nonwoven geotextiles (Geosynthetics PP-15 and PP-16) using the confined wide-width test device shown in figure 20. Each test was conducted using the following test procedures:

- Beach sand was placed in the lower half of the containment box and compacted by hand tamping to form a 3-in- (76-mm-) thick bedding layer. The sand was compacted to approximately 95 percent of its maximum dry unit weight (standard Proctor test) under dry conditions.

- A geotextile specimen was trimmed from the bulk sample and placed on top of the compacted sand. Each end of the geotextile specimen was clamped between two steel plates, which form the test specimen clamps.

- Additional beach sand was then placed in the upper half of the containment box and compacted by hand tamping to form a 3-in- (76-mm-) thick layer of sand above the geotextile specimen. The sand was compacted to approximately 95 percent of its maximum dry unit weight under dry conditions.

- A load cell was then attached to the loading harness and connected to the other end of the front test specimen clamp. The rear end of the test specimen was attached to the specimen clamp and fixed to the rear of the pullout box.

- The normal stress was then applied to the test specimen through an air cylinder.

- The geotextile specimen was loaded under a constant rate of strain until tensile failure occurred.

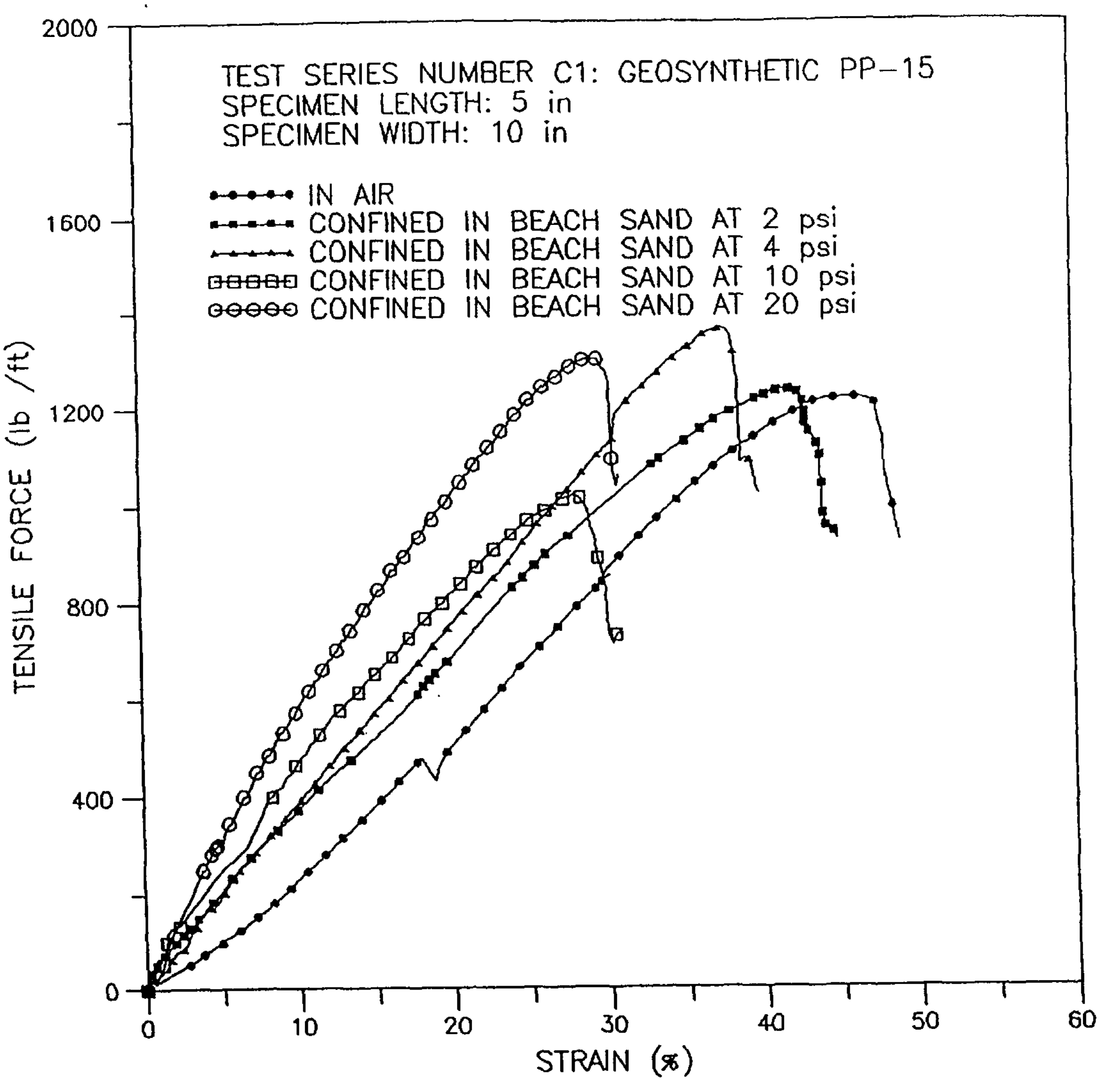
For purposes of these initial tests, attempts were not made to eliminate friction effects within the testing device. If the confined wide-width device was shown to have potential for this study, this variable would be assessed in subsequent investigations. The initial tests were conducted using a fixed soil thickness and a fixed geosynthetic length and width.

c. Test Results

For each test in the two-test series, tensile stresses and strains were calculated on the basis of the initial specimen width and length. The calculated stresses and strains were used to develop the confined stress-strain curves for each geotextile specimen as shown in figures 21 and 22. For comparison, the unconfined stress-strain curve of each geotextile that was obtained using the same device are also shown in the corresponding figures. The results of the two confined test series indicate that soil confinement improves the stiffness (i.e., modulus) of nonwoven geotextiles.

d. Conclusion

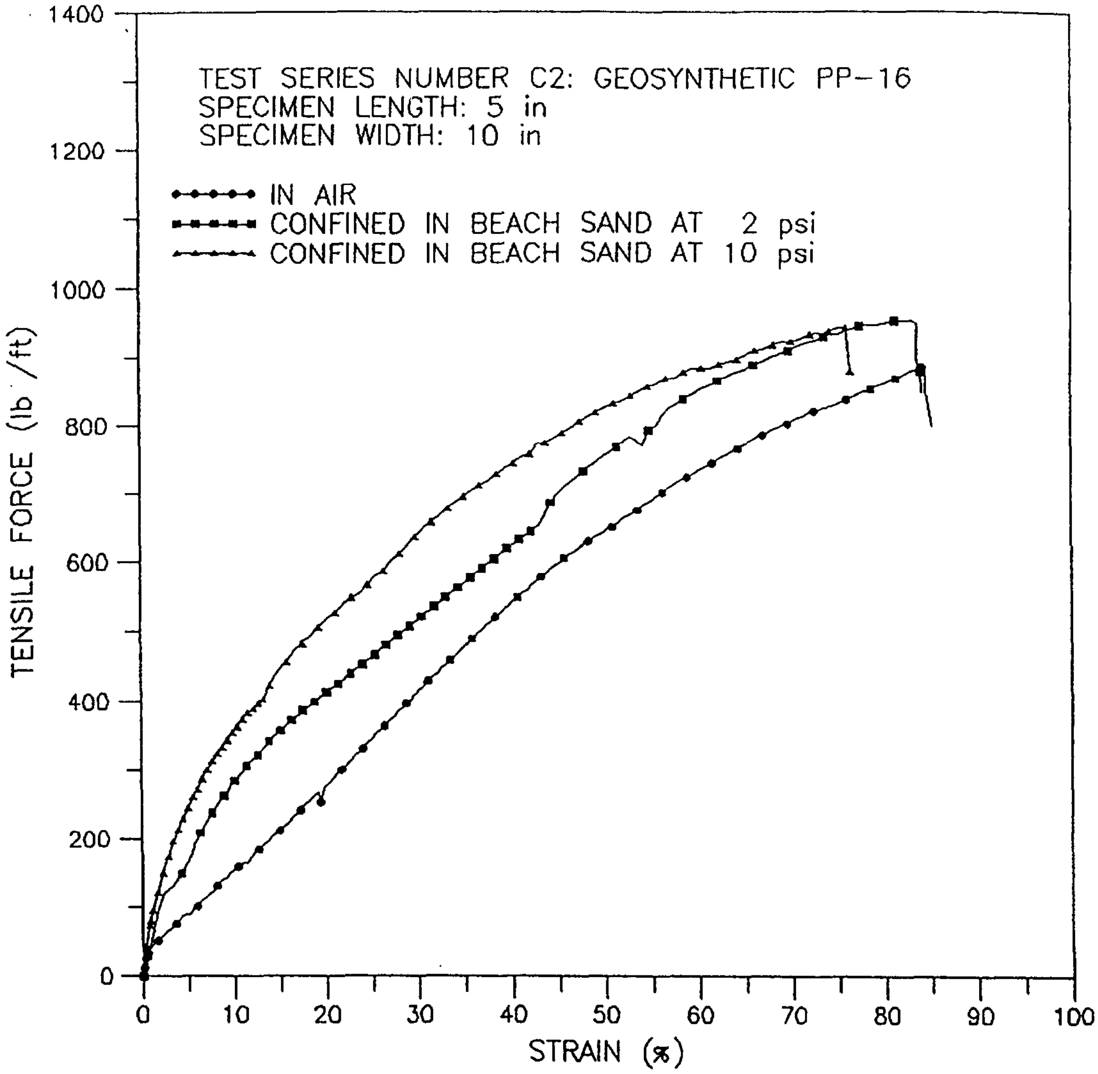
The prototype confined extension test apparatus appears to offer several advantages over the pullout testing equipment. These advantages include: (i) the relative ease of test set-up and operation under controlled conditions; (ii) a relatively constant aspect ratio of the geosynthetic specimen during testing (i.e., no necking observed); and (iii) a constant strain rate that can be applied to the test specimen. Because the geosynthetic specimen is subjected to a constant aspect ratio and constant rate of strain conditions during the confined extension test using the prototype confined extension test device, the confined response can be directly compared with the unconfined response to evaluate the effect of soil confinement. On the basis of these findings, it was concluded that the confined extension/creep testing protocol be developed using a device similar to the prototype confined extension test apparatus. The design of this testing equipment is presented in the chapter 3.



Note: Each test specimen failed due to rupture.

1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 21. Tensile force vesurs strain curves for Geosynthetic PP-15 confined in beach sand using prototype confined wide-width test device.



Note: Each test specimen failed due to rupture.

1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 22. Tensile force versus strain curves for Geosynthetic PP-16 confined in beach sand using prototype confined wide-width test device.

CHAPTER 3

DEVELOPMENT OF CONFINED EXTENSION/ CREEP TEST EQUIPMENT

3.1 OVERVIEW

The prototype confined extension test device described in the previous section was designed to operate within a pullout box and was equipped with only one load cell to measure tensile loads applied to the front of the geosynthetic specimen. Furthermore, the prototype device was designed for conducting confined extension testing under a constant rate of strain condition, and special precautions were not initially introduced to eliminate friction. It was decided to design and fabricate a new test apparatus with two load cells and other new features so that it can be used for both confined extension and confined creep testing. The development of this new equipment is described in the following section.

3.2 PROTOCOL EQUIPMENT

a. Description of Protocol Equipment

A new confined extension/creep test device (protocol device) was designed and fabricated. The protocol device is conceptually similar to the device presented in McGown et al. [1982], as will be discussed subsequently. The device consisted of the following major components:

- A rigid supporting table consisting of a 0.5-in- (13-mm-) thick steel plate welded to a rigid steel frame. The overall plan dimensions of the supporting table were 42 in (1067 mm) in length by 28 in (711 mm) in width.

- A confinement box made of 0.5-in- (13-mm-) thick steel plates. The internal dimensions of the confinement box were 17 in by 12 in (432 mm by 305 mm) in plan and 6 in (152 mm) in depth. An air bladder system was incorporated into the top and bottom of the confinement box and was used for applying normal stresses to the test specimen. The air bladder was made of 0.125-in- (3-mm-) thick gum rubber.

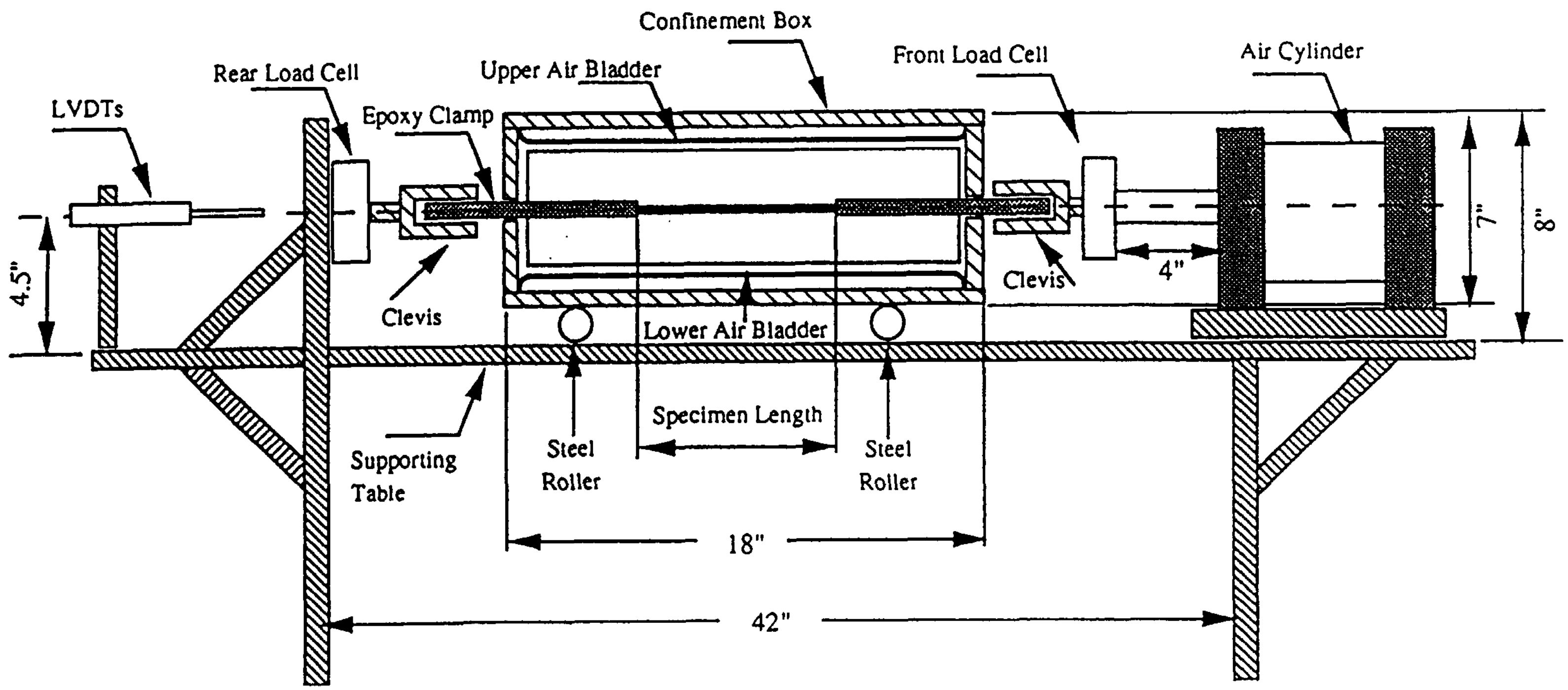
- A 6-in (152-mm) diameter air cylinder for applying tensile loads to the geosynthetic specimen. The air cylinder was mounted on the front of the supporting table. For the confined extension test, a constant rate of strain was achieved by manually adjusting the rate of air flow into the air cylinder. For the confined creep test, a constant load was maintained by applying a constant air pressure into the air cylinder.

A detailed, cross-section drawing of the test equipment is shown in figure 23. As shown, two steel rollers are placed between the bottom of the confinement box and the top of the supporting table. This setup allowed the confinement box to move together with the geosynthetic specimen in the horizontal direction during the confined extension/creep tests.

The protocol device was designed for performing confined extension tests (i.e., constant rate of strain tests) and confined creep tests (i.e., constant load tests). For the confined extension testing, a constant strain rate was achieved by manually adjusting the rate of air flow into the air cylinder. For the confined creep testing, a constant load was achieved by maintaining a constant air pressure within the air cylinder. The protocol device was designed to have the following capacities: (i) a maximum tensile loading capacity of 10,000 lb (44.5 kN); (ii) a maximum confining stress capacity of 50 psi (345 kPa); (iii) a maximum geosynthetic specimen size of 8 in (203 mm) in width by 12 in (305 mm) in length; and (iv) a maximum confining soil thickness of 3 in (76 mm) above and below the geosynthetic specimen.

The protocol device was equipped with two load cells and two linear variable differential transformers (LVDTs). As shown in figure 23, the front load cell was attached to the air cylinder and connected to the specimen clamp with the use of a clevis to allow direct measurement of tensile loads applied to the front of the geosynthetic specimen. The rear load cell was mounted on a steel plate that was welded to the rear reaction frame. The rear load cell was connected to the specimen clamp with a clevis and was used to measure the tensile loads transmitted to the rear of the test specimen. The two LVDTs were used to measure displacements at select locations along the specimen length. The load and displacement data were recorded with the use of a computer data acquisition system.

The protocol test device is similar in principle to that used by McGown et al. [1982] and Wilson-Fahmy et al. [1993]. However, the device developed by McGown et al. and modified by Wilson-Fahmy et al. consisted of a stationary box rather than a moving box. For testing that utilized the stationary box, the soil-geosynthetic interaction was minimized by using lubricated membranes placed between the confining soil and pressure bellows or bladders. For the protocol test device, the soil-geosynthetic interaction was minimized by



1 in = 25.4 mm

Figure 23. Detailed drawing of confined extension creep testing device.

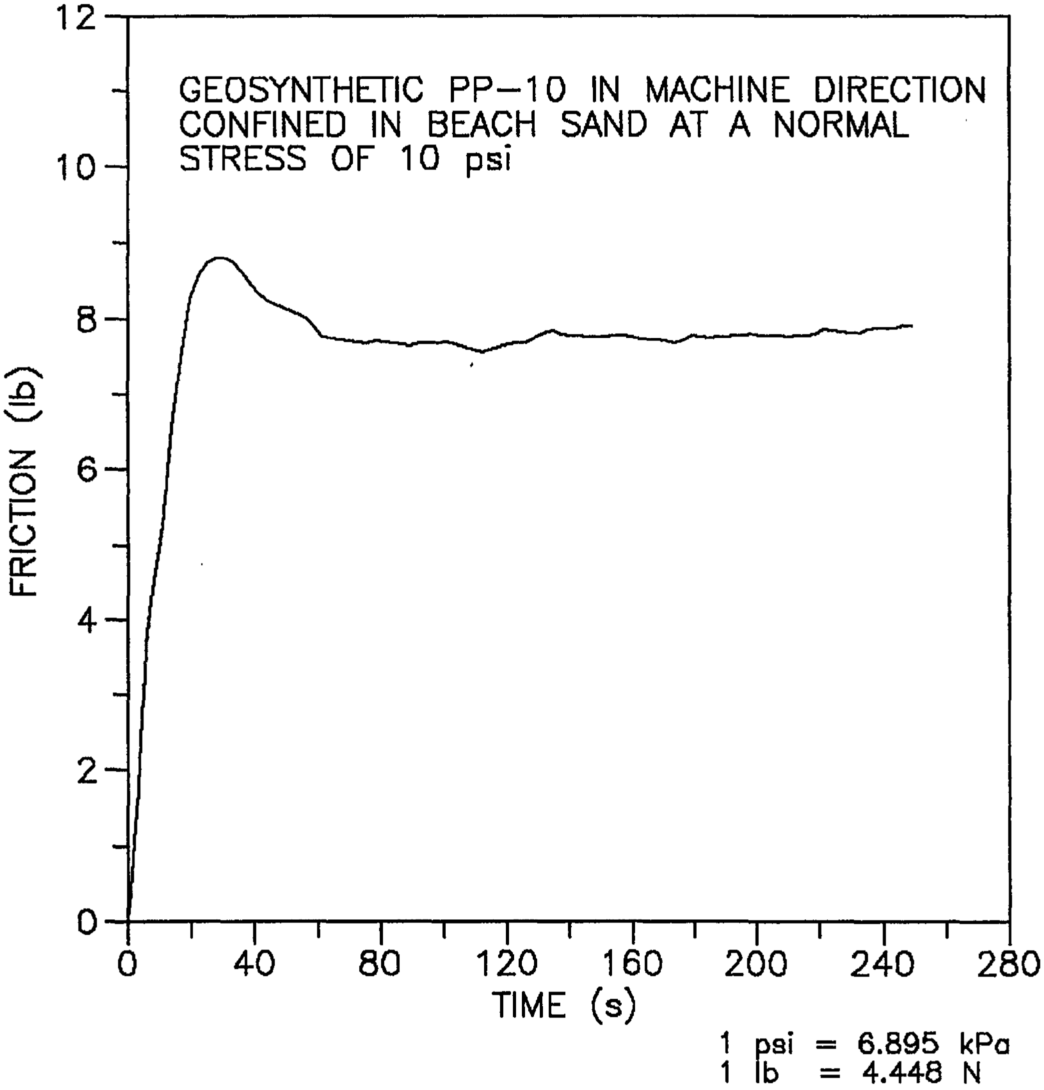
placing the entire box on low-friction steel rollers, as shown in figure 23. This modification greatly simplifies the test set-up procedures and allows for either constant rate of strain or constant load tests to be performed.

b. Calibration of Protocol Equipment

To ensure that the protocol confined extension/creep test device worked as designed, the test device was evaluated through calibration tests conducted in accordance with the following procedures:

- calibrate the pressure gages, load cells, and LVDTs that were to be mounted on the test device;
- adjust elevation of the air cylinder and the rear load cell so that a common center line was established through the loading harness and test specimen, as shown in figure 23;
- calibrate the mobilized friction that develops between the confinement box and steel rollers during a confined extension test;
- calibrate the confining pressure;
- calibrate strain distribution along the geosynthetic specimen to ensure uniformity of strain distribution along the test specimen length;
- conduct a confined creep test to evaluate variation of an applied constant load during the duration of testing; and
- conduct three confined extension tests on Geosynthetic PP-10 under the same confining pressure of 10 psi (69 kPa) to check reproducibilty of the test results.

To evaluate the mobilized friction between the confinement box and steel rollers during testing, a test specimen was fabricated using Geosynthetic PP-10, and a tensile load was applied to the front of the test specimen. Tensile loads were simultaneously measured by the two load cells. The mobilized friction was obtained by subtracting the load measured by the rear load cell from the load measured by the front load cell. The results of this test are shown in figure 24. The maximum measured friction was approximately 9 lb (40 N). The curve in figure 24 indicates that the friction reached its peak shortly after application of



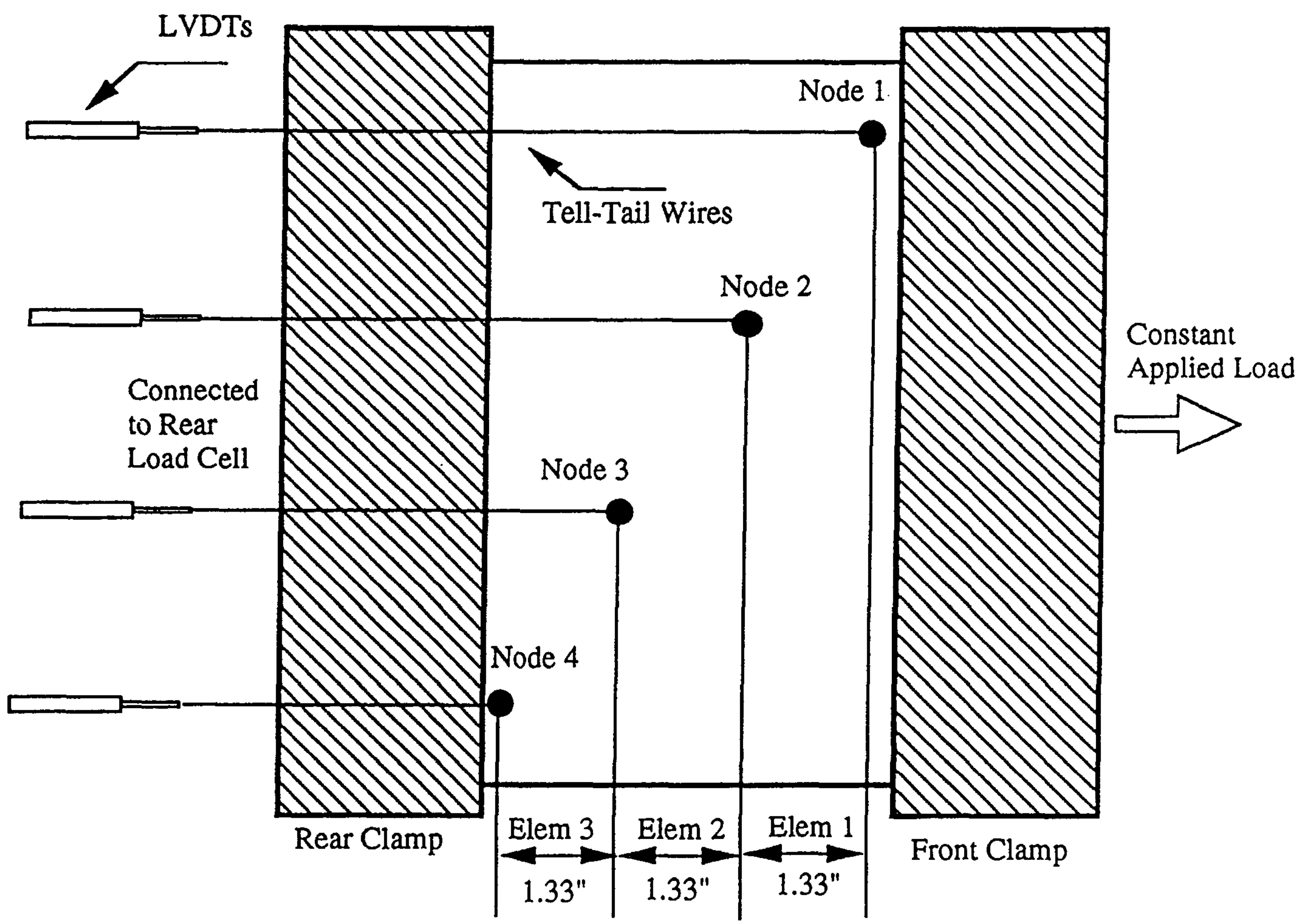
NOTE: The friction curve was obtained by subtracting the load measured by the rear load cell from the load measured by the front load cell.

Figure 24. Friction between confinement box and rollers in confined extension test.

tensile load and reduced to a steady value of approximately 8 lb (36 N). The results of additional tests indicate that the mobilized frictions were approximately the same under different confining pressures. This observation is supported by the fact that the contact force between the steel rollers and confinement box does not vary under the applied air pressures. The mobilized friction simply equals the sum of the total weight (i.e., weight of soil and box) times the friction coefficient between steel rollers and confinement box. To further understand the friction developed between the confinement box and the steel rollers, the confined box was filled with soil and was pulled at the front end while the rear remained unattached to the supporting table. The peak load measured in this simple pull test was 8 lb (36 N), which is in good agreement with the results shown in figure 24.

During the confined extension testing, a constant air pressure is applied into the air bladders and then transmitted to the geosynthetic specimen through the confining soil. Friction is anticipated to develop at the interface between the soil and the internal surfaces of the confinement box (i.e., side wall friction), and it is believed that this friction would reduce the overall pressure on the center plane of the soil specimen under which the geosynthetic specimen is located. A series of tests were performed to assess the overall pressure loss for the 6-in- (152-mm-) thick soil specimen. During each test, the upper bladder was filled with tap water and connected to a pressure gage but not directly connected to a pressure source. A constant air pressure was applied to the lower bladder, which pushed the soil against the upper bladder. Measured pressures in the upper bladder indicate a typical loss of 5 to 10 percent of applied pressures ranging from 5 to 20 psi (35 to 138 kPa) in the lower bladder. However, based on experience in measuring confining pressures on geosynthetic specimens in a pullout box using earth pressure cells, the pressure in the central portion of the soil specimen is nearly the same as the applied pressure. A direct measurement of soil pressures immediately above or below the geosynthetic specimen was not performed during this calibration due to both the unavailability and reliability of small diameter earth pressure cells.

Although it has been verified that the applied tensile load was transmitted to the rear of the geosynthetic specimen with a minor friction loss, a question remained as to how the applied tensile load is transmitted to the rear end of the test specimen. There was a concern about the uniformity of tension or strain distribution over the specimen length. This concern was addressed by evaluating the strain distribution along the geosynthetic specimen in a confined creep test (Test No. C1B) conducted as part of the confined creep testing program. Four tell-tail wires were attached to specific locations along the geosynthetic specimen as shown in figure 25. Displacements at these locations were measured by LVDTs connected to the tell-tail wires. The measured displacements were used to calculate average strains over each



1 in = 25.4 mm

Figure 25. Schematic diagrams showing four tell-tail wires.

element. To show the strain distribution along the specimen length, the average strain over each element at an elapsed time of 100 hours is presented in figure 26. As shown in figure 26, the strain distribution over the specimen length is approximately uniform. A larger strain within the center element (Element 2) is likely due to the necking effect of the test specimen that was observed after completion of the test.

To evaluate the potential for the prototype equipment to maintain a constant load during a creep test, a test was conducted on Geosynthetic PP-10. Tensile loads were measured by the two load cells and recorded by the computer data acquisition system. The tensile load history of the front load cell is shown in figure 27. The maximum variation was approximately ± 10 lb (± 45 N) at the tested load level of 1,000 lb (4.5 kN). With respect to the applied load level in this particular test, the variation of tensile load during the test was ± 1 percent.

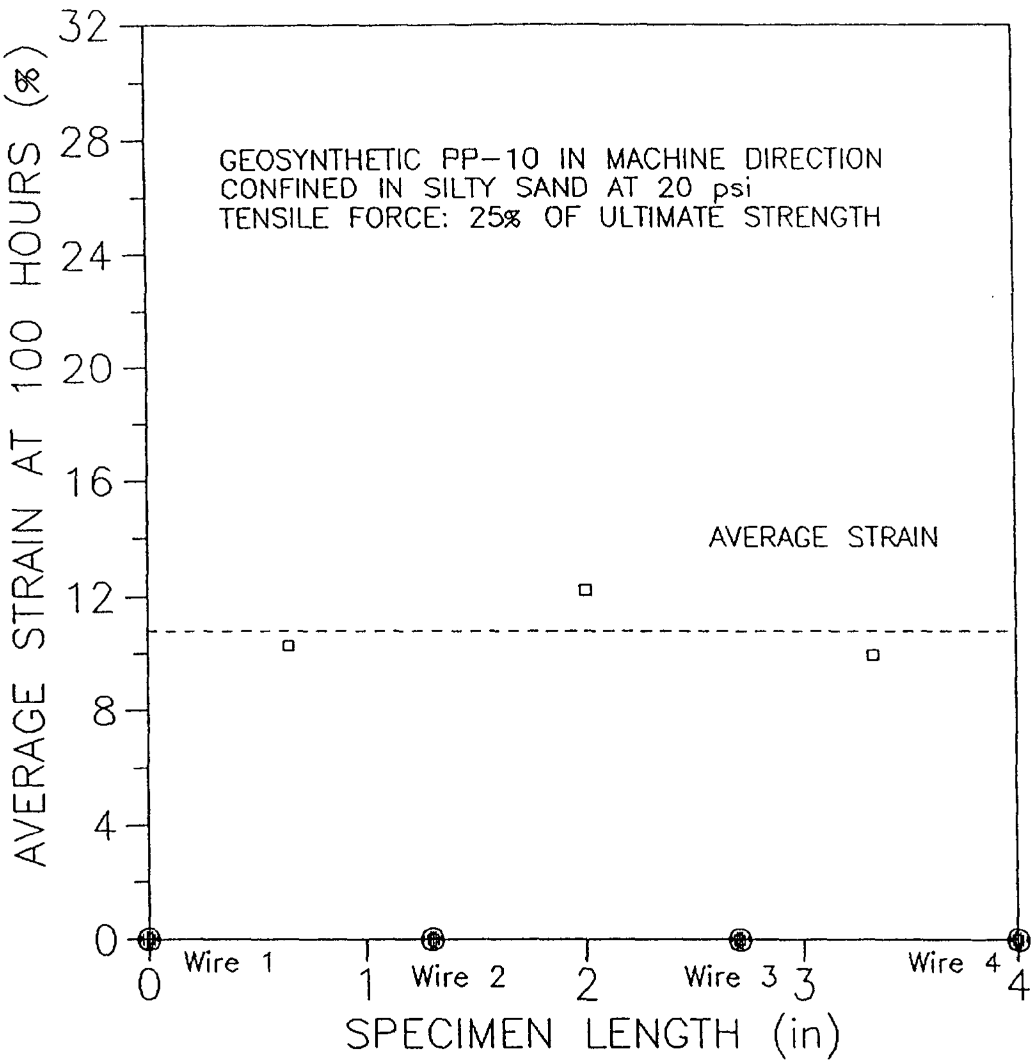
The test reproducibility was assessed by conducting three tests on Geosynthetic PE-13, an unaxially drawn, high-density polyethylene geogrid, confined in the beach sand under a normal stress of 10 psi (69 kPa). Each specimen was tested under the same conditions. The results of the three tests are shown in figure 28 and indicate that the differences between the three confined stress-strain curves are relatively small.

3.3 SUMMARY

The test equipment was designed and fabricated for the confined extension/creep tests. Pressure gages, load cells, and LVDTs were calibrated by an external calibration agency prior to being installed onto the test equipment. Specific calibration tests were conducted, and the results of these specific calibration tests are summarized below:

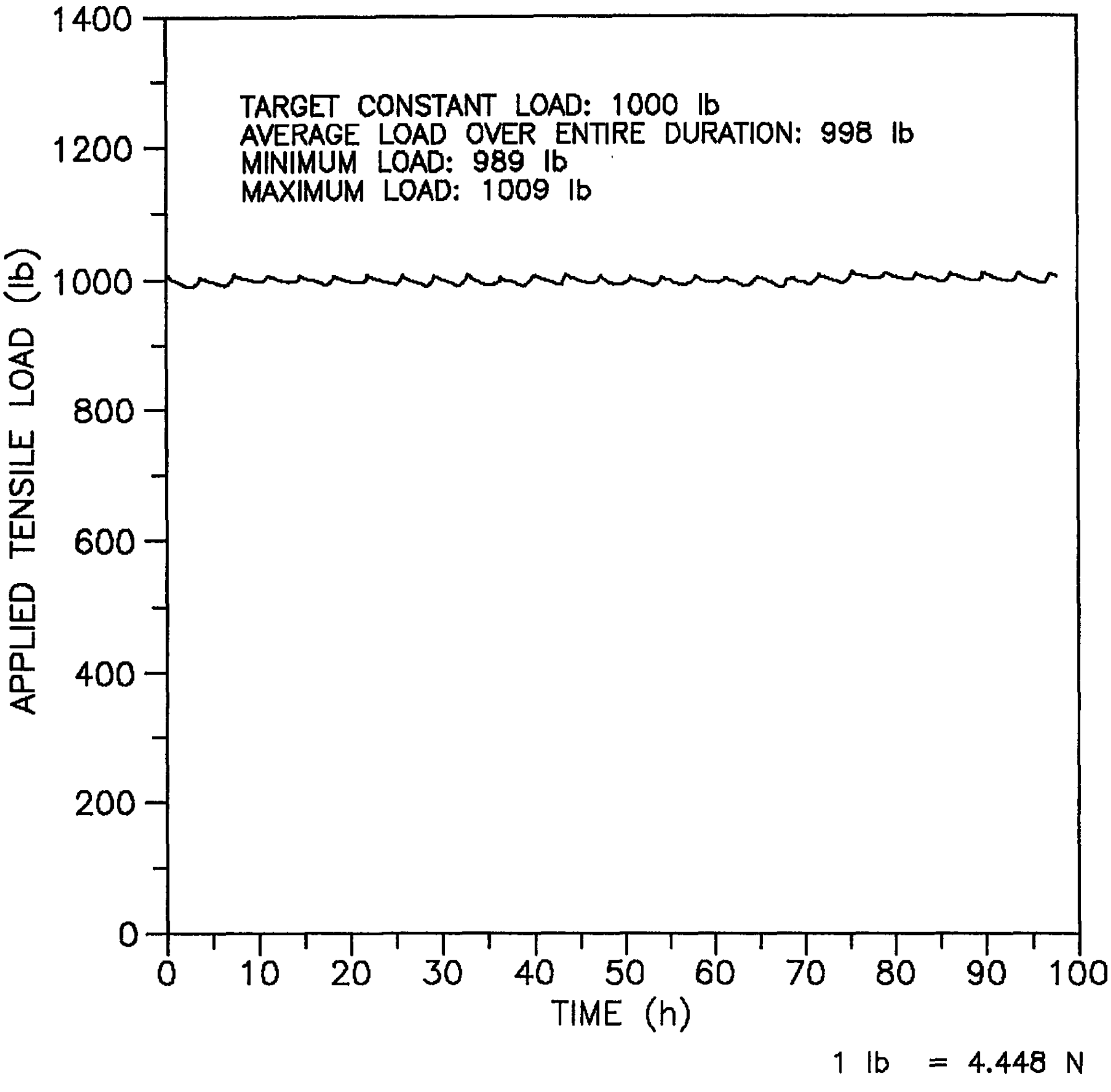
- The peak friction between the confinement box and steel rollers is on the order of 1 percent of anticipated maximum tension in both the confined extension test and the confined creep test.

- The loss of confining pressure because of side wall friction for a 6-in- (152-mm-) thick soil specimen was 5 to 10 percent of the applied pressures in the range of 5 to 20 psi (35 to 138 kPa). However, the confining pressure transmitted to the geosynthetic specimen in the confined extension and confined creep tests was considered the same as the pressure applied to the bladders on the basis of our experience.



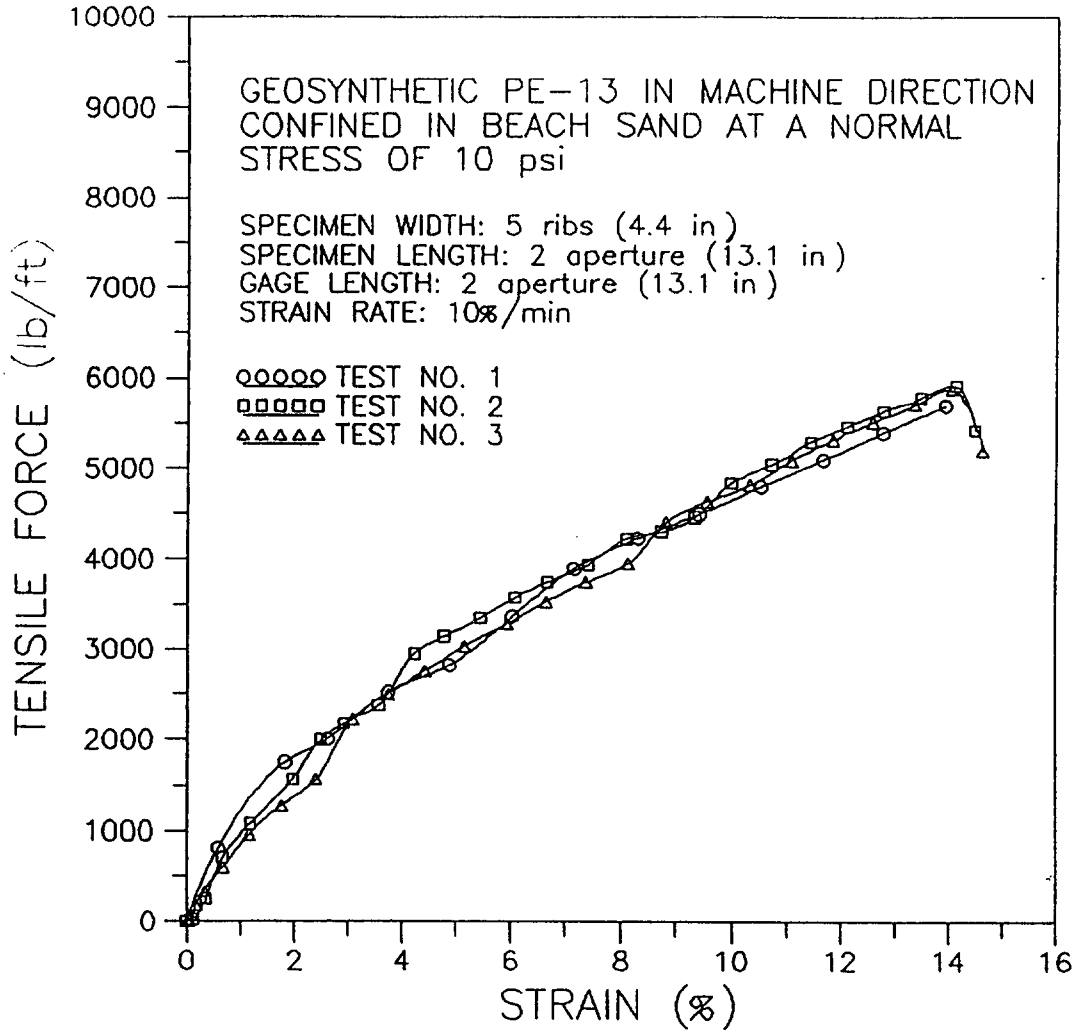
1 in = 25.4 mm
1 psi = 6.89 kPa

Figure 26. Strain distribution over each element along the specimen length.



NOTE: It appears that the tensile load varied periodically. This periodic variation is more likely related to compression cycles of the air compressor used in this testing program.

Figure 27. Variation of tensile loads in confined creep test.



1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 28. Reproducibility of confined extension test results.

- The distribution of tensile strain along the specimen length was nearly uniform.

- The test equipment was able to provide a relatively constant tensile load to the test specimen for the creep tests, with a variation on the order of 1 percent of the anticipated creep loads.

- The test equipment has the ability to produce consistent test results.

It is noted that the allowable peak friction between the steel rollers and confinement box (i.e., the difference between the loads measured by the front and rear load cells) and the variation of a desired constant load during a creep test have not been established for the confined extension and creep tests so far. It appears that a relative measurement for each of these two variables is appropriate. Specifically, the friction is measured relative to an anticipated maximum tensile load of the geosynthetic test specimen, and the variation of desired constant load is measured relative to the applied creep load. As described previously, the friction is approximately 1 percent or less of anticipated maximum tensile load to be used in the confined extension and creep tests, and the variation of the applied creep load is approximately ± 1 percent of anticipated creep load for the confined creep tests. These measured values are herein considered within an acceptable range and will be controlled within these limits during the actual confined extension/creep testing program.

Based on the results of the Phase II program, the confined wide-width device, herein referred to as the protocol device, appears to offer the greatest potential to achieve the goals of the research program. As discussed in this section, this device is conceptually similar to devices presented by McGown et al. [1982] and Wilson-Fahmy et al. [1993]. The authors of this report note that these investigators reported that specific testing procedure efforts (i.e., lubricated bladders, thin soil specimens, etc.) influence the measured test results. These procedural effects were explicitly not assessed during Phase II but will be a specific focus of the Phase III program presented in the subsequent chapters.

CHAPTER 4

VERIFICATION OF CONFINED EXTENSION/ CREEP TEST EQUIPMENT

4.1 OVERVIEW

It has been shown in the preceding chapter that the protocol confined extension/creep test device functioned appropriately and can be used for the verification testing program. The measured response of confined geosynthetics, however, may be influenced by other factors, which may not be related to the test device itself. These factors and their potential effects on the stress-strain properties of the confined geosynthetics comprise Phase III of the program and are discussed in the following sections.

4.2 VERIFICATION TESTING PROGRAM

a. General Testing Procedures

A general test procedure was developed to evaluate the confined extension and creep behavior of geosynthetics using the protocol test equipment. This test procedure was used for each test conducted during the confined extension/creep testing program and is described below:

- The soil material (i.e., beach sand or silty sand) was compacted into the lower half of the confinement box to form a lower confining layer. The upper surface of the lower confining layer was placed so that it would be level with the center line of the loading harness (i.e., air cylinder and the rear load cell). Each soil was compacted by hand tamping to a desired unit weight under specific moisture conditions; the beach sand was placed at 95 percent of its maximum dry unit weight under dry conditions and the silty sand was placed at 95 percent of its maximum dry unit weight at its optimum moisture content. The maximum dry unit weights for the two soil materials were determined in accordance with ASTM D 698.

- A geosynthetic specimen was trimmed from one of the bulk samples of the geosynthetic material. For the three geotextile materials, the test specimen was trimmed to have an aspect ratio (i.e., width to length ratio) of approximately 2:1. For the two geogrid materials, the test specimen was trimmed in such way that it had a length containing two complete apertures in the direction of manufacture (i.e., machine direction) and a width containing five ribs in the cross-machine direction. The end of each geosynthetic specimen was cast in a low-temperature curing epoxy resin that was reinforced using layers of impregnated nonwoven geotextile to facilitate clamping of each geosynthetic. The epoxy resin was prepared by mixing equal volumes of epoxy compound and curing agent. During the 24-hour-long curing period, each end of the specimen was confined between smooth steel plates under a normal stress of 0.15 psi (1 kPa) to ensure a uniform casting, which facilitates clamping.

- After preparing the geosynthetic specimen, the test specimen was then placed on top of the lower confining soil layer. The two cast ends of the geosynthetic specimen were then connected to the front clevis and rear clevis components of the loading system, as shown previously in figure 23.

- Two tell-tail wires were used to monitor displacement of the geosynthetic specimen within the confinement box. The wires were connected to the two ends of the geosynthetic specimen. Each wire was then connected to LVDTs mounted to the rear of the supporting table.

- A pretension force was applied to the geosynthetic specimen to eliminate slack within the geosynthetic specimen. The amount of pretension force was preselected for each test.

- Additional soil was placed above the geosynthetic in the upper half of the confinement box and compacted by hand tamping to form the upper confining layer above the geosynthetic specimen. The soil was compacted by hand tamping to the same unit weight and was at the same specific moisture content as the lower confining soil layer.

- A normal stress was then applied to the test specimen by pressurizing the air bladder loading systems. A predetermined source pressure was applied simultaneously through the lower and upper air bladders.

- For the confined extension testing, each geosynthetic specimen was loaded under a constant rate of displacement, as measured on the front specimen clamp. For the confined creep testing, a constant load was applied to the test specimen in a relatively fast but controlled manner.

The general test procedure involves the selection of specific values for five major test variables. These test variables include:

- the level of pretension force to be used in the confined extension and creep tests;

- the strain rate to be used in the confined extension test;

- the aspect ratio to be used in the confined extension and creep tests;

- the initial loading rate (rate of application of the constant tension load) to be used in the confined creep testing;

- the thickness of confining soil to be used in the confined extension and creep tests; and

- the magnitude of friction along the geosynthetic specimen during the confined extension tests.

These factors (variables) may influence the confined response of geosynthetics. An appropriate value for each variable was selected on the basis of existing ASTM standards or was determined from conducting specific verification tests.

b. Pretension Force

Similar to what is already known about the in-air wide-width stress-strain properties of geosynthetics, the confined stress-strain response of a geosynthetic is also influenced by the pretension force applied to the geosynthetic specimen prior to initiation of the testing. The pretension force reduces or eliminates slack within the test specimen, provides the same initial stress-strain conditions for similar test specimens, and allows the results of the confined extension/creep tests to be compared with those of unconfined tests. It is noted that application of a pretension force on a test specimen is a laboratory testing procedure established for conditioning the test specimen so that it will have a repeatable starting point, thus contributing to the comparison of the test results. Pretensioning may or may not simulate the actual behavior of the geosynthetic material deployed in a reinforced soil structure since the reinforcing geosynthetic may not be subjected to a specific amount of tensile force prior to the construction loading.

Since the results of the confined extension and confined creep testing are to be compared with the results of standard wide-width tensile testing and unconfined creep testing, respectively, it was logical to use the procedures established in the current in-air wide-width tensile testing standard (i.e., ASTM D 4595) for selection of the pretension force for the various geosynthetics. Following the procedures described in ASTM D 4595, a pretension force equal to 1.25 percent of the expected breaking force was applied to each geosynthetic specimen. However, at any given time, the total applied pretension force was not less than 10 lb (45 N) or greater than 50 lb (222 N), as recommended in ASTM D 4595. It should be noted that the pretension force was applied to the geosynthetic specimen prior to placement of the soil above the geosynthetic specimen.

c. Strain Rate

The effect of strain rate on the unconfined stress-strain properties of geosynthetic materials has been studied by McGown et al. [1984]. The reported results indicate that a geosynthetic exhibits a higher modulus and greater ultimate tensile strength when tested at high rates of strain. The strain rate is likely to have a similar effect on the confined stress-strain properties of geosynthetics. For the confined creep testing, the strain rate also influences the total strain versus time response since it is recognized that a constant load can be applied to the test specimen under different strain/loading rates.

A constant strain rate of 10 percent/min was selected to load each test specimen during this testing program. Selection of this specific rate was based on the procedures established in ASTM D 4595. It should be noted that geosynthetic materials used in reinforced soil structures may be subjected to faster or slower loading rates during construction and much slower strain rates during their service life time. Furthermore, for a safely designed reinforced soil structure, the strain rate in the reinforcing geosynthetic decreases with time after construction. Therefore, the constant strain rate test was designed to evaluate the stress-strain properties under a specific reproducible strain rate rather than to simulate actual loading conditions that the reinforcing geosynthetic within a reinforced soil structure would experience during its construction and/or service life time.

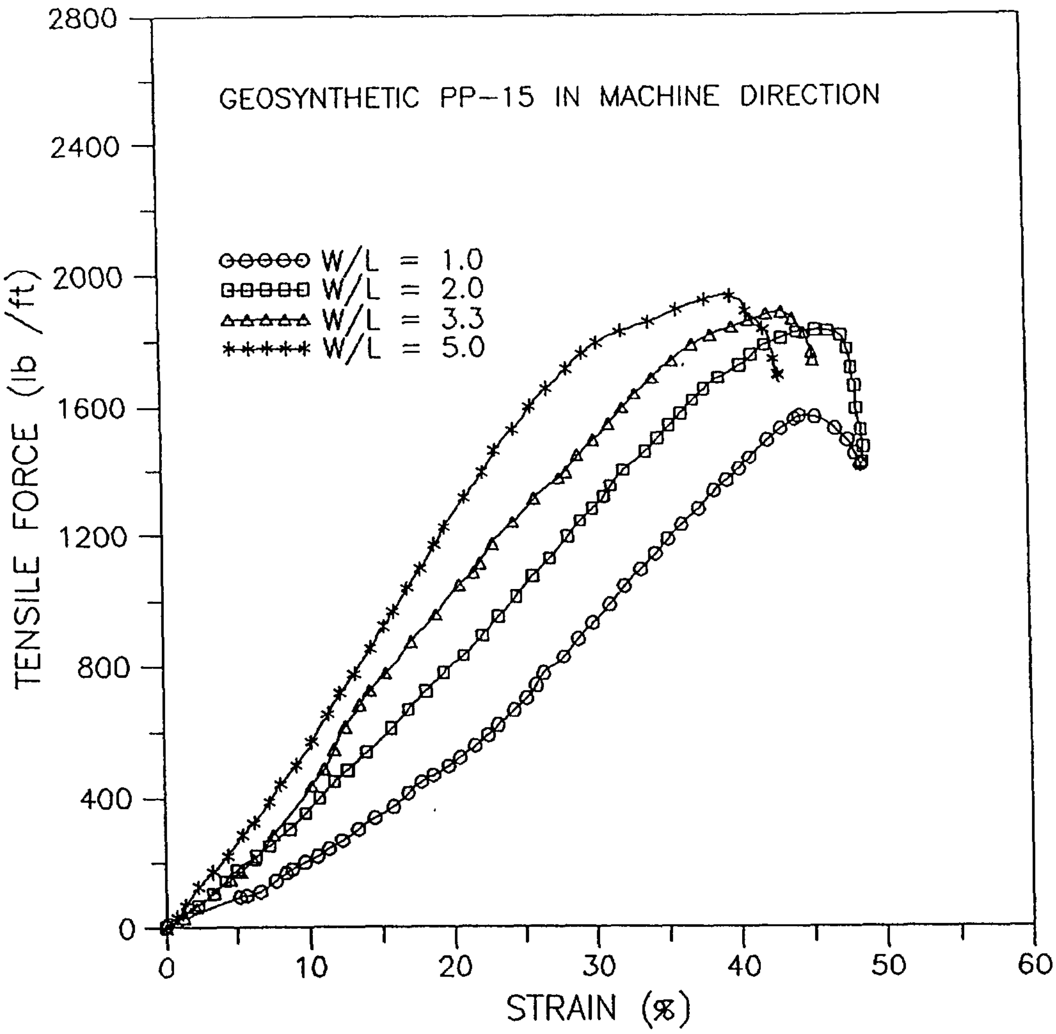
d. Aspect Ratio

The effect of aspect ratio on measured stress-strain properties of a nonwoven geotextile was studied by conducting a four-test series of tensile tests on Geosynthetic PP-15 using aspect ratios varying from 1:1 to 5:1. The results of this test series are shown in figure 29; these results indicate that, as the aspect ratio increases, the nonwoven geotextile exhibits a higher modulus and a slightly higher strength. For woven geotextiles and geogrids, however, it has been reported that the increase of aspect ratio results in a reduction of strength (Myles and Carswell, 1986).

For all of the geotextile materials used subsequently in this confined extension/creep testing program, an aspect ratio of approximately 2:1 was selected as the test aspect ratio, based on the recommendations presented in ASTM D 4595. For the geogrid materials, a constant aspect ratio was not able to be used among the products tested in order to maintain complete apertures (i.e., a whole number of ribs) within the test specimens. It was decided that each geogrid specimen was to be trimmed in such way that it had two complete apertures in the machine direction and five ribs in the cross-machine direction.

e. Initial Loading Rate

Since the stress-strain properties of geosynthetic materials are strain-rate dependent, it is expected that variation of the initial loading rate will affect the total strain versus time curve in a long-term constant load creep test. To evaluate the effect of initial loading rates on the confined creep response of geosynthetics, two confined creep tests were conducted on Geosynthetic PE-13. For each test, the geosynthetic specimen was confined within the beach sand at a normal stress of 10 psi (69 kPa). In one test, a target load corresponding to 50 percent of the ultimate tensile strength of the geogrid was applied to the test specimen at a strain rate of approximately 1 percent/min. In the other test, the same target load was applied to the test specimen at a strain rate of approximately 50 percent/min. The results of the two confined creep tests are shown in figure 30. As anticipated, figure 30 indicates that the initial portion of the total strain versus time curve is significantly affected by the loading rate. However, the difference between the two creep curves becomes smaller as time increases. More tests at different load rates need to be conducted in a future study to definitively confirm that the initial loading rate effect does not significantly affect the total creep response curve.



1 lb/ft = 14.59 N/m

Figure 29. Results of unconfined wide-width tensile tests using specimens with different aspect ratios.

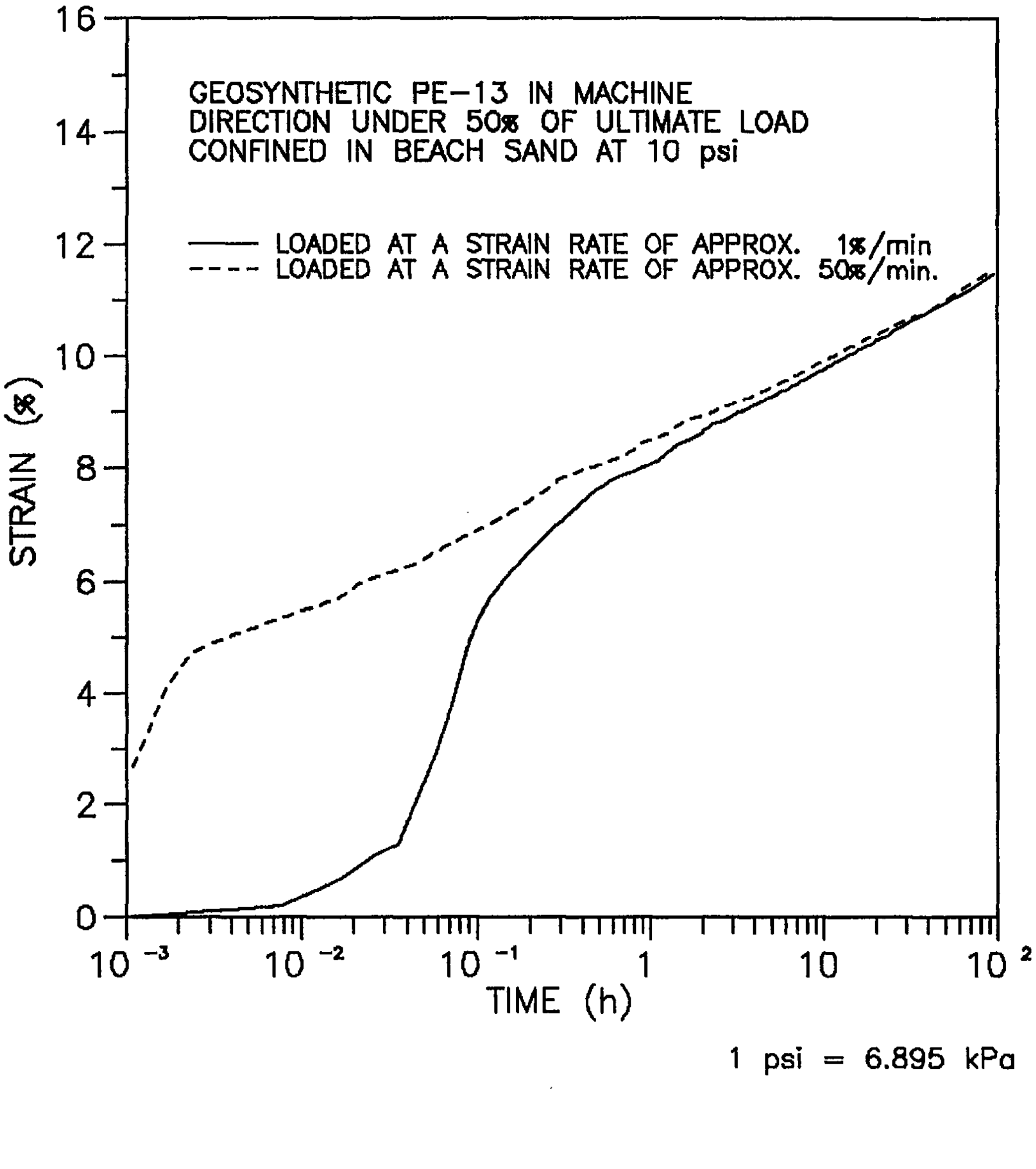


Figure 30. **Results of two confined creep tests having different initial loading rates.**

It has been shown that the initial strain rate at least influences the initial portion of total strain versus time curve obtained from the confined creep test. A specific loading rate is required for conducting the confined and unconfined creep tests so that the results of the creep tests conducted during this testing program are comparable. On the basis of the test procedure established in ASTM D 5262, a constant strain rate of 10 ±3 percent/per min was selected to load each creep test specimen.

f. Confining Soil Thickness

In the confined extension and creep tests, an applied normal stress is transferred to the geosynthetic specimen through the confining soil. The friction between the confining soil and the internal lateral surfaces of the confinement box (i.e., soil/side wall interface friction) may influence the normal stress transmitted to the geosynthetic specimen and thus affect the measured confined stress-strain properties of the geosynthetic. It was anticipated that there would be increasing soil/side wall friction for increasingly thicker confining soil layers. Therefore, the effect of confining soil thickness on the confined stress-strain properties of a nonwoven geotextile was investigated by conducting a series of tests, each conducted at a specific soil thickness.

Geosynthetic PP-10 was selected for studying the thickness effect of the confining soil on the confined stress-strain properties of geosynthetics. The selection was based on the fact that the behavior of nonwoven geotextiles may be significantly affected by soil confinement. Therefore, the effect of soil thickness on the confined behavior should be readily defined by a series of tests in which this type of geotextile is confined within different thicknesses of soil.

Four tests were performed using Geosynthetic PP-10. Each geosynthetic specimen was confined in the beach sand under a total normal stress of 10 psi (69 kPa) and tested under a constant strain rate of 10 percent/min. Four different thicknesses of the beach sand were used:

- soil thickness of 0.4 in (10 mm) above and below the geotextile specimen;
- soil thickness of 1.0 in (25 mm) above and below the geotextile specimen;
- soil thickness of 2.0 in (51 mm) above and below the geotextile specimen; and
- soil thickness of 3.0 in (76 mm) above and below the geotextile specimen.

It should be noted that the confinement box was designed to contain a typical 3.0-in- (76-mm-) thick soil specimen above and below the geosynthetic specimen. To confine the geosynthetic between thinner soil layers, a rigid substrate of appropriate thickness was first placed between the lower soil layer and lower air bladder. After compaction of the upper soil layer, another rigid substrate of appropriate thickness was placed between the upper soil layer and upper air bladder.

The confined stress-strain curves obtained from the four tests are presented in figure 31. These data show that the confined stress-strain curves are almost identical for the tests conducted at soil thicknesses of 1, 2, and 3 in (25, 51, and 76 mm). It appears that varying the confining soil thickness from 1 to 3 in (25 to 76 mm) has little effect on the confined stress-strain behavior of the geosynthetic. Further, the geotextile specimens were each placed 2 in (51 mm) away from the side walls of the confinement box, which appears to be far away enough to eliminate or at least minimize the effect of the side wall friction.

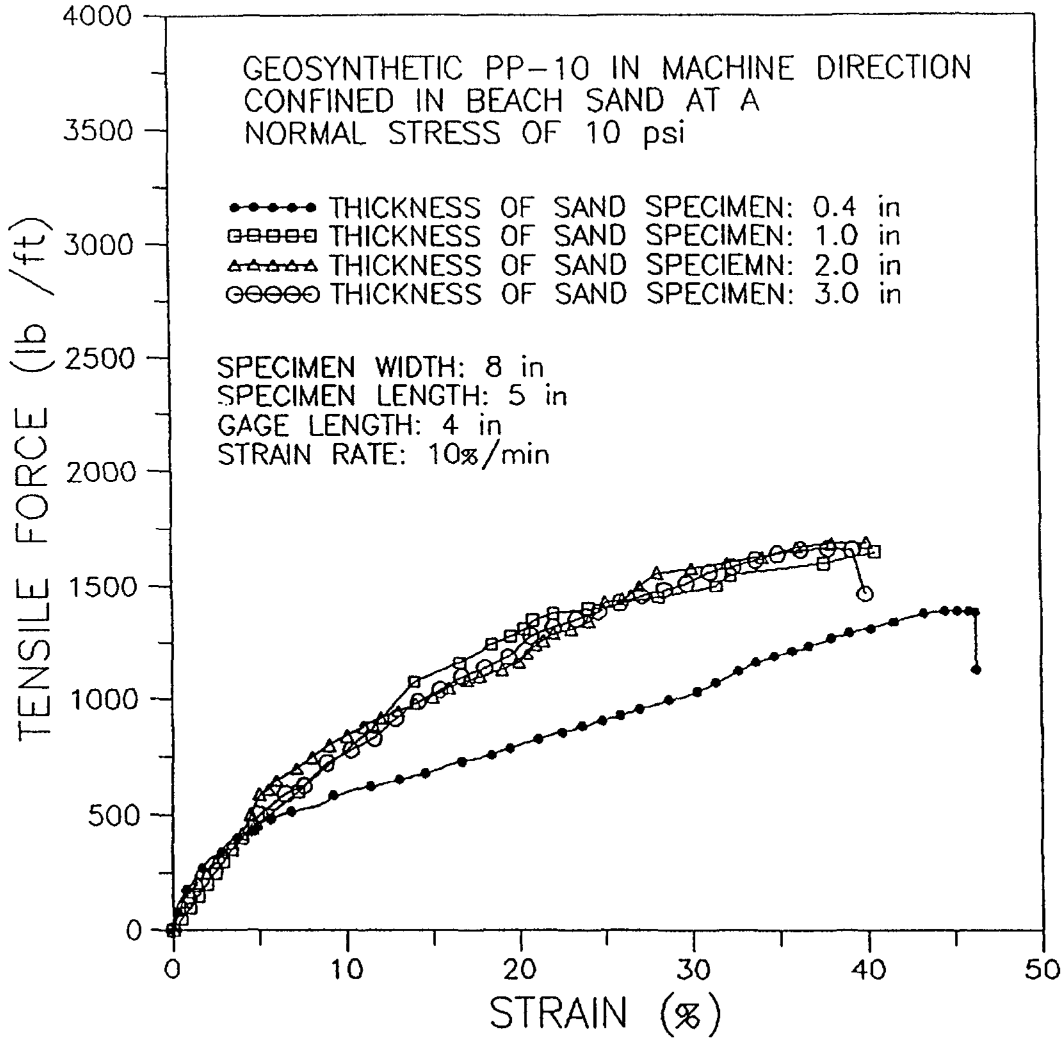
However, for the test conducted at a soil thickness of 0.4 in (10 mm), the results indicate the soil confinement effect was significant. Inspection of the test specimen after testing indicates that the geotextile specimen was only partially confined within the soil due to the fact that "cracks" developed through the thickness of the upper and lower thin soil layers. This likely explains why the confined stress-strain response was different, and specifically is less stiff and weaker than the response of geotextiles between the thicker soil layers. To avoid potential interpretation difficulties caused by cracking of the thin soil layer, it was preliminarily concluded that a soil thickness of 3 in (76 mm) above and below the geotextile specimen would be used for all of the confined extension and creep tests.

4.3 FRICTION ALONG THE GEOSYNTHETIC SPECIMEN

The uncharacteristic cracking observed when thin soil specimens were used, coupled with a corresponding difference in confined geosynthetic response, warranted additional investigation. It is believed that the observed confined response is due at least in part to the friction mobilized at the soil-geosynthetic interface. A study was conducted to investigate the effect of friction. Results are presented in this section.

a. Strain Compatibility Between Confining Soil and Geosynthetic

In the confined extension test, a geosynthetic specimen confined between two soil layers is



1 lb/ft = 14.59 N/m

Figure 31. Results of confined extension tests when confined by various thickness of soil layer.

typically loaded in tension at a constant rate of strain (or an incrementally increasing load). As the geosynthetic specimen deforms upon application of tensile forces, the confining soil may deform with the geosynthetic specimen at the same rate (i.e., strain compatibility) or the slower rate (i.e., strain incompatibility), depending on:

- strains of the geosynthetic and the confining soil at the failure (i.e., rupture of the geosynthetic and development of active state for the confining soil); and

- boundary conditions imposed on the confining soil specimen.

For a majority of geosynthetic materials used for reinforcement/stabilization, strains at failure are within the range of 10 to 20 percent while the confining soil requires only a small tensile strain (typically less than 0.5 percent) in granular media prior to the development of a peak failure condition or an "active" state-of-stress condition. The strain compatibility between the confining soil and the geosynthetic may exist during the initial stage of confined extension test.

However, strain incompatibility between the confining soil and the geosynthetic is likely to develop during the later stage of the test. Therefore, the relative movement between the confining soil and geosynthetic specimen will occur in the later stage of the test, as shown in figure 32, and the friction will be mobilized along the soil-geosynthetic interface.

It appears that the friction along the soil-geosynthetic interface cannot be totally eliminated due to the fact that there is a significant difference between the failure strains of the confining soil and the geosynthetic material. However, this friction can be reduced by two different methods: (i) imposing low-friction boundary conditions on the confining soil using procedures recommended by McGown et al. [1982] and Wilson-Fahmy et al. [1993], and/or (ii) allowing the confinement box to move during confined extension testing. Both of these methods for reducing the friction were evaluated and results are presented in the following section.

b. Evaluation of Different Methods for Reducing Friction

A testing program was conducted to evaluate the two different methods for reducing the friction between the confining soil and the geosynthetic specimen. Specifically, a series of confined extension tests was conducted to determine the confined response of a nonwoven geotextile (i.e., Geosynthetic PP-10) under the same normal stress condition of 10 psi (70

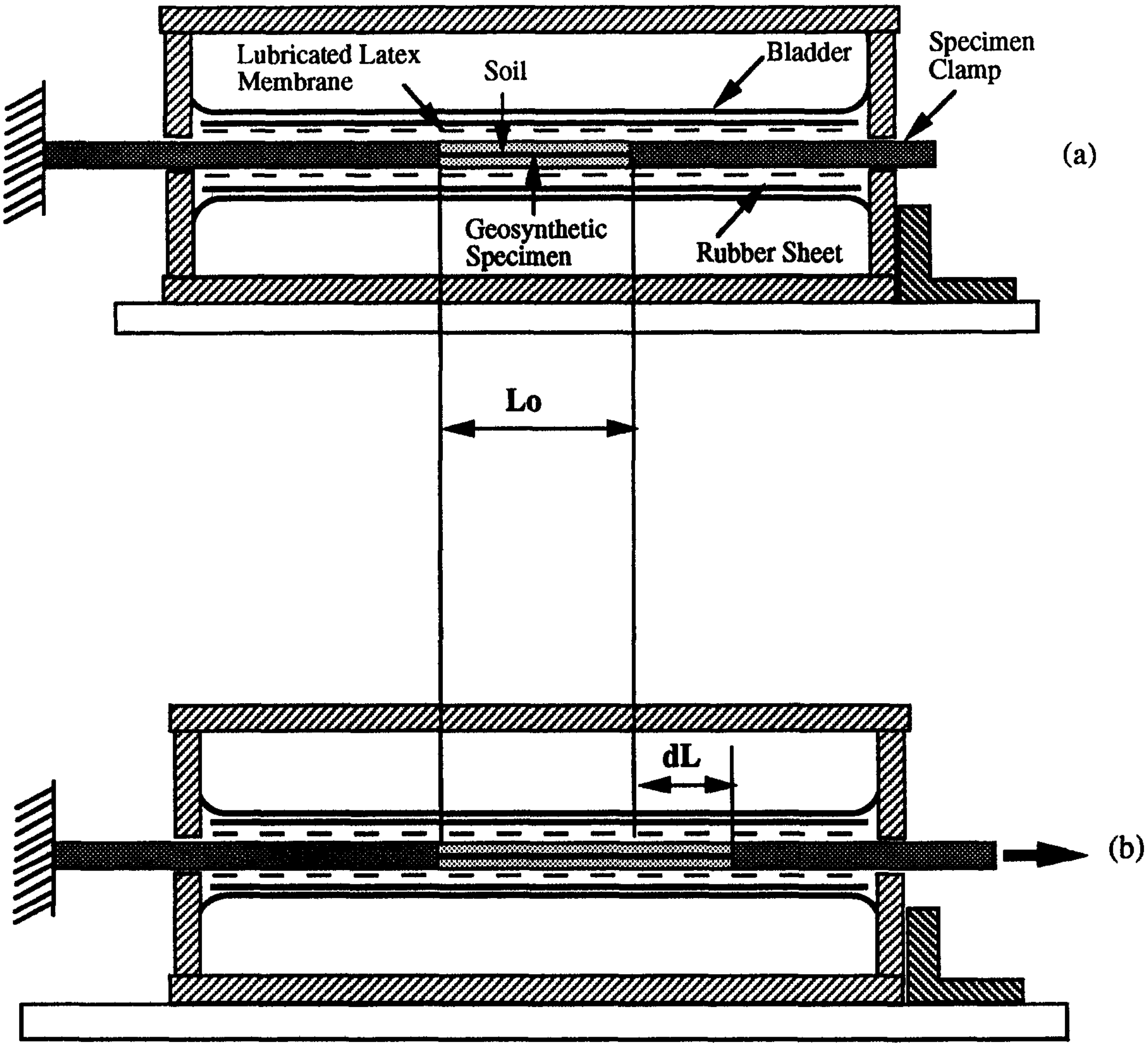


Figure 32. Cross-section of confined extension testing with lubricated boundary conditions: (a) initial configuration, (b) deformed configuration.

kPa) but with different lateral boundary conditions. Details of the lateral boundary conditions for each test are described below:

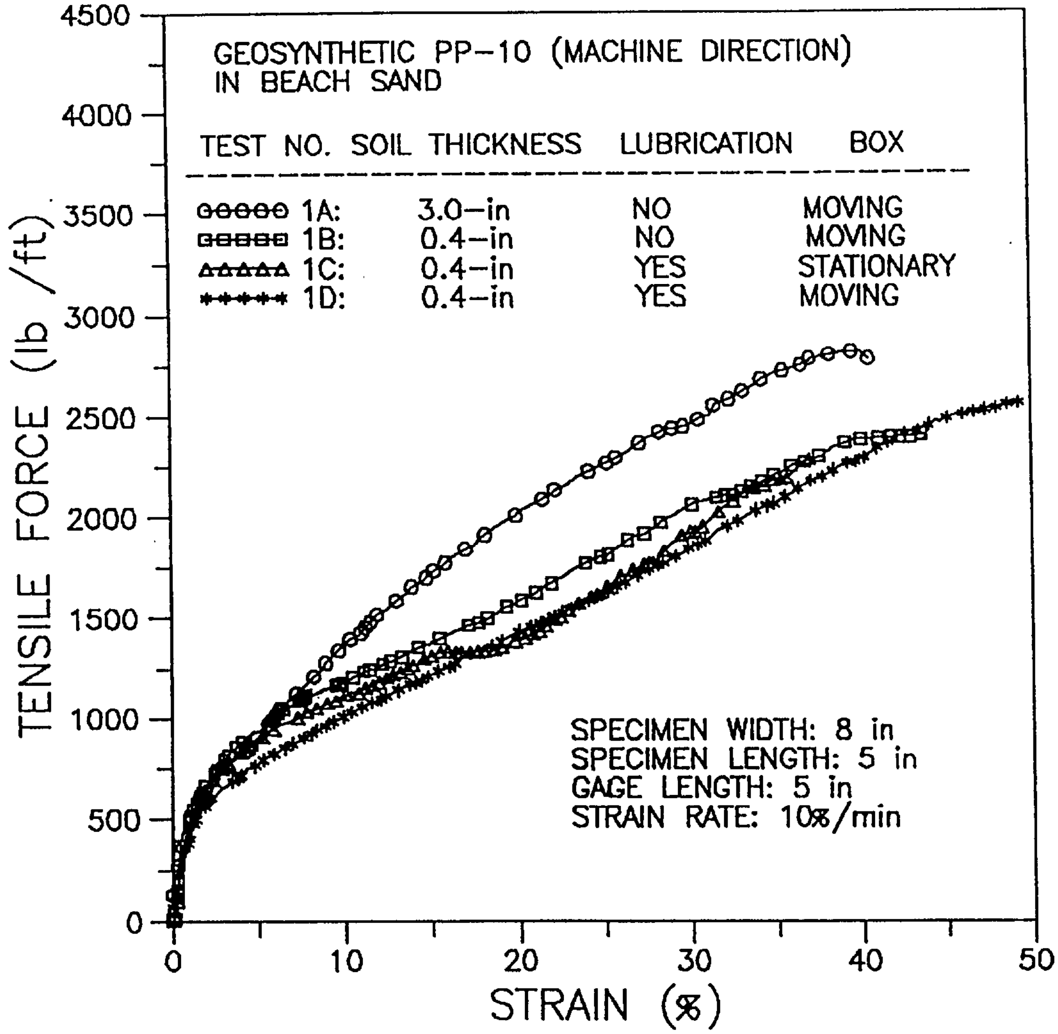
- *Test Number 1A:* The geotextile specimen was confined between two 0.4-in- (10-mm-) thick layers of beach sand. The confinement box was placed on steel rollers and allowed to move during testing. No lubricated rubber sheets and latex membranes were placed on the top of the upper soil layer and below the bottom of the lower soil layer.

- *Test Number 1B:* The geotextile specimen was confined between two 0.4-in- (10-mm-) thick layers of beach sand. The confinement box was placed on steel rollers and allowed to move during testing. Lubricated rubber sheets and latex membranes were placed on the top of the upper soil layer and below the bottom of the lower soil layer.

- *Test Number 1C:* The geotextile specimen was confined between two 0.4-in- (10-mm-) thick layers of beach sand. Lubricated rubber sheets and latex membranes were placed on the top of the upper soil layer and below the bottom of the lower soil layer. The confinement box was fixed to the top of its supporting table.

The results of the three confined extension tests are presented in a plot of tensile force versus average strain, as shown in figure 33. The comparison of the confined stress-strain curves in figure 33 indicates that the methods developed by McGown et al. [1982] and Wilson-Fahmy et al. [1993] for reducing the friction between the confining soil (i.e., lubricated rubber sheets) and the methods developed under this research (i.e., low-friction movable confining box) produce similar results. This indicates that the two methods can effectively reduce the friction between the confining soil and the geosynthetic specimen. In fact, it follows that the friction can be further reduced by imposing lower friction boundary conditions on the confining soil and allowing the confinement box to move during testing, as indicated by the results of Test 1B.

An additional confined test (i.e., Test 1D) was conducted on Geotextile PP-10 with a confining soil thickness of 3 in (75 mm). No lubricated rubber sheets and latex membranes were placed on the top of the upper soil layer or below the bottom of the lower soil layer. The confined response from Test 1D is also shown in figure 33. Compared with the confined responses from the other three tests (i.e., Test 1A, 1B, and 1C), the soil confinement effect was significantly improved. This is due to the fact that the geotextile specimen was fully confined within the soil during the entire test when the confining soil was



1 in = 25.4 mm
1 lb/ft = 14.59 N/m

Figure 33. Confined response of GeoSynthetic PP-10 under lubricated and unlubricated boundary conditions.

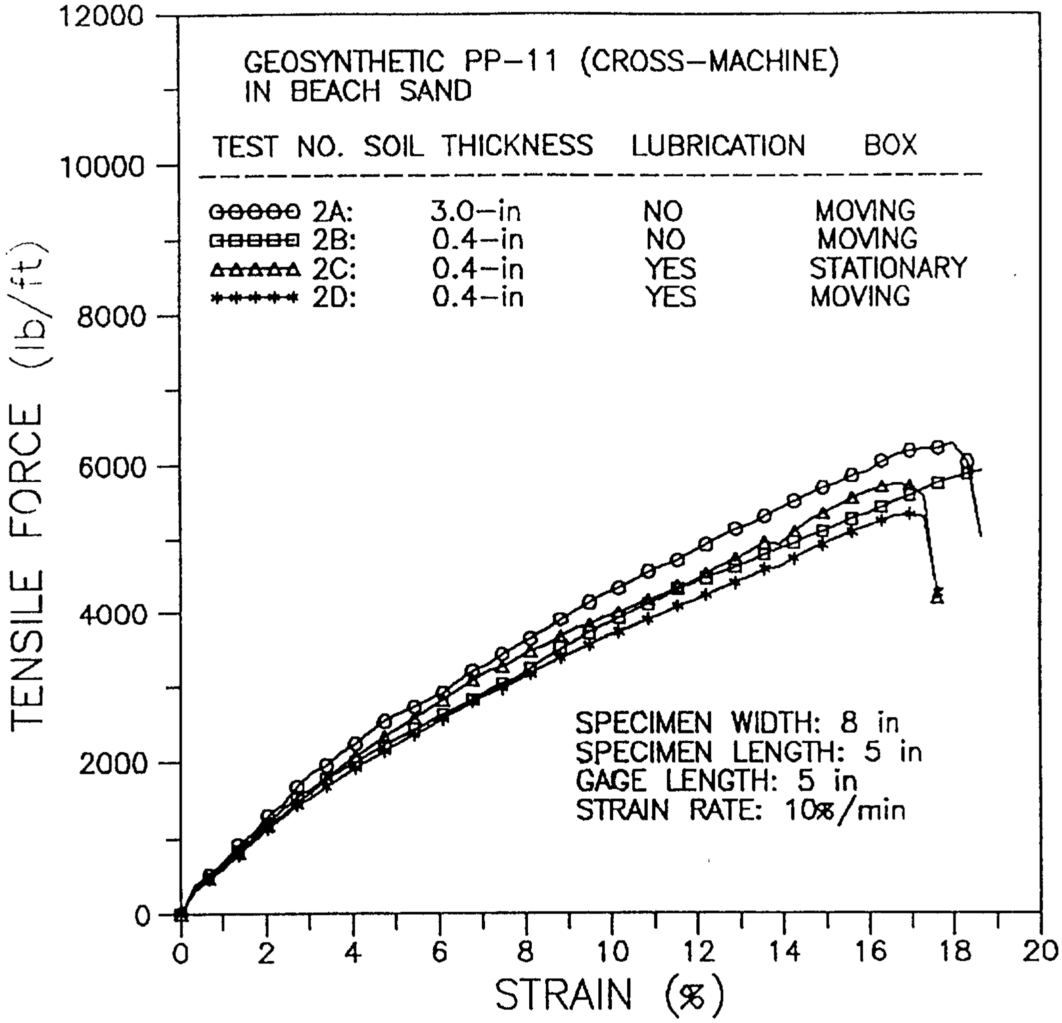
3-in (75-mm) thick. As the confining soil thickness was reduced to 0.4 in (10 mm), cracks were observed to occur within the confining soil layer at the end of the test. It is believed that the geotextile specimen that is initially confined between two thin layers of soil may become only partially confined within the soil in the later stage of the test. This likely explains why the soil confinement effect was significantly reduced when the geotextile was confined between two 0.4-in- (10-mm-) thick soil layers. A similar, although more subdued, response was observed when this test series was repeated using a woven geotextile (i.e., Geotextile PP-12). Results are presented in figure 34.

c. Assessment of Test Results

Assessment of results from confined tests, regardless of the type of laboratory test device and test configuration, ideally involves consideration of the degree to which the laboratory test simulates conditions within actual geosynthetic-reinforced structures under working conditions. It was demonstrated in chapter 2 that test devices exist, specifically the UCD and the APSR, which offer a potentially more realistic model of actual reinforced soil response than the relatively simple confined extension device used with the testing protocol developed herein. Specifically, the developers of the UCD and APSR note that the normal stress and shear stress along the confined geosynthetic specimen varies as the confining soil moves relative to the geosynthetic during the test. In contrast, the confined extension device provides a constant normal stress, which is selected prior to testing.

While the UCD and APSR may offer a potential advantage with respect to the ability to model actual reinforced soil response, this potential advantage is tempered by the fact that actual stress/confinement conditions within geosynthetic-reinforced structures are usually uncertain. The UCD and APSR are also sophisticated devices that may not be accessible to most nonresearch organizations wanting to conduct confined creep testing. On the basis of these considerations, the confined extension device was selected for this program because of its demonstrated capability to measure the effect of controlled confinement on the response of geosynthetics to tensile loading. Designers of reinforced-soil structures will likely debate the most appropriate use of measured values from the confined extension device. Nevertheless, it is believed that, by using the confined extension device and selecting reasonable testing conditions, designers will obtain practical test results needed for design or for a comparative evaluation of candidate soil and geosynthetic materials.

The confined extension device can model either full or partial confinement conditions and a protocol for either confinement condition was developed as part of this project. The



1 in = 25.4 mm
1 lb/ft = 14.59 N/m

Figure 34. Confined response of geosynthetic PP-11 under lubricated and unlubricated boundary conditions.

selection of testing conditions for the confined extension device therefore includes using partial or full confinement. A discussion regarding the difference between partial or full confinement is given below.

- *Partial Confinement:* It was demonstrated that the thin-soil test specimen coupled with lubricated rubber sheets provide full confinement in the early stages of the confined extension tests. However, as deformation continues, strain incompatibility of the soil and geotextile causes cracking of the soil and only partial confinement to the geotextile. It has been argued that this is an appropriate model for the reinforced soil within the active zone of a reinforced backfill. Since the partially confined response also shows a smaller effect of confinement compared with the fully confined response, it has been suggested that the geosynthetic response in the partially confined condition be utilized to provide a *conservative design*.

- *Full Confinement:* It was similarly demonstrated that, unless relatively extreme measures are taken to reduce soil-geosynthetic interface friction, only a relatively thin layer of soil (i.e., only 1 in (25 mm) is needed to provide full confinement and restrict the actual development of cracks in the soil. Therefore, this may better model the actual condition in the field. Furthermore, it can be argued that the fully confined condition models the anchorage zone of the reinforcement.

It is noted that, for the production testing component of the testing program, a fully confined condition was utilized because of the consistency of the test results and the belief that partial confinement (and certainly no confinement) may provide an overly conservative stress-strain response.

4.4 SUMMARY AND CONCLUSIONS

A general test procedure was developed for conducting the confined extension/creep tests using the protocol confined extension/creep test equipment. The test procedure involved the selection of specific values for: (i) pretension force; (ii) strain rate for extension testing; (iii) aspect ratio; (iv) initial rate of loading for conducting creep testing; and (v) thickness of the confining soil. All of these variables except the confining soil thickness are associated with the test procedures for unconfined extension and unconfined creep tests. Standard values for these common variables have been established in ASTM D 4595 for the wide-width tensile testing and ASTM D 5262 for the unconfined tension creep testing. These standard values were adopted in this test procedure for the confined extension/creep tests and are summarized below:

- *Pretension Force:* A total pretension force equal to 1.25 percent of the expected breaking force, but not less than 10 lb (45 N) or greater than 50 lb (222 N), is to be applied to the geosynthetic specimen in the confined extension and creep tests.

- *Strain Rate:* A constant strain rate of 10 percent/min is to be applied to the geosynthetic specimen during the confined or unconfined extension test.

- *Aspect Ratio:* An aspect ratio of approximately 2:1 for geotextiles is to be used in both the confined or unconfined extension and creep tests. For geogrids, each test specimen is to be trimmed in such way that it has two complete apertures in the machine direction and five ribs in the cross-machine direction.

- *Initial Loading Rate:* A constant strain rate of 10 $\pm$3 percent/min. was selected to load each creep test specimen to a specific target load level.

For the confining soil thickness, its potential effect on confined stress-strain properties was studied by performing four confined extension tests, each conducted at a different soil thickness ranging from 0.4 to 3 in (10 to 76 mm). The results of the tests conducted at soil thicknesses of 1 to 3 in (25 to 76 mm) were approximately the same, indicating that varying the confining soil thickness from 1 to 3 in (25 to 76 mm) has little effect on the confined stress-strain behavior of the tested geotextile. However, when the soil thickness was reduced to 0.4 in (10 mm), cracks developed through the thickness of the soil layers, and the soil confinement effect was significantly reduced. Because of the potential effect of test reproducibility and because a partially confined condition may provide an overly conservative estimate of the confined response, a 3-in (76-mm) thickness of confining soil was selected for the confined extension/creep testing program, which will be discussed in chapter 5. The selected testing device, however, can readily be used to conduct partially confined tests incorporating relatively thin soil specimens.

CHAPTER 5

CONFINED EXTENSION/CREEP TESTING PROGRAM

5.1 INTRODUCTION

The test procedure for conducting the confined extension and creep tests was developed as described in chapter 4. Using this established test procedure, a confined extension/creep testing program was conducted. The testing program and the results of the confined extension/creep testing program are presented in the following sections.

5.2 CONFINED AND UNCONFINED EXTENSION TESTING PROGRAM

a. Test Matrix

Ten test series were conducted in the confined and unconfined testing program. Each test series consisted of one unconfined and two confined extension tests on one of the five selected geosynthetic materials (i.e., Geosynthetics PP-10, PP-11, PP-12, PE-13, and PET-14). For the confined extension tests, each geosynthetic material was confined within beach sand (Test Series T1A through T5A) or silty sand (Test Series T1B through T5B) under two different normal stresses (i.e., 10 and 20 psi (69 and 138 kPa)). A summary of test conditions used during the testing program is presented in table 4 (Test Series T1A through T5A) and table 5 (Test Series T1B through T5B). It should be noted that only one unconfined extension test was conducted for each geosynthetic material; the test result is presented in each of the two tables.

b. Test Results

For each confined extension test, the tension load and displacement on the test specimen were measured continuously during the test. The test data were then plotted as tension force versus strain. The tension force was defined as the total measured load divided by the initial width of the geosynthetic specimen (i.e., units of F/L (lbs/ft (1 lb/ft = 14.59N/m)) and the strain was defined as the total measured deformation of the test specimen withing the gage length deivided by the initial gage length of the geosynthetic specimen. The results of each confined extension test are presented as tension force versus strain curves in Appendix A. For each test series, the

Table 4. Summary of test conditions for confined and unconfined extension tests in beach sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Test Specimen Width	Test Specimen Gage Length	Strain Rate (%/min)
T1A	Geosynthetic PP-10 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	10 10 10
T2A	Geosynthetic PP-11 in Cross-Machine Direction	In-air Beach Sand Beach Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	10 10 10
T3A	Geosynthetic PP-12 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	10 10 10
T4A	Geosynthetic PE-13 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	10 10 10
T5A	Geosynthetic PET-14 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	10 10 10

1 in = 25.4 mm
psi = 6.895 kPa

Table 5. Summary of tests conditions for confined and unconfined extension tests in silty sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Test Specimen Width	Test Specimen Gage Length	Strain Rate (%/min)
T1B	Geosynthetic PP-10 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	10 10 10
T2B	Geosynthetic PP-11 in Cross-Machine Direction	In-air Silty Sand Silty Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	10 10 10
T3B	Geosynthetic PP-12 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	10 10 10
T4B	Geosynthetic PE-13 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	10 10 10
T5B	Geosynthetic PET-14 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	10 10 10

1 in = 25.4 mm
psi = 6.895 kPa

tension force versus strain curves at the three normal stresses (i.e., 0, 10, and 20 psi (0, 69, and 138 kPa)) are presented in a single plot. This presentation allows direct comparison between the measured confined and unconfined response of the geosynthetic material.

For Geosynthetic PP-10, figures A-1 and A-6 indicate that the soil confinement improves both the modulus and peak strength and significantly reduces the total strain at both the peak strength and failure. For Geosynthetics PP-11, PP-12, PE-13, and PET-14, the results shown in figures A-2 through A-5 and A-7 through A-10 also indicate a noticeable improvement in modulus and strength resulting from soil confinement. However, the relative increase of modulus and strength resulting from soil confinement for these four geosynthetic materials appears to be much less than the increase noted for Geosynthetic PP-10 with the least effect noted for the uniaxial geogrid (i.e., Geosynthetic PE-13). To further quantify the improvement resulting from soil confinement, secant moduli at 1, 2, 5, and 10 percent strain levels, peak strength, and strain at peak strength were calculated for each test. The results of these calculations are summarized in table 6 (Test Series T1A through T5A) and table 7 (Test Series T1B through T5B).

The calculated secant moduli at 5 percent strain presented in tables 6 and 7 were selected to further demonstrate the soil confinement effect on the confined response. The improvement of secant moduli at 5 percent strain was plotted versus confining pressure for each geosynthetic material confined in the beach sand and in the silty sand as shown in figures 35 and 36, respectively. In these plots, "improvement" is defined as the ratio of the confined secant modulus to the unconfined secant modulus at the selected strain level. These figures clearly demonstrate that the nonwoven geotextile is significantly affected by soil confinement while the other four geosynthetic materials are much less affected by soil confinement. Figure 37 shows a comparison of the secant moduli at 5 percent strain for the nonwoven geotextile confined in the beach sand and the silty sand. The comparison indicates that the confinement effect of the beach sand is greater than that of the silty sand. The secant moduli at 5 percent strain of the nonwoven geotextile confined in the beach sand and the silty sand are also compared with those of similar nonwoven geotextiles reported by other researchers; this comparison is graphically presented in figure 38. The results from this testing program are similar.

c. Interpretation

The test results presented in the previous section clearly demonstrate that soil confinement improves the confined response of the needle-punched nonwoven geotextile; the observed

Table 6. Summary of secant moduli at select strains, peak strength, and strain at peak for unconfined and confined extension tests in beach sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Modulus at 1% Strain (lb/ft)	Modulus at 2% Strain (lb/ft)	Modulus at 5% Strain (lb/ft)	Modulus at 10% Strain (lb/ft)	Peak Strength (lb/ft)	Strain at Peak (%)
T1A	Geosynthetic PP-10 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	5602 9383 23401	5141 12259 23201	4035 15915 22979	4292 11112 16891	1352 1813 2542	38.5 33.8 28.0
T2A	Geosynthetic PP-11 in Cross-Machine Direction	In-air Beach Sand Beach Sand	0 10 20	46174 56703 54068	45875 53805 54746	42298 57533 57265	38354 48371 48945	6020 6547 7432	17.9 17.1 19.0
T3A	Geosynthetic PP-12 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	38295 53611 65556	38219 44944 50076	28548 32902 36063	22344 26085 29067	3400 3845 4228	22.6 21.0 20.6
T4A	Geosynthetic PE-13 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	77738 83608 88314	70917 68855 85284	56987 59444 64909	46568 47454 46220	5856 5879 5936	14.0 14.0 14.6
T5A	Geosynthetic PET-14 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	67734 62109 65846	62210 63597 90986	63669 75103 93152	57281 62548 67298	6320 6469 7097	14.0 13.2 11.9

lb/ft = 14.59 N/m
psi = 6.895 kPa

Table 7. Summary of secant moduli at select strains, peak strength, and strain at peak for unconfined and confined extension tests in silty sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Modulus at 1% Strain (lbs/ft)	Modulus at 2% Strain (lb/ft)	Modulus at 5% Strain (lb/ft)	Modulus at 10% Strain (lb/ft)	Peak Strength (lb/ft)	Strain at Peak (%)
T1B	Geosynthetic PP-10 in Machine Direction	In-air Silty Soil Silty Soil	0 10 20	5602 8000 19011	5141 7981 18446	4035 10490 19574	4292 7401 15999	1352 1664 2154	38.5 37.8 25.3
T2B	Geosynthetic PP-11 in Cross-Machine Direction	In-air Silty Soil Silty Soil	0 10 20	46174 63943 74566	45875 62391 72536	42298 50052 60220	38354 42473 52654	6020 6751 7145	17.9 18.2 16.1
T3B	Geosynthetic PP-12 in Machine Direction	In-air Silty Soil Silty Soil	0 10 20	38295 44096 51610	38219 44598 49856	28548 31990 35620	22344 24944 26899	3400 3612 4109	22.6 20.8 20.5
T4B	Geosynthetic PE-13 in Machine Direction	In-air Silty Soil Silty Soil	0 10 20	77738 88717 90534	70917 76885 92230	56987 58447 67860	46568 49686 52586	5856 5780 5980	14.0 15.7 12.9
T5B	Geosynthetic PET-14 in Machine Direction	In-air Silty Soil Silty Soil	0 10 20	67734 80403 95665	62210 85332 94743	63669 71604 85572	57281 59930 67404	6320 6688 7196	14.0 12.4 12.4

lb/ft = 14.59 N/m
psi = 6.895 kPa

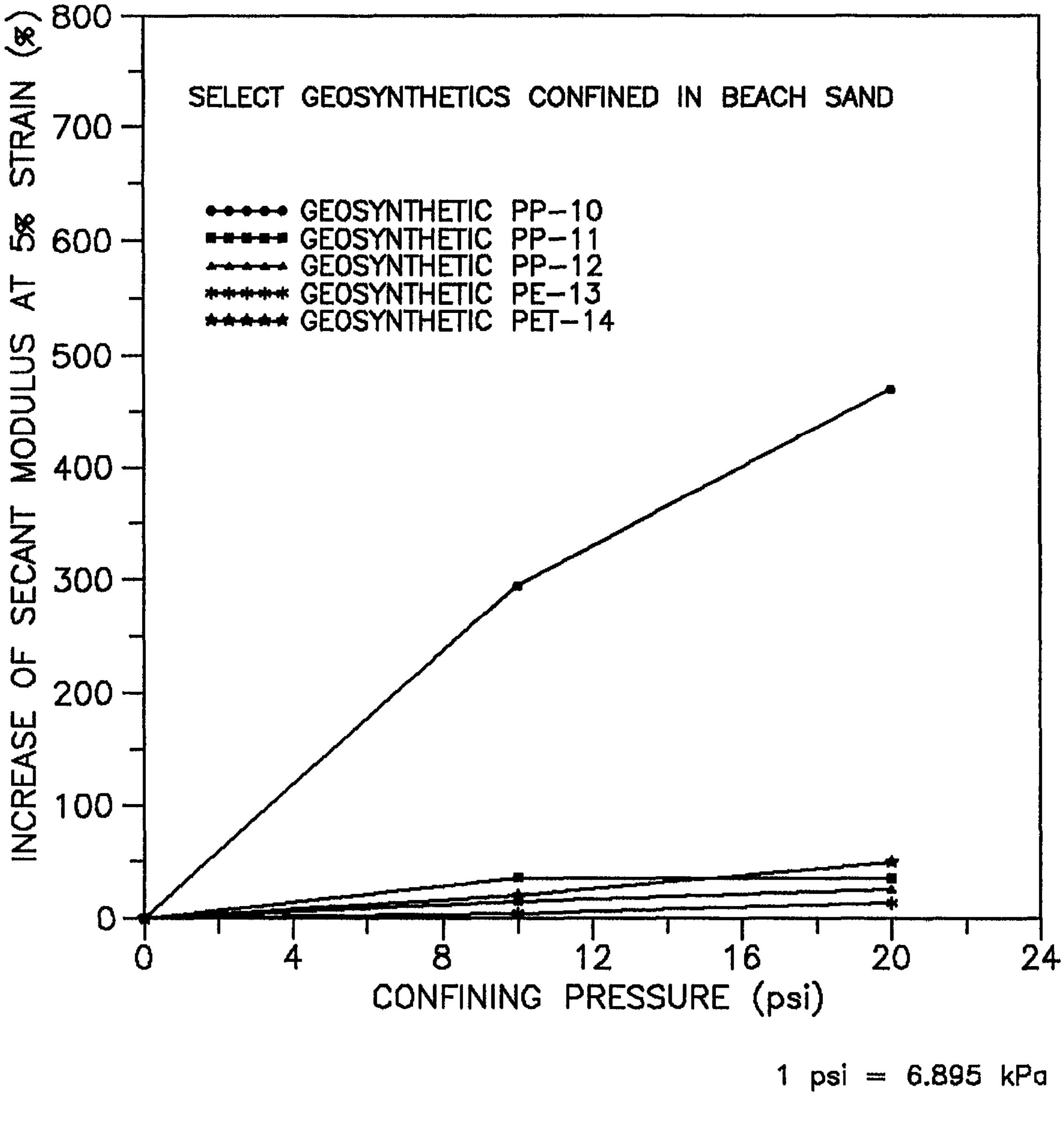
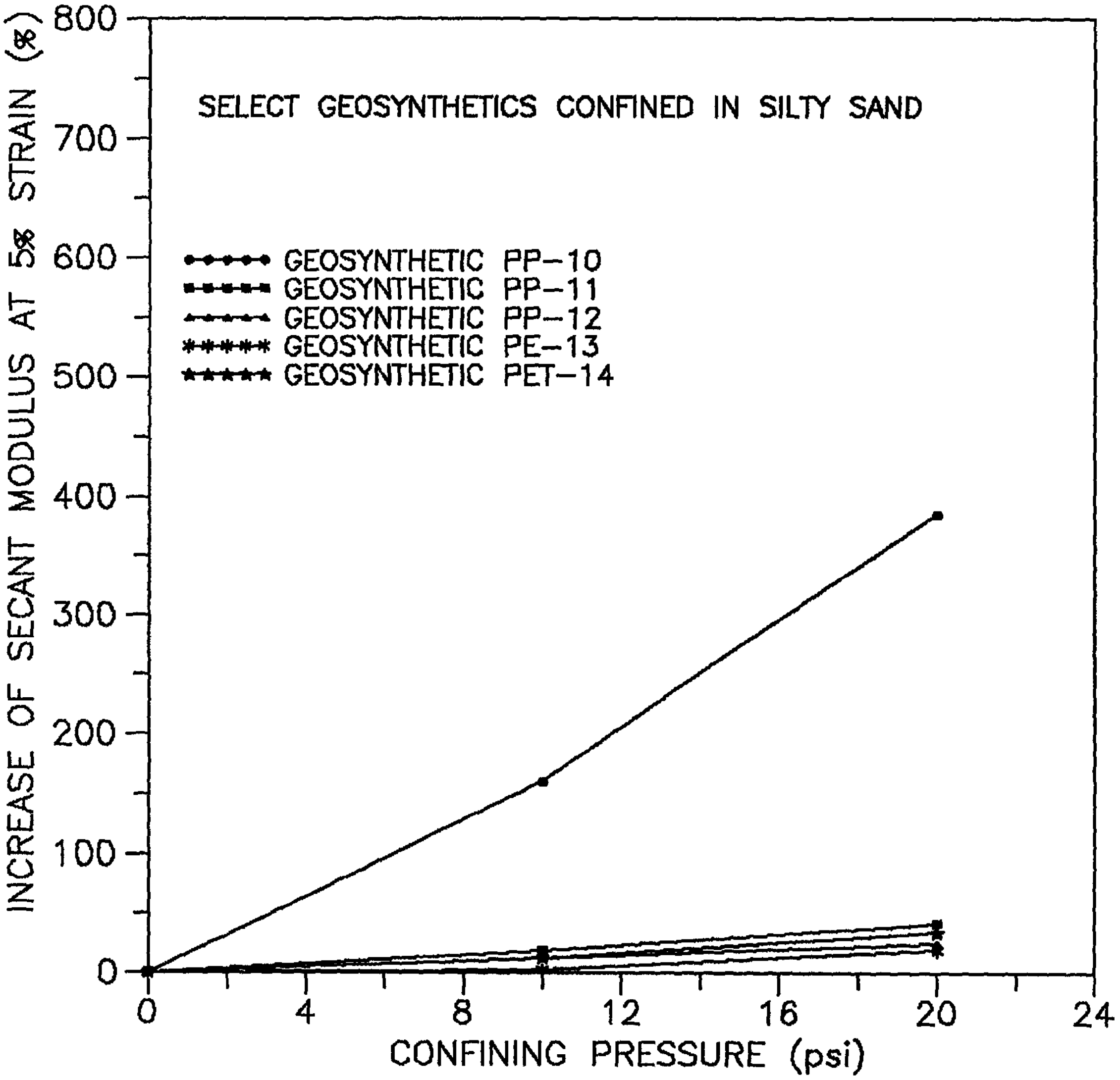


Figure 35. **Soil confinement effect on secant moduli at 5 percent strain for selected geosynthetic materials confined in beach sand.**



1 psi = 6.895 kPa

Figure 36. **Soil confinement effect on secant moduli at 5 percent strain for selected geosynthetic materials confined in silty sand.**

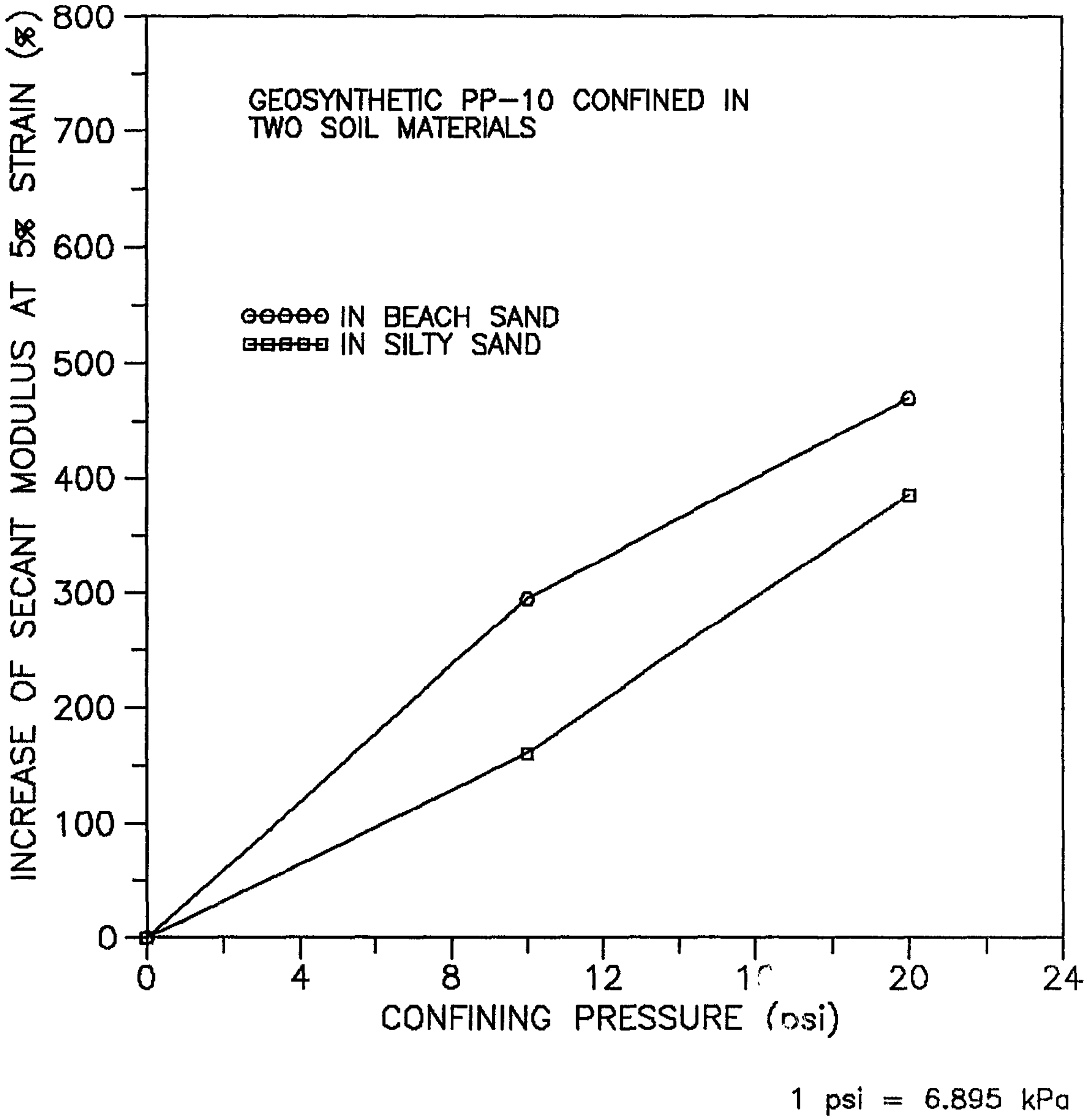
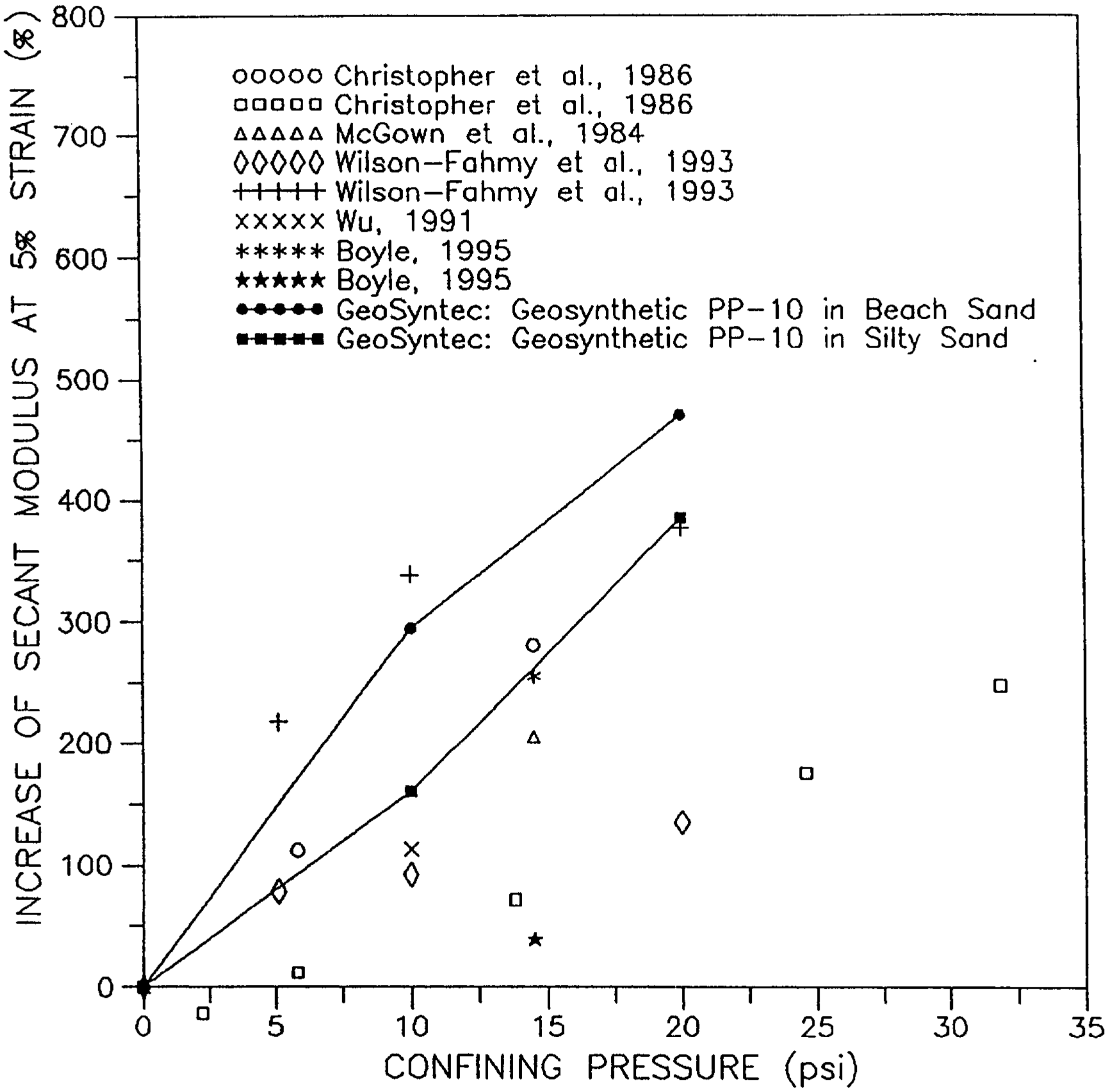


Figure 37. **Comparison of secant moduli at 5 percent strain for Geosynthetic PP-10 confined in beach sand.**



1 psi = 6.89 kPa

Figure 38. Comparison of secant moduli at 5 percent strain for Geosynthetic PP-10 confined in beach sand and silty sand with data of similar geosynthetic materials reported by other researchers.

improvement is smaller on the confined response of the other four geosynthetic materials (i.e., two woven geotextiles and two geogrids). It is not well understood why soil confinement can improve the stress-strain properties of geosynthetics or why different types of geosynthetics have different responses to soil confinement. Three mechanisms of interaction between the soil and geosynthetic during a confined extension test are proposed to provide a framework for qualitatively understanding the confined extension test results:

- *Internal Friction:* referred to as the friction between the basic components (i.e., fibers or yarns) within a geosynthetic product during confined extension testing. Internal friction constrains reorientation and alignment of fibers or yarns and slippage between fibers or yarns.

- *Tortuosity:* referred to as the curvature of the basic components (i.e., fibers or yarns) within a geosynthetic product. Soil confinement constrains alignment of curved fiber or yarns.

- *Interlocking:* referred to as strike-through or penetration of soil into openings or apertures of a geosynthetic product during confined extension testing. Interlocking constrains reorientation of fibers or yarns.

For a nonwoven geotextile, discrete fibers or continuous yarns are randomly placed and interconnected by needle-punching or another process during manufacturing. Deformation is primarily caused by reorientation of fibers and interfiber slippage. It is anticipated that all three mechanisms are well developed during confined extension testing and therefore the soil confinement can significantly improve the confined stress-strain properties of a nonwoven geotextile.

For a woven geotextile and PET geogrid, fibers or yarns are continuous in the direction of loading. It is anticipated that each fiber or yarn carries approximately the same level of load as that applied to the entire test specimen. There likely exists little interfiber friction. However, the actual fibers or yarns within these types of geosynthetic materials are somewhat curved (i.e., tortuosity), there are fill fibers and cross-overs at intersections between the warp and fill fibers, and there exist certain degrees of interlocking that depend on the ratio of soil-particle size to geotextile openings or geogrid apertures. It is anticipated that soil confinement improves the confined stress-strain properties of these types of geosynthetics but to a lesser degree than for a nonwoven geotextile.

For the PE geogrid, each rib is simply a solid piece and little internal friction is anticipated to be mobilized within the ribs during a confined extension test. However, soil can strike through apertures of the geogrid. Consequently, while soil confinement may improve the confined stress-strain properties of the PE geogrid, it does so to a lesser degree in comparison with the other types of geosynthetics tested in this program.

5.3 CONFINED AND UNCONFINED CREEP TESTING PROGRAM

a. Test Matrix

Ten test series were conducted in the confined and unconfined creep testing program. Each test series consisted of an unconfined tension creep test and two or three confined tension creep tests conducted on one of the five geosynthetic materials and one of the two soil materials. For the confined tension creep tests, herein referred to as creep tests, each geosynthetic material was confined within the beach sand (Test Series C1A through C5A) or silty sand (Test Series C1B through C5B) under two different normal stresses (i.e., 10 and 20 psi (69 and 138 kPa)). A summary of test conditions used during the testing program is presented in table 8 (Test Series C1A through C5A) and table 9 (Test Series C1B through C5B). It should be noted that the unconfined creep test on the specific geosynthetic material presented in each of the two tables is actually the same test.

b. Test Results

For each confined or unconfined creep test, elongations of the geosynthetic specimen within the gage length were monitored over time by the use of two LVDTs. Measured elongations were used to calculate the total strain and incremental strain rate for each test specimen. The total strain was defined as the total deformation of the test specimen within the gage length divided by the initial gage length of the geosynthetic specimen. The incremental strain rate was defined as the change in strain with respect to time between two successive monitoring periods. For each test, the calculated strains were plotted on a graph of total strain versus logarithm of time and the calculated incremental strain rates were plotted on a graph of logarithm of incremental strain rate versus total strain. The incremental strain rates were also plotted on a graph of logarithm of incremental strain rate versus logarithm of time. The results of the 10 creep test series are presented graphically in appendix B.

Table 8. Summary of test conditions for confined and unconfined creep tests in beach sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Test Specimen Width	Test Specimen Gage Length	Applied Tensile Load (% of Ult.)	Total Duration (hrs)
C1A	Geosynthetic PP-10 in Machine Direction	In-air Beach Sand Beach Sand Beach Sand	0 10 20 10	8.0 in 8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in 4.0 in	25 25 25 25	100 100 100 1000
C2A	Geosynthetic PP-11 in Cross-Machine Direction	In-air Beach Sand Beach Sand Beach Sand	0 10 20 10	8.0 in 8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in 4.0 in	50 50 50 50	100 100 100 1000
C3A	Geosynthetic PP-12 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	50 50 50	100 100 100
C4A	Geosynthetic PE-13 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	50 50 50	100 100 100
C5A	Geosynthetic PET-14 in Machine Direction	In-air Beach Sand Beach Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	60 60 60	100 100 100

1 in = 25.4 mm

Table 9. Summary of test conditions for confined and unconfined creep tests in silty sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Test Specimen Width	Test Specimen Gauge Length	Applied Tensile Load (% of Ult.)	Total Duration (hrs)
C1B	Geosynthetic PP-10 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	25 25 25	100 100 100
C2B	Geosynthetic PP-11 in Cross-Machine Direction	In-air Silty Sand Silty Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	50 50 50	100 100 100
C3B	Geosynthetic PP-12 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	8.0 in 8.0 in 8.0 in	4.0 in 4.0 in 4.0 in	50 50 50	100 100 100
C4B	Geosynthetic PE-13 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	50 50 50	100 100 100
C5B	Geosynthetic PET-14 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	5 ribs 5 ribs 5 ribs	2 apertures 2 apertures 2 apertures	60 60 60	100 100 100

1 in = 25.4 mm
psi = 6.895 kPa

A summary of the test results is presented in tables 10 through 13. These tables summarize the total strain and incremental strain rate at 1, 10, 100, 500, and 1,000 hours of elapsed time for each test. It is noted that the values of total strain and incremental strain rate at the selected times presented in tables 10 through 13 were derived by linear interpolation between the actually measured data points at each specific time period of interest.

The results presented in appendix B and in tables 10 and 11 indicate that the soil confinement *significantly reduces the total strain for the nonwoven geotextile* (i.e., Geosynthetic PP-10). For the other four geosynthetic materials (Geosynthetics PP-11, PP-12, PE-13, and PET-14), soil confinement also reduces the total strain but the decrease is less than that measured for the nonwoven geotextile.

c. Interpretation

Since a confined creep test specimen is initially subjected to loading conditions similar to those in the confined extension testing, it is anticipated that all three mechanisms previously discussed can be used to explain the soil confinement effect on the initial portion (i.e., loading phase) of confined creep response for each of the five geosynthetic materials tested.

As discussed previously, deformation of a nonwoven geotextile is primarily caused by reorientation of fibers and interfiber slippage. Elongation of the fibers may contribute little to the total deformation due to the fact that the actual tension within a fiber may be a small percentage of its tensile strength even when rupture of the nonwoven geosynthetic specimen occurs. The tensile creep of the nonwoven geotextile, as defined in current engineering practice, may actually be time-dependent slippage (i.e., shear creep) between fibers. This time-dependent interfiber slippage almost disappears shortly after application of a constant load to the nonwoven geotextile, as indicated in figures B-1 and B-4. This may be due to the fact that the confining pressure of 10 or 20 psi (69 or 138 kPa) is high enough to prevent any time-dependent interfiber slippage within the nonwoven geotextile.

For the woven geotextiles and PET geogrid, fibers or yarns within the two woven geotextiles and PET geogrid are continuous in the direction of loading. It is anticipated that each fiber or yarn carries approximately the same level of load as that applied to the entire test specimen. Therefore, the measured time-dependent behavior truly reflects the tension creep behavior of these types of geosynthetic materials. When these geosynthetic materials are confined in a soil, they are likely to creep as they do under unconfined conditions.

Table 10. Summary of total strains at select times for unconfined and confined tension creep tests in beach sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Percentage of Ultimate Strength(1)	Total Strain (%) at Elapsed Times (hrs)				
					1	10	100	500	1000
C1A	Geosynthetic PP-10 in Machine Direction	In-air	0	25	15.8	16.9	20.7	(2)	(2)
		Beach Sand	10	25	11.2	11.2	11.4	(2)	(2)
		Beach Sand	20	25	10.6	10.6	10.6	(2)	(2)
		Beach Sand	10	25	11.5	11.6	11.7	11.7	11.8
C2A	Geosynthetic PP-11 in Cross-Machine Direction	In-air	0	50	6.2	8.0	12.1	(2)	(2)
		Beach Sand	10	50	5.5	7.0	9.3	(2)	(2)
		Beach Sand	20	50	5.1	6.4	8.5	(2)	(2)
		Beach Sand	10	50	5.7	7.1	8.8	10.1	10.5
C3A	Geosynthetic PP-12 in Machine Direction	In-air	0	50	10.7	12.6	19.2	(2)	(2)
		Beach Sand	10	50	9.3	11.7	14.9	(2)	(2)
		Beach Sand	20	50	8.3	10.4	12.6	(2)	(2)
C4A	Geosynthetic PE-13 in Machine Direction	In-air	0	50	8.3	9.4	11.3	(2)	(2)
		Beach Sand	10	50	8.1	9.3	10.8	(2)	(2)
		Beach Sand	20	50	7.7	8.9	10.3	(2)	(2)
C5A	Geosynthetic PET-14 in Machine Direction	In-air	0	60	4.8	5.1	5.3	(2)	(2)
		Beach Sand	10	60	4.1	4.4	4.6	(2)	(2)
		Beach Sand	20	60	3.7	4.0	4.2	(2)	(2)

psi = 6.895 kPa

Notes: (1) Ultimate strength was determined in accordance with ASTM D 4595.
(2) The test was terminated at an elapsed time of 100 hours.

Table 11. **Summary of total strains at selected times for unconfined and confined creep tests in silty sand.**

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Percentage of Ultimate Strength(1)	Total Strain (%) at Elapsed Times (hrs)				
					1	10	100	500	1000
C1B	Geosynthetic PP-10 in Machine Direction	In-air	0	25	15.8	16.9	20.7	(2)	(2)
		Silty Soil	10	25	11.5	11.5	11.7	(2)	(2)
		Silty Soil	20	25	10.8	10.8	10.8	(2)	(2)
C2B	Geosynthetic PP-11 in Cross-Machine Direction	In-air	0	50	6.2	8.0	12.1	(2)	(2)
		Silty Soil	10	50	5.4	6.9	9.7	(2)	(2)
		Silty Soil	20	50	4.8	6.0	7.8	(2)	(2)
C3B	Geosynthetic PP-12 in Machine Direction	In-air	0	50	10.7	12.6	19.2	(2)	(2)
		Silty Soil	10	50	9.9	12.4	15.9	(2)	(2)
		Silty Soil	20	50	8.7	11.0	13.3	(2)	(2)
4B	Geosynthetic PE-13 in Machine Direction	In-air	0	50	8.3	9.4	11.3	(2)	(2)
		Silty Soil	10	50	8.3	9.5	11.1	(2)	(2)
		Silty Soil	20	50	8.0	9.3	10.8	(2)	(2)
C5B	Geosynthetic PET-14 in Machine Direction	In-air	0	60	4.8	5.1	5.3	(2)	(2)
		Silty Soil	10	60	4.3	4.5	4.7	(2)	(2)
		Silty Soil	20	60	3.8	4.0	4.3	(2)	(2)

psi = 6.895 kPa

Notes: (1) Ultimate strength was determined in accordance with ASTM D 4595.
(2) The test was terminated at an elapsed time of 100 hours.

Table 12. Summary of incremental strain rates at select times for confined and unconfined tension creep tests in beach sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Percentage of Ultimate Strength	Incremental Strain Rates (%/min) at Elapsed Times (hrs)				
					1	10	100	500	1000
C1A	Geosynthetic PP-10 in Machine Direction	In-air	0	25	6.67×10^{-3}	3.54×10^{-3}	4.51×10^{-4}	(1)	(1)
		Beach Sand	10	25	1.36×10^{-5}	6.52×10^{-6}	3.33×10^{-5}	(1)	(1)
		Beach Sand	20	25	2.00×10^{-4}	1.33×10^{-4}	1.75×10^{-6}	(1)	(1)
		Beach Sand	10	25	2.09×10^{-4}	4.66×10^{-5}	5.91×10^{-5}	1.21×10^{-5}	8.14×10^{-6}
C2A	Geosynthetic PP-11 in Cross-Machine Direction	In-air	0	50	1.33×10^{-2}	1.14×10^{-3}	3.67×10^{-4}	(1)	(1)
		Beach Sand	10	50	7.31×10^{-3}	1.65×10^{-3}	1.51×10^{-4}	(1)	(1)
		Beach Sand	20	50	5.72×10^{-3}	1.86×10^{-3}	1.20×10^{-4}	(1)	(1)
		Beach Sand	10	50	9.30×10^{-3}	1.19×10^{-3}	1.56×10^{-4}	2.85×10^{-5}	1.16×10^{-5}
C3A	Geosynthetic PP-12 in Machine Direction	In-air	0	50	2.50×10^{-2}	1.29×10^{-2}	8.30×10^{-4}	(1)	(1)
		Beach Sand	10	50	1.47×10^{-2}	2.22×10^{-3}	3.43×10^{-4}	(1)	(1)
		Beach Sand	20	50	1.31×10^{-2}	1.98×10^{-3}	2.22×10^{-4}	(1)	(1)
C4A	Geosynthetic PE-13 in Machine Direction	In-air	0	50	1.51×10^{-2}	4.75×10^{-3}	2.42×10^{-4}	(1)	(1)
		Beach Sand	10	50	1.40×10^{-2}	2.80×10^{-3}	1.21×10^{-4}	(1)	(1)
		Beach Sand	20	50	1.67×10^{-2}	2.70×10^{-3}	1.18×10^{-4}	(1)	(1)
C5A	Geosynthetic PET-14 in Machine Direction	In-air	0	60	1.63×10^{-3}	7.13×10^{-5}	2.20×10^{-5}	(1)	(1)
		Beach Sand	10	60	2.34×10^{-3}	3.30×10^{-4}	1.22×10^{-5}	(1)	(1)
		Beach Sand	20	60	2.03×10^{-3}	1.88×10^{-4}	1.11×10^{-5}	(1)	(1)

psi = 6.895 kPa

Note: (1) The test was terminated at an elapsed time of 100 hours.

Table 13. Summary of incremental strain rates at select times for unconfined and confined tension creep tests in silty sand.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Percentage of Ultimate Strength	Total Strain (%) at Elapsed Times (hrs)				
					1	10	100	500	1000
C1B	Geosynthetic PP-10 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	25 25 25	6.67×10^{-3} 4.00×10^{-6} 2.00×10^{-4}	3.54×10^{-3} 3.51×10^{-8} 1.30×10^{-4}	4.51×10^{-4} 0.00×10^{-0} 1.75×10^{-6}	(1) (1) (1)	(1) (1) (1)
C2B	Geosynthetic PP-11 in Cross-Machine Direction	In-air Silty Sand Silty Sand	0 10 20	50 50 50	1.33×10^{-2} 6.11×10^{-3} 5.36×10^{-3}	1.14×10^{-3} 1.04×10^{-3} 1.74×10^{-3}	3.67×10^{-4} 1.50×10^{-4} 4.11×10^{-4}	(1) (1) (1)	(1) (1) (1)
C3B	Geosynthetic PP-12 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	50 50 50	2.50×10^{-2} 1.56×10^{-2} 1.38×10^{-2}	1.29×10^{-2} 2.36×10^{-3} 2.09×10^{-3}	8.30×10^{-4} 3.68×10^{-4} 1.94×10^{-4}	(1) (1) (1)	(1) (1) (1)
C4B	Geosynthetic PE-13 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	50 50 50	1.51×10^{-2} 1.75×10^{-2} 1.68×10^{-2}	4.75×10^{-3} 2.58×10^{-3} 2.70×10^{-3}	2.42×10^{-4} 1.31×10^{-5} 1.19×10^{-4}	(1) (1) (1)	(1) (1) (1)
C5B	Geosynthetic PET-14 in Machine Direction	In-air Silty Sand Silty Sand	0 10 20	60 60 60	1.63×10^{-3} 2.28×10^{-3} 1.16×10^{-3}	7.13×10^{-5} 9.22×10^{-5} 1.45×10^{-4}	2.20×10^{-5} 1.50×10^{-5} 1.47×10^{-5}	(1) (1) (1)	(1) (1) (1)

psi = 6.895 kPa

Note: (1) The test was terminated at an elapsed time of 100 hours.

However, during the creep phase, there are still fill fibers and cross-overs at intersections between the warp and fill fibers and certain degrees of interlocking even though the tortuosity may disappear during the initial loading phase. It is anticipated that the creep strain may also be reduced because of soil confinement, as supported by the test results.

For the PE geogrid, little internal friction is anticipated to be mobilized between or within ribs. Therefore, the creep behavior of the PE geogrid is likely to be least affected by the soil confinement. This observation is also supported by the test results.

5.4 SUMMARY AND CONCLUSIONS

Confined and unconfined extension and creep tests were conducted on the five geosynthetic materials with the use of the confined extension/creep testing device discussed in chapter 4. The geosynthetic materials included a needle-punched nonwoven PP geotextile, two woven PP geotextiles, a PET geogrid, and a PE geogrid. These geosynthetic materials were tested in an unconfined mode and subsequently confined in beach sand and silty sand. The following conclusions can be drawn on the basis of the obtained test results:

- Soil confinement significantly improves the moduli and strength of Geosynthetic PP-10 (i.e., a needle-punched nonwoven geotextile). The relative improvement of confined modulus at a specific level of strain varied from approximately 200 to 400 percent. The relative increase of strength varied from approximately 25 to 85 percent. As the confining pressure increased, the improvement in the moduli and strength also increased for the nonwoven geotextile.

- For tests conducted at a specific confining pressure for Geosynthetic PP-10, confined extension tests conducted using beach sand showed a more significant effect of confinement than tests conducted using silty sand.

- There was a noticeable confinement effect for the other four geosynthetic materials when confined in the beach sand or silty sand. The improvement of confined moduli at 5 percent strain ranged from approximately 5 to 30 percent for the two woven geotextiles and two geogrids at a normal stress of 20 psi (138 kPa). The increase can be considered significant with respect to unconfined moduli of these materials, although the improvement is not as significant when compared with the response for the nonwoven geotextile.

- Improvement of the confined stress-strain properties for a given geosynthetic material is believed to be primarily related to the reorientation of fibers and interfiber friction within the geosynthetic material. There are significant interfiber interactions for the nonwoven geotextile, slight interactions between fibers and yarns for the woven geotextile and PET geogrid, and little interaction between or within the ribs for the PE geogrid. This leads to an important conclusion that soil confinement has much less of an effect on the woven geotextiles and PET geogrid and an even lower effect on the PE geogrid when compared with the response of the nonwoven geotextile.

- Soil confinement significantly reduces the measured time-dependent total strain of Geosynthetic PP-10 relative to the unconfined response. There is a large reduction in the measured total strain for this material relative to the response of the other geosynthetics at high confining pressures.

- Soil confinement does not significantly reduce the measured time-dependent total strain for Geosynthetic PP-11, PP-12, PE-13, and PET-14 relative to the unconfined response.

CHAPTER 6

CONFINED EXTENSION TESTS USING TRIAXIAL-TYPE TEST DEVICE

6.1 INTRODUCTION

One of the primary purposes of this research program was to assess the influence of confinement on the tensile load versus strain (i.e., stress-strain) response of geosynthetic materials. One of the key steps in making this assessment was to evaluate and develop the most appropriate equipment for conducting confined extension tests in the laboratory. To this end, Polytechnic University (Polytechnic) participated in a collaborative effort to develop alternate and appropriate laboratory testing equipment to conduct confined extension and potentially confined creep testing of geosynthetics. The results of the Polytechnic triaxial testing program, which focused exclusively on confined extension testing using a modified triaxial apparatus (i.e., triaxial-type device), are summarized in this section. In addition, a comparison of the two confined extension test results from the testing programs is presented.

6.2 LABORATORY TESTING EQUIPMENT

a. Testing Equipment

To meet the objectives of this research program, it is necessary to compare the response of geosynthetic materials under confined and unconfined conditions while test "variables" (i.e., pretension force, aspect ratio, and strain rate) remain unchanged. Specifically, the stress-strain properties of geosynthetics have been shown to vary with respect to soil confinement, pretension force, aspect ratio, and strain rate, and possibly other unknown test variables. Therefore, with two or more test variables changing simultaneously in a test, it would be difficult to isolate the influence of a specific variable on the test results. As was demonstrated previously, any test device developed for conducting the confined extension testing should at least meet the following two requirements: (i) provide a constant strain rate to the test specimen; and (ii) maintain a constant aspect ratio of the test specimen throughout the test.

On the basis of the results of a literature review and the initial pullout testing program, the following two confined extension test devices were identified to have the potential to meet these two requirements:

- *In-Soil Test Apparatus* developed by McGown et al. [1982] and modified by Wilson-Fahmy et al. [1993]; and

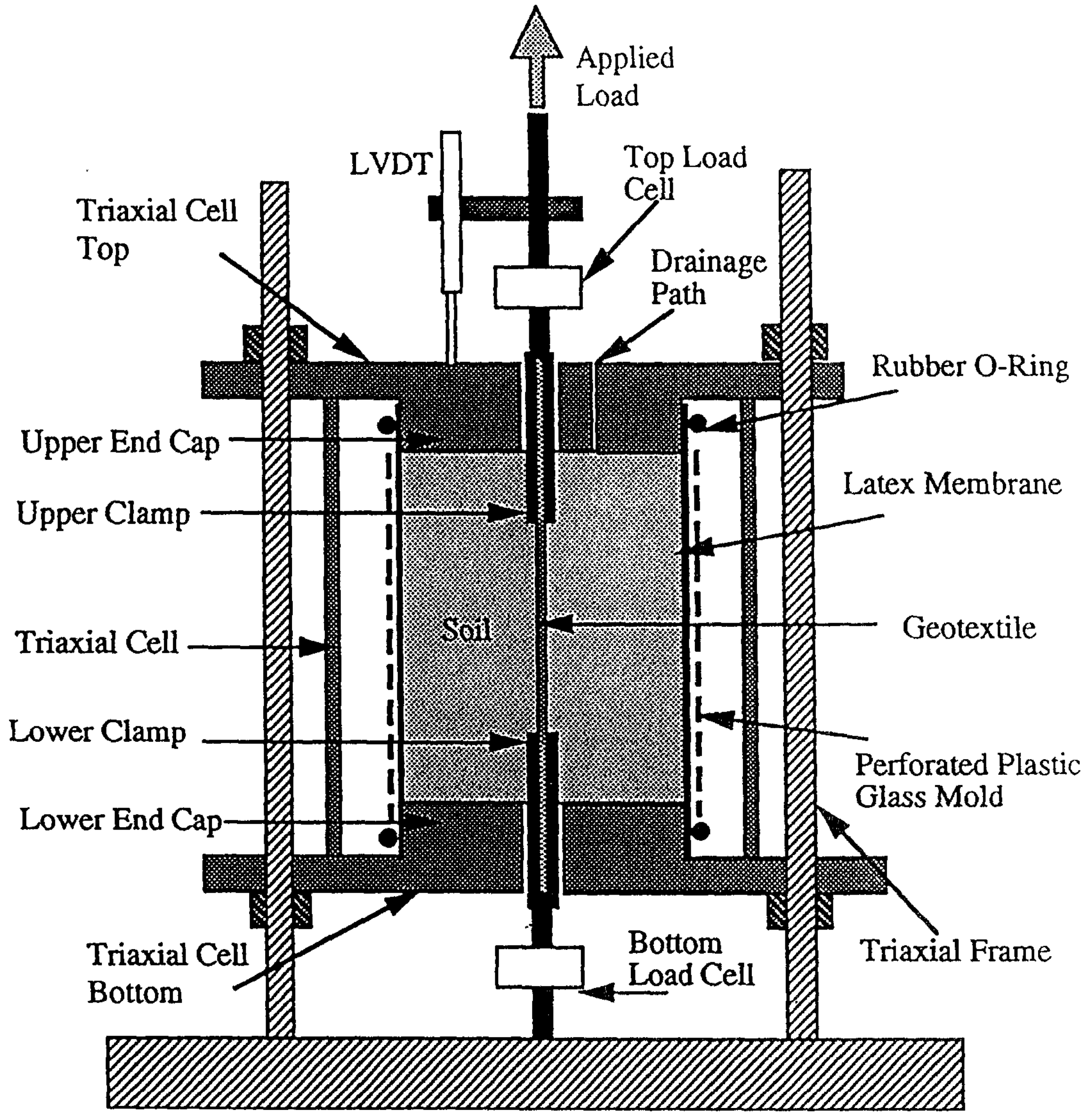
- *Modified Triaxial Apparatus* developed by Ling et al. [1991] and Wu [1991].

The triaxial-type device used for this program consists of a triaxial (extension) cell and a tension loading system. A schematic diagram of this triaxial-type device is shown in figure 39. A typical test setup using this equipment involves placing a geotextile specimen in a vertical orientation inside of a cylindrical soil specimen that is encased in a latex membrane. Each end of the geotextile specimen is fixed within a metal clamp. The lower clamp is then fit through a slot in the bottom of the triaxial cell and connected to the bottom load cell. The bottom load cell is fixed to the platform of the triaxial frame. Similarly, the upper clamp is fit through a slot in the cover of the triaxial cell and connected to the upper load cell. The upper load cell is connected to the tension loading system. An LVDT is attached to the upper clamp to measure test specimen displacement. With reference to figure 39, it is explicitly noted that the cylindrical soil specimen is prepared in such a way that its top and bottom are in direct contact with the top and bottom of the triaxial cell, respectively. Therefore, during the extension testing, the confining soil is constrained in the vertical direction while the geotextile moves through the soil.

The triaxial-type device can accommodate 8-in- (203-mm-) wide and 4-in- (102-mm-) long specimens and can provide up to 22,000 lb (98 kN) of tensile loading capacity on specimens confined under a maximum confining stress of 100 psi (690 kPa).

b. Equipment Calibration

The triaxial-type test device was calibrated electronically and mechanically. In electronic calibration, the electronic data measurement components (i.e., an LVDT and two load cells) were calibrated to verify that the loads or displacements applied to the instruments were properly conditioned and correctly recorded in the data acquisition computer. In mechanical calibration, tests were conducted on the equipment to assess friction losses in the equipment and/or effects due to the influence of the equipment and to check reproducibilty of the test results. The calibration of the triaxial-type device included the following steps:



(Note: Not to Scale)

Figure 39. Schematic diagram of triaxial-type device developed by Polytechnic University.

- Calibration of an LVDT and two load cells.

- Calibration of the "triaxial cell effect" on the in-air tensile test results by conducting two in-air tensile tests on Geosynthetic PP-15: one with the triaxial cell and the other without the triaxial cell.

- Evaluation of the reproducibility of the test results by conducting duplicate in-air tensile tests on Geosynthetics PP-15 and PP-16 under nearly identical test conditions.

- Evaluation of the friction between the upper clamp and soil.

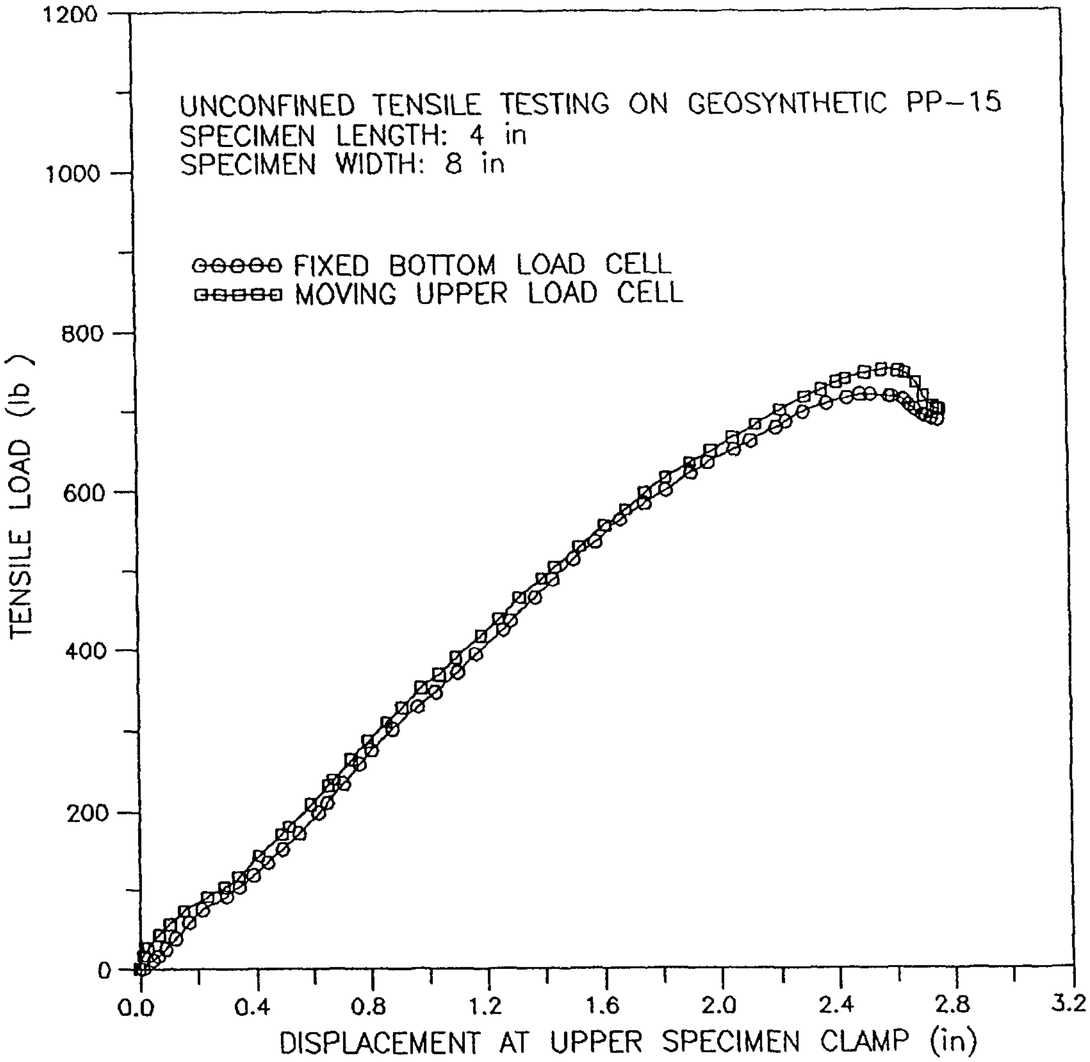
The results of the calibration tests are summarized as follows:

- Both the top and bottom load cells had a precision of ±2.2 lb (±10 N); the LVDT had a precision of ±0.0005 in (±0.01 mm).

- No influence of the triaxial cell on the unconfined extension test results was detected. The movement of the upper specimen clamp through the cover of the cell did not influence the tension measurements. Loads measured by the two load cells were very consistent, as shown in figure 40.

- Duplicate in-air tensile tests were conducted on Geosynthetics PP-15 and PP- 16. The results of two sets of tests indicate that tensile forces varied about 5 percent for Geosynthetic PP-15 and 20 percent for Geosynthetic PP-16 for strains up to 10 percent.

- Friction developed between the upper clamp and confining soil when the clamp was pulled out of the soil. A friction of approximately 25 lb (110 N) was measured when the upper clamp alone was confined in the beach sand at confining pressures in the range of 2 to 20 psi (14 to 138 kPa). The friction was subtracted from tensile loads during reduction of confined extension test data. Little friction was anticipated to develop between the lower clamp and soil because the lower clamp is attached to the stationary bottom load cell during testing.



1 in = 25.4 mm
1 lb = 0.454 Kg

Figure 40. Comparison of loads measured by top and bottom load cells in unconfined wide-width tensile test.

6.3 TEST PROCEDURE

A test procedure was developed for conducting the confined extension tests using the triaxial-type device. With reference to figure 39, the step-by-step test procedure is described as follows:

- *Stretch of Membrane:* An 8-in- (203-mm-) diameter latex membrane is stretched to fit inside a perforated plastic glass mold. Each end of the membrane is folded back over the outside of the mold and fastened with a rubber O-ring. The mold is then placed on the lower end cap.

- *Preparation of Geosynthetic Specimen:* A geotextile specimen is trimmed from the bulk sample and each end of the geotextile specimen is fixed within metal clamps. The lower clamp is then fit through the slot in the bottom of the triaxial cell and connected to the bottom load cell. The upper clamp is fit through the slot in the cover of the triaxial cell and attached to the top load cell. The geotextile is then slightly pretensioned to ensure that the geotextile stands vertically inside the mold.

- *Preparation of Soil Specimen:* The beach sand or silty sand is placed within the mold around the geotextile specimen in layers. Each layer of soil is compacted to approximately 70 to 75 percent relative density.

- *Assembly of Triaxial Cell:* The triaxial cell is placed around the mold containing the test specimen. Subsequently, each end of the triaxial membrane is fitted onto the lower or upper end cap and fastened with the rubber O-ring. The top of the triaxial cell is placed in direct contact with the upper end cap. The top and bottom of the triaxial cell is rigidly attached to the loading frame.

- *Attachment of LVDT:* An LVDT is attached to the upper clamp to measure displacements of the geotextile specimen.

- *Application of Confining Pressure:* An isotropic confining pressure is applied to the cylindrical soil specimen by pressurizing the triaxial cell and consolidating the soil specimen.

- *Extension of Geosynthetic Specimen:* After application of the confining pressure, the upper clamp is pulled at a constant displacement rate, corresponding to an average strain rate of 10 percent/min relative to the initial specimen length.

- *Monitoring of Test:* Loads and displacements measured by the load cells and LVDT are recorded using a computer data acquisition system. Monitoring of the test is continued until rupture of the geotextile specimen occurs.

It should be noted that the extension tests reported in this section were conducted on the geotextile specimens having initial dimensions of 8-in (203-mm) wide by 4-in (102-mm) long.

6.4 CONFINED EXTENSION TESTING PROGRAM

a. Test Matrix

The confined extension testing program consisted of four test series conducted on Geosynthetics PP-15 and PP-16 confined in the beach sand and silty sand. Each test series consisted of an unconfined tension test and several confined extension tests under confining pressures ranging from 2 to 20 psi (14 to 138 kPa). At each test confining pressure, two or five "identical" tests were conducted, and the average results of the tests were used to assess the confined stress-strain properties of the geotextile. A summary of test conditions used for conducting these four test series is presented in table 14.

b. Test Results and Interpretation

For each confined or unconfined extension test, the directly measured results include:

- load measured by the top load cell at the upper specimen clamp versus displacement measured by the LVDT attached to the upper specimen clamp, referred to as the top load versus displacement data; and

- load measured by the bottom load cell at the lower specimen clamp versus displacement measured by the LVDT attached to the upper specimen clamp, referred to as the bottom load versus displacement data.

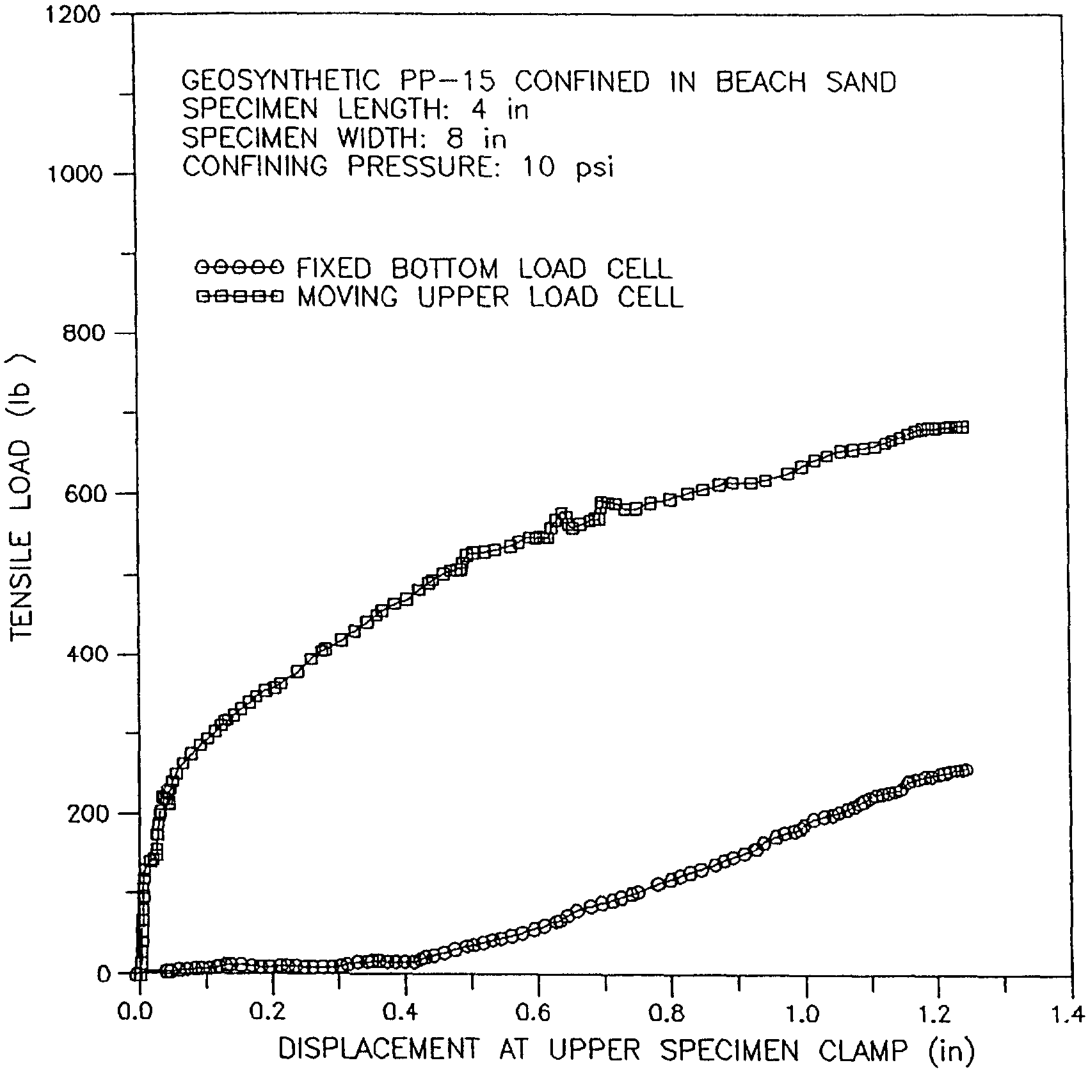
The results of a confined extension test on Geosynthetic PP-15 confined in the beach sand at a confining pressure of 10 psi (69 kPa) is presented in figure 41. This result is typical of the test results obtained in the triaxial apparatus. The top load versus displacement data and bottom load versus displacement data are graphically represented. It is observed from figure 41 that there is a significant difference between the two curves. The difference or

Table 14. **Summary of unconfined and confined extension test conditions conducted at Polytechnic University.**

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Number of Tests[(1)]	Test Specimen Width (in)	Test Specimen Length (in)	Average Strain Rate[(2)] (%/min)
TX1	Geosynthetic PP-15 in Machine Direction	In-air	0	2	8	4	10
		Beach Sand	2	2	8	4	10
		Beach Sand	4	2	8	4	10
		Beach Sand	10	5	8	4	10
		Beach Sand	20	2	8	4	10
TX2	Geosynthetic PP-15 in Machine Direction	In-air	0	2	8	4	10
		Silty Sand	4	2	8	4	10
		Silty Sand	10	2	8	4	10
TX3	Geosynthetic PP-16 in Machine Direction	In-air	0	2	8	4	10
		Beach Sand	2	2	8	4	10
		Beach Sand	4	2	8	4	10
		Beach Sand	10	5	8	4	10
		Beach Sand	20	2	8	4	10
TX4	Geosynthetic PP-16 in Machine Direction	In-air	0	2	8	4	10
		Silty Soil	4	2	8	4	10
		Silty Soil	10	2	8	4	10

1 in = 25.4 mm
psi = 6.895 kPa

Note: (1) Number of tests refers to number of tests conducted at the same confining pressure under nearly identical conditions.
(2) Average strain rate was defined as total displacement measured at the upper clamp divided by the initial specimen length.



1 in = 25.4 mm
1 lb = 0.454 Kg
1 psi = 6.89 kPa

Figure 41. Load versus displacement responses from confined extension test on Geosynthetic PP-15 at a normal stress of 10 psi.

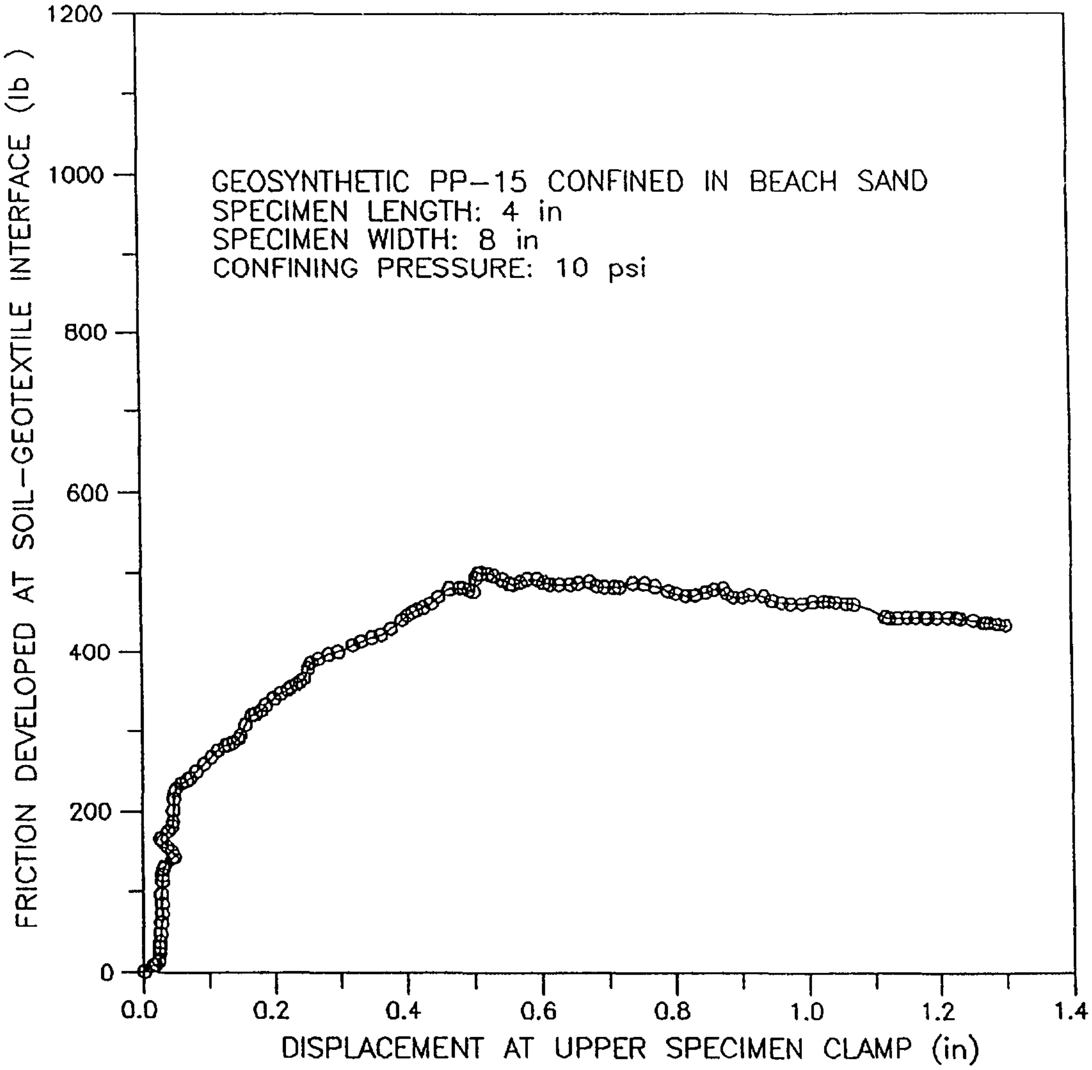
differential load is caused by the friction mobilized between the constrained soil and the moving geotextile specimen. The friction response can be readily obtained by plotting differential load versus displacement, as shown in figure 42. The friction versus displacement curve shown in figure 42 is similar to that of a typical pullout response for a geosynthetic material.

Examining the results of the confined extension tests conducted in the triaxial cell indicates the friction developed between the constrained soil and moving geotextile increases with increasing confining pressures for a given geosynthetic material. At low confining pressures of 2 to 4 psi (14 and 28 kPa), the friction is in the range of 10 and 20 lb (45 to 90 N). However, at high confining pressures of 10 and 20 psi (69 and 138 kPa), the friction is in the range of 200 to 800 lb (890 to 3560 N).

It is believed that the top load versus displacement response obtained from this type of confined extension testing is a coupled response of geotextile extension and soil-geotextile interface friction. At low confining pressures, the friction developed between the constrained soil and moving geotextile is relative small, and distribution of tension along the geotextile specimen is relatively uniform. For these considerations, tensile forces and strains can be calculated directly from the upper load versus displacement data as follows:

- divide the displacement at the top by the initial specimen length to obtain the strain; and
- divide the top load by the initial specimen width to obtain the tensile force (i.e., load per unit width).

At high confining pressures, the interface friction becomes a significant component. An appropriate interpretation procedure is required to calculate tensile forces and strains of a confined geotextile specimen. However, due to the lack of displacement data along the length of the geotextile specimen (between the two ends of the geotextile specimen), the actual strain distribution cannot be adequately evaluated. At best, an average strain along the specimen can be estimated. The authors of this report believe that use of an interpretation procedure to define the confined stress-strain properties involves significant assumptions that limit the utility of these data, as described previously in the discussion on the pullout test results. For the triaxial tests, the tensile forces and strains of the geotextile confined in soil at high confining pressures were estimated using the same method that was used for interpreting the results of confined extension tests at low confining pressures.



1 in = 25.4 mm
1 lb = 0.454 Kg
1 psi = 6.89 kPa

Figure 42. Friction versus displacement response from confined extension test on Geosynthetic PP-15 at a normal stress of 10 psi.

Using the tensile force and strain data from each confined or unconfined extension test, the following properties were calculated to characterize the confined or unconfined response: (i) secant modulus at 5 percent strain; (ii) secant modulus at 10 percent strain; (iii) peak strength; and (iv) strain at the peak strength (i.e., failure strain). It is noted that two or five confined extension tests were conducted on the same geotextile under nearly identical test conditions. An average value of each of these four characterization properties was calculated from the results of the duplicate tests. A summary of the average values of these characterization properties is presented in table 15.

6.5 COMPARISON OF CONFINED EXTENSION TEST EQUIPMENT AND RESULTS

a. Comparison of Test Devices

The triaxial-type device and the protocol confined extension/creep test device are similar in the following aspects:

- capability to provide flexible boundary conditions over a major portion of the soil specimen surface; in the extension/creep device, the top and bottom of the soil specimen are in contact with air bladders; in the triaxial device, the soil specimen is encased in a latex membrane;

- capability to apply a constant confining pressure to the test specimen;

- capability to apply a constant strain rate to the test specimen; and

- potential to maintain an approximately constant aspect ratio for the geosynthetic specimen.

However, there are the following two major differences between the two test devices:

- The triaxial device applies an isotropic pressure to the entire test specimen while the confined/creep device applies a vertical (normal) pressure to the test specimen. It is anticipated that the geosynthetic specimen encased in the cylindrical specimen in the triaxial device is under compression in all directions. Compression in the direction of width (i.e., in-plane compression) may influence the confined response of the geotextile.

Table 15. Summary of unconfined and confined extension test results conducted at Polytechnic University.

Test Series Number	Geosynthetic Material	Confining Material	Confining Pressure (psi)	Number of Tests(1)	Modulus at 5% Strain(2) (lb/ft)	Modulus at 10% Strain(2) (lb/ft)	Peak Strength(3) (lb/ft)	Strain at Peak(4) (%)
TX1	Geosynthetic PP-15 in Machine Direction	In-air	0	2	2,352	1,848	948	65
		Beach Sand	2	2	1,800	1,692	768	44
		Beach Sand	4	2	3,300	2,292	888	51
		Beach Sand	10	5	9,840	6,240	1,008	43
		Beach Sand	20	2	15,840	8,760	996	36
TX2	Geosynthetic PP-15 in Machine Direction	In-air	0	2	2,352	1,848	948	65
		Silty Sand	4	2	2,700	4,656	888	88
		Silty Sand	10	2	1,572	2,772	756	61
TX3	Geosynthetic PP-16 in Machine Direction	In-air	0	2	2,328	2,076	804	112
		Beach Sand	2	2	4,080	2,640	888	135
		Beach Sand	4	2	1,800	1,344	840	140
		Beach Sand	10	5	2,784	1,800	900	123
		Beach Sand	20	2	7,344	4,572	948	97
TX4	Geosynthetic PP-16 in Machine Direction	In-air	0	2	2,328	2,076	804	112
		Silty Soil	4	2	1,044	528	444	150
		Silty Soil	10	2	6,144	3,027	1,104	120

psi = 6.895 kPa
lb/ft = 14.59 N/m

Notes:
(1) Number of tests refers to number of tests conducted at the same confining pressure under nearly identical conditions.
(2) Modulus is an average modulus calculated from two or five duplicate tests conducted under the same conditions.
(3) Peak strength was measured at the upper clamp.
(4) Strain rate was defined as total displacement measured at the upper clamp divided by the initial specimen length.

- In the triaxial device, the geotextile moves within the cylindrical soil specimen, which is constrained in the vertical direction. A friction is developed at the soil-geosynthetic interface, which causes a nonuniform distribution of tension along the specimen length. As a result, strain and strain rate are anticipated to decrease from the upper to lower end of the test specimen. In the confined extension/creep device, the soil tends to move together with the geotextile specimen. The mobilized soil-geosynthetic interface friction is relatively small. Therefore, the distribution of tension along the geosynthetic specimen is nearly uniform in this device.

b. Comparison of Test Results

In the context of the entire research program, there is only one component of the program that leads to a direct comparison between the two devices. To this end, a comparison is presented of the short-term confined and unconfined extension test results for Geosynthetics PP-15 and PP-10 confined in the beach sand and silty sand. Geosynthetics PP-15 and PP-10 were two nonwoven geotextiles produced by the same manufacturer. On the basis of information provided by the manufacturer, the two geotextiles were considered as the same material as far as their average properties are concerned. The following summary comments reflect this comparison:

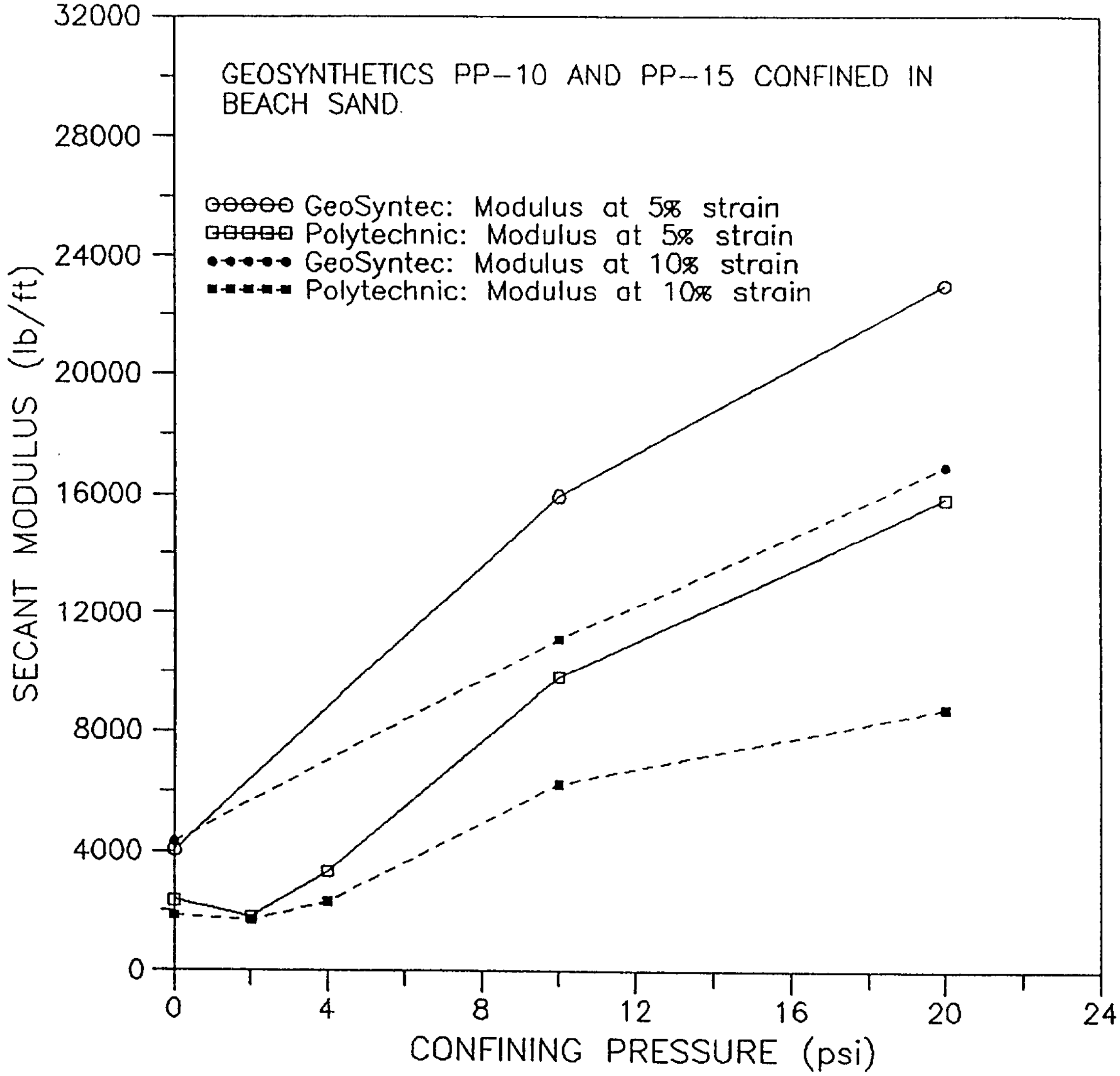
- *Unconfined Tensile Strength:* In the confined extension/creep device, a peak strength of 1,352 lb/ft (19.8 kN/m) at a strain of 39 percent for Geosynthetic PP-10 was measured; the triaxial device measured a peak strength of 948 lb/ft (13.9 kN/m) at a strain of 65 percent for Geosynthetic PP-15. A direct comparison indicates that there is a significant difference between the two peak strengths and failure strains of the two geotextiles. To understand what caused the difference between the results obtained by the two organizations for these unconfined test results, two explanations were explored: (i) the difference between the two materials as measured by mass per unit area; and (ii) inherent variability of Geosynthetic PP-15. Geosynthetic PP-15 tested at Polytechnic had a mass per unit area of 8.3 oz/yd^2 (282 g/m^2) while Geosynthetic PP-10 tested at GeoSyntec had a mass per unit area of 10.1 oz/yd^2 (343 g/m^2). It is expected that Geosynthetic PP-10 would be stronger than Geosynthetic PP-15; this is confirmed by the test results.

  Inherent variability of Geosynthetic PP-15 was studied by analyzing a set of in-air test data (10 tests) on Geosynthetic PP-15 provided by the manufacturer. The results of statistical analysis are as follows: (i) strengths in the machine direction in the range from 940 to 1,421 lb/ft (13.7 to 20.7 kN/m) with a mean of 1,043 lb/ft (15.2 kN/m); (ii) a calculated standard deviation of 175 lb/ft (2.6 kN/m); and (iii) a calculated coefficient of variation of 17 percent. The statistical analysis indicates that Geosynthetic PP-15 is highly variable in terms of tensile strengths. The unconfined tensile strengths of the two geotextiles measured by the two organizations fall in the range of the strength data provided by the manufacturer, yet the differences make a direct comparison difficult.

- *Confined Modulus at 5 and 10 Percent Strains:* Figures 43 and 44 present a summary plot of the laboratory-measured moduli at 5 and 10 percent strain for the geotextiles confined in the two soil materials. The results are generally consistent and indicate that: (i) confinement of each soil significantly improves the modulus; (ii) relative to the improved modulus, the higher the confining pressure, the greater the improvement; and (iii) under the same confining pressure, the confinement effect of the beach sand is greater than that of the silty sand. The triaxial results, however, indicate a potential slight reduction in stiffness compared with the in-air stiffness at low confining pressures. This may be due to inherent variability in the geotextile specimen, as previously described. The improvement in moduli at 5 percent strain for the nonwoven geotextiles confined in the beach sand obtained by both techniques are also compared with those for similar materials obtained by other researchers,as shown in figure 45.

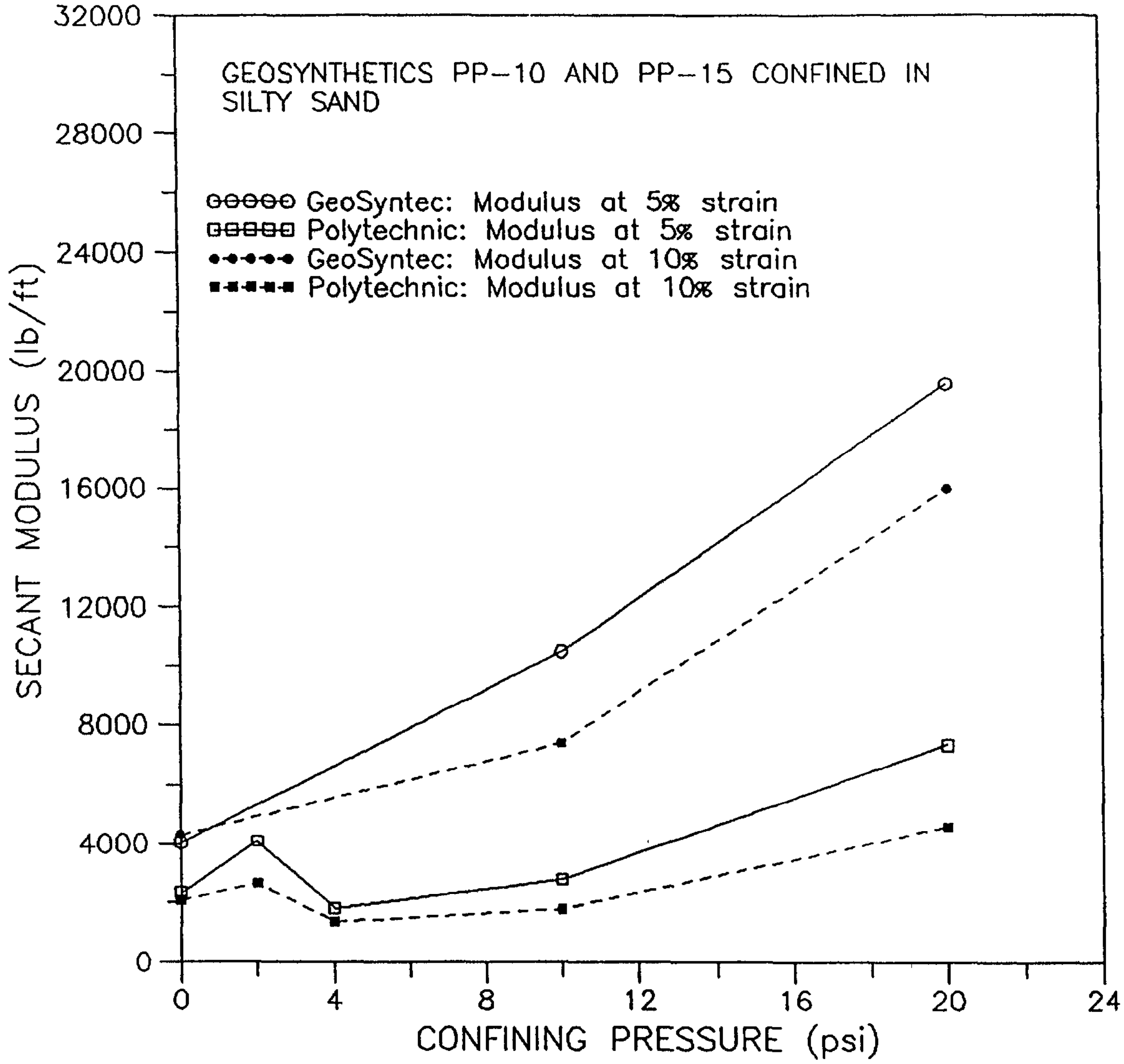
- *Confinement Effect on Strength:* Figure 46 presents a summary plot of the laboratory-measured peak strength for the confined test specimen. The confined extension creep device results indicate that there is consistent improvement in the peak strength as a result of soil confinement. The triaxial results indicates essentially no increase in peak strength. The internal consistency in both test results indicate that these results are likely not the result of inherent sample variability, but rather an effect of the specific test conditions (i.e., effect of clamping system, specimen geometry, testing equipment, etc.). At this stage, however, it is premature to provide a detailed evaluation of the observed response.

Regardless of the detailed observation described above, the results indicate that: (i) soil confinement imposes beneficial effects on the stress-strain response of the nonwoven geotextile; (ii) a higher confining pressure results in a greater improvement of the confined secant modulus; and (iii) the confinement effect of the beach sand is greater than that of the silty sand.



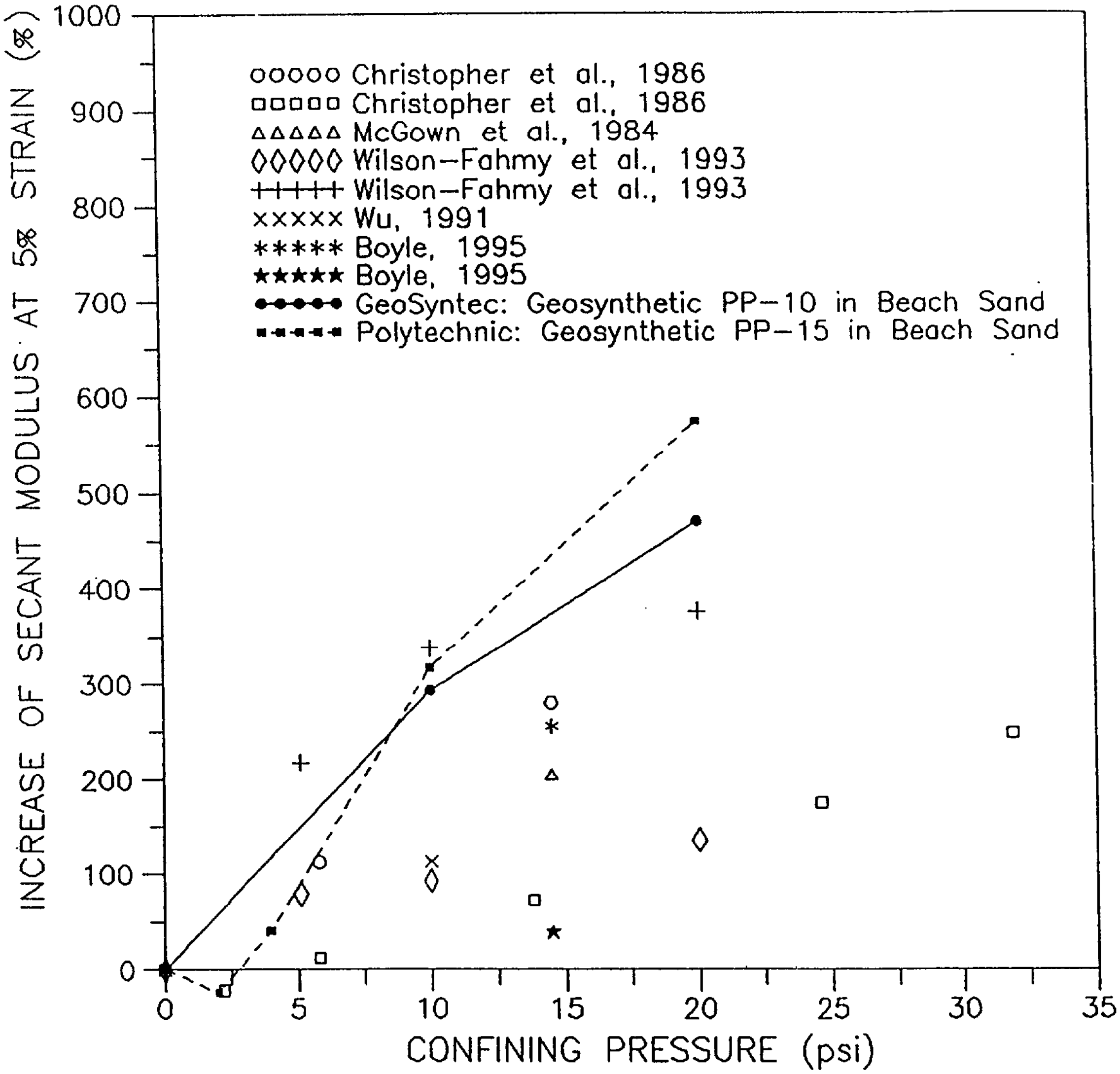
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 43. Comparison of GeoSyntec and Polytechnic test results (secant moduli of Geosynthetics PP-10 and PP-15 confined in beach sand.



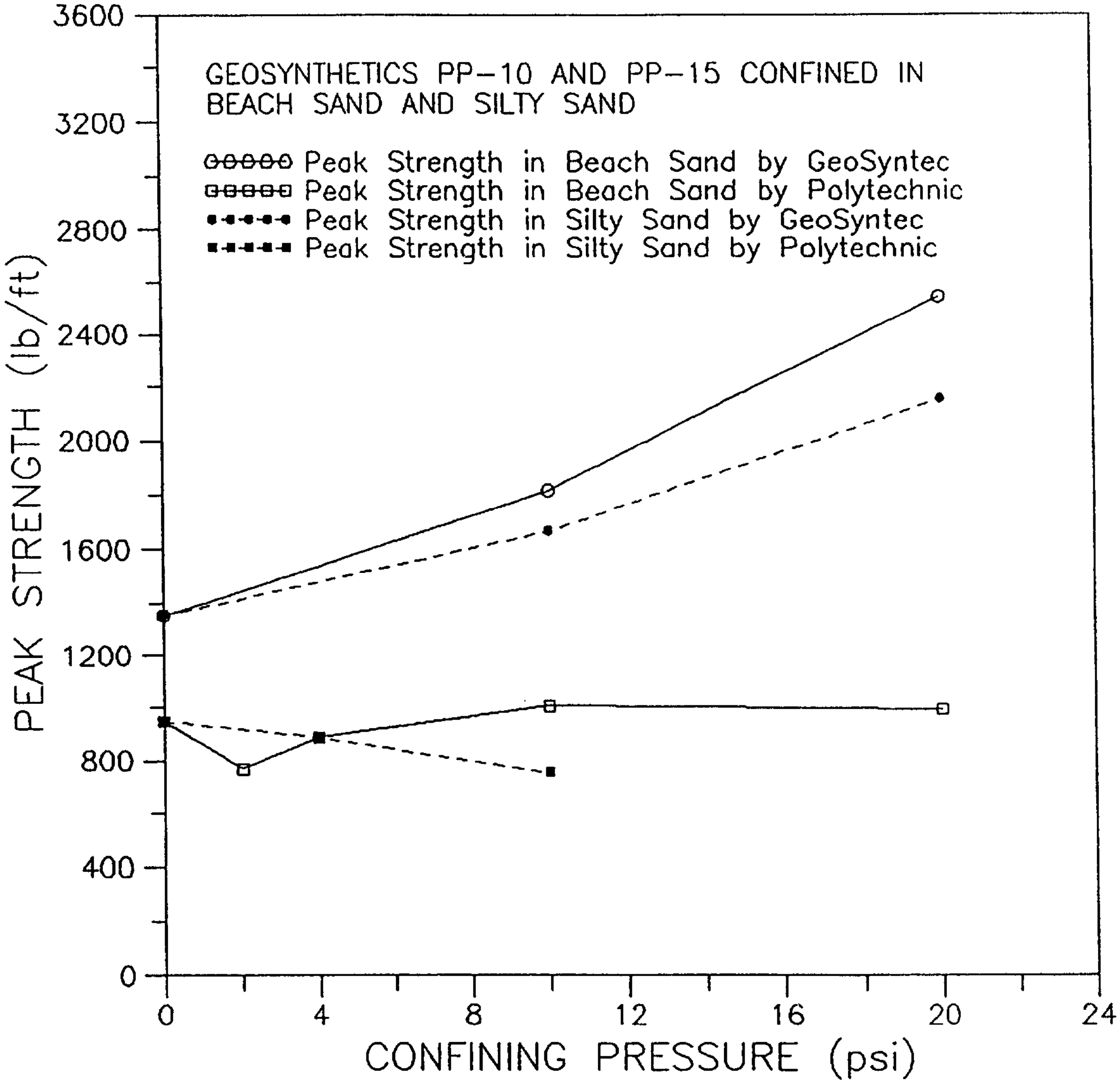
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 44. Comparison of GeoSyntec and Polytechnic test results (secant moduli of Geosynthetics PP-10 and PP-15 confined in silty sand.



1 psi = 6.89 kPa

Figure 45. Comparison of secant moduli at 5 percent strain for Geosynthetics PP-10 and PP-15 confined in beach sand obtained by GeoSyntec and Polytechnic with data of similar geosynthetic materials reported by other researchers.



1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 46. Comparison of GeoSyntec and Polytechnic test results (peak strengths of Geosynthetics PP-10 and PP-15 confined in beach sand and silty sand.

6.6 SUMMARY COMMENTS AND RECOMMENDATIONS

The results of the collaborative project provide somewhat comparable results; specifically, there is a beneficial effect of confinement on the confined stress-strain behavior of a nonwoven geotextile. A detailed comparison of test results indicates that there is a noticeable difference between the stress-strain properties of the nonwoven geotextiles obtained by the two types of equipment. The difference is likely due to the fact that: (i) the two nonwoven geotextiles are highly variable, as suggested by the manufacturer data; and (ii) there are significant differences the two test devices.

It was observed from the test results that the triaxial device works in such a way that a potentially significant friction is developed at the soil-geotextile interface at high confining pressures. The interface friction causes a nonuniform distribution of tension along the geosynthetic specimen similar to the authors' reported assessment of the pullout test. It is difficult to account for the effect of friction on the confined extension properties of geosynthetics through an interpretation procedure. The authors believe that it is premature to adopt the triaxial-type device for evaluating confined stress-strain properties of geosynthetics unless an appropriate procedure is developed to account for the soil-geosynthetic friction effect during interpretation and subsequently verified. However, the triaxial device provides an alternative for measuring the pullout response of geosynthetics under saturated conditions, which cannot be easily simulated in the traditional pullout test device. Soil-geosynthetic interaction parameters determined from the triaxial device may have direct applications in design and analysis of reinforced soil structures, but additional comparison testing is needed prior to adopting this test.

As indicated previously, the results of the confined extension tests conducted in the modified in-soil device were internally consistent. The utilized equipment has been found to be appropriate for confined extension tests. As a component of this project, a testing protocol for conducting short-term confined extension tests and long-term confined creep tests has been developed. At this stage of development, the authors believe that the confined extension, also referred to as a confined wide-width device, offers more potential than the triaxial-type device. It is recommended that the confined extension testing equipment and the testing protocol be utilized to produce, at the very least, a baseline reference for evaluating the confined response of geosynthetics. Additional testing is warranted and recommended. It is recommended that this additional testing focus on: (i) confined extension for a wide range of soil materials; (ii) confined creep at different tensile stress levels; (iii) confined creep beyond 1000 hours; (iv) detailed testing of geosynthetics that are used primarily for reinforcement; and (v) identifying mechanisms that lead to the understanding of the soil confinement effects on the confined response of geosynthetic materials.

CHAPTER 7

DEVELOPMENT OF WRITTEN PROTOCOL FOR CONFINED EXTENSION/CREEP TESTING

7.1 OVERVIEW

The final component of this program is the development of a protocol for conducting confined extension and creep tests. The protocol was developed on the basis of chapters 3, 4, and 5 of this report. The test protocol was written in accordance with the format established by the American Society for Testing and Materials (ASTM) for the preparation of a standard test method, and is presented in appendix C.

7.2 DISCUSSION

Using the confined extension equipment developed and the results of the verification testing program, a protocol has been established for conducting confined extension and creep tests. The protocol presented in appendix C of this report is essentially a "stand-alone" document. Several major factors were considered in the development of this protocol. These factors were discussed in the previous sections of this report and are summarized below:

- *Friction Loss:* It was found that the tensile load applied to the front of the geosynthetic specimen was not fully transferred to the rear of the geosynthetic specimen. The difference between the front and rear loads was mainly caused by the mobilized friction between the soil and geosynthetic specimen and specimen clamp. The friction loss was minimized by placing steel rollers between the confinement box and the supporting table. The overall friction loss should be measured through calibration. The friction should be controlled within 2 percent of the anticipated maximum load in the confined extension test or the applied creep load in the confined creep test in order to achieve a nearly uniform distribution of tensile loads along the geosynthetic specimen length. Uniformity should be checked by monitoring the strain distribution over the length of a test specimen.

- *Strain Measurement:* The tensile strain is to be measured by the use of two tell-tail wires connected to the geosynthetic specimen and monitored by electronic measurement devices such as LVDTs; however, dial gages could also be used. The location of the two tell-tail wires defines the gage length. A gage length of 4 in (102 mm) should be used for geotextiles. For the geogrids, the gage length should include at least two full geogrid apertures but should not be less than 4 in (102 mm) in length. In cases where it is necessary to verify the uniformity of the strain distribution across the geosynthetic, a minimum of four tell-tails should be mounted over the gage length of the test specimen.

- *Pretension Force:* In accordance with the procedure established in ASTM D 4595 for in-air tensile testing of geosynthetics, a total pretension force equal to 1.25 percent of the expected breaking force should be applied to each geosynthetic specimen. However, the total pretension force should not be less than 10 lb (45 N) or greater than 50 lb (222 N) in any case. The pretension force should be applied to the geosynthetic specimen prior to placement of the upper confining soil layer. This allows examination of the geosynthetic specimen to assess whether the geosynthetic is in uniform contact with the top of the lower confining soil layer.

- *Strain Rate:* A constant rate of strain of 10 percent/min should be applied to the geosynthetic specimen in the confined extension test. Selection of this constant rate of strain is based on the standard loading rate specified in ASTM D 4595. Use of this strain rate allows for a direct comparison between the confined and unconfined stress-strain properties of geosynthetics.

- *Aspect Ratio:* An aspect ratio of 2:1 should be used for geotextile specimens. For geogrid specimens, a constant aspect ratio cannot be specified for various currently available geogrid products. A geogrid specimen should be trimmed in such a way that it has a length containing at least two complete apertures in the direction of testing (i.e., typically the machine direction) and a width containing at least five ribs in the cross-test direction (i.e., typically the cross-machine direction). For any geogrid, a minimum width of 6 in (152 mm) is recommended.

- *Initial Loading Rate for Creep Tests:* A strain rate of 10 ± 3 percent/min should be used to load each creep test specimen. Selection of this initial loading rate is based on the standard loading rate in ASTM D 5262 for conducting unconfined tension creep tests of geosynthetics.

- *Confining Soil Thickness:* It has been shown that the confined stress-strain curves were almost identical for the geotextile specimens when confined in thicknesses of soil ranging from 1 to 3 in (25 to 76 mm) and when the geotextile specimens were placed at a distance of 2 in (51 mm) away from side walls of the confinement box. For ease of the test set-up, a soil thickness of 3 in (76 mm) should be used to assess the fully confined response of an 8-in- (203-mm-) wide geosynthetic specimen placed within a 12-in- (305-mm-) wide confinement box. To assess the partially confined response, a 0.4-in- (41-mm-) thick soil layer should be placed above and below the geosynthetic.

- *Friction Along The Geosynthetic Specimen:* It has been shown that the friction along the soil-geosynthetic interface cannot be totally eliminated due to the fact that there is a significant difference between the failure strains of the confining soil and the geosynthetic material. However, the friction along the soil-geosynthetic interface can be reduced by imposing low friction boundary conditions to the confining soil similar to that which was used by McGown et al. [1982] and Wilson-Fahmy et al. [1993]. The proposed test protocol identifies two different test procedures for conducting a test. Procedure A consists of a nonlubricated interface between the soil and geosynthetic where the test specimen is set up to model a fully confined condition. Procedure B consists of a lubricated interface between the soil and geosynthetic to model a partially confined condition. The selection of the specific test procedure should be based on the designers' selected design approach.

7.3 FUTURE USE

As stated, the testing protocol presented in appendix C has been prepared in the format of an ASTM standard test method. The protocol in its current state should be offered to the ASTM D-35 committee on geosynthetics for consideration as a potential new test method. If accepted by the committee, a task group will be formed by ASTM to further review and test the method with the hope of eventually approving it as an ASTM standard.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY AND CONCLUSIONS

The objectives of the four-phase research program were to: (i) develop and assess the performance of test equipment for evaluating confined stress-strain properties of geosynthetics; (ii) establish testing procedures for conducting confined extension and confined creep tests on geosynthetics; (iii) verify the performance of the test equipment and confirm the validity of the procedures by testing representative geosynthetics; and (iv) develop a written protocol for conducting confined extension and confined creep testing. These objectives were achieved through the completion of several specific tasks. A brief discussion is presented of the most significant conclusions of each task:

- *Literature Review:* The literature review identified 12 distinct references in which confined extension and/or creep testing equipment and/or test results were described. This review indicated that several types of laboratory testing equipment, including the pullout device, in-soil test device, and triaxial-type device, have been used to assess the confined stress-strain response of geosynthetics. A summary of the test equipment and test results reported in the references was presented. The pullout device developed by Juran et al. [1991], in-soil test device developed by McGown et al. [1982], and modified triaxial device developed by Ling et al. [1991] were identified as having a high potential for measuring a confined response of a geosynthetic that can be directly compared to an unconfined response of the geosynthetic in order to evaluate the effect of soil confinement. The reported results in these references indicate that soil confinement significantly improves the stress-strain properties of nonwoven geotextiles but does not significantly affect the stress-strain properties of woven geotextiles.

- *Initial Base-Line Testing:* Tests conducted utilizing the pullout device showed that there was an effect of soil confinement on the pullout response of various geosynthetic products. However, the results from the pullout testing indicate that the confined extension pullout test has the following four problems: (i) necking of the nonwoven geotextile specimen; (ii) variation of the "mobilized" aspect-ratio during a test; (iii) variation of the strain rate along the test specimen; and (iv) arbitrary selection of the size of the first element length for interpretation. Because of these problems, it was concluded that it would be difficult to "uncouple" the confined stress-strain response and provide a measure of the actual confined geosynthetic response. Therefore, the pullout test was abandoned in favor of the in-soil apparatus developed by McGown et al. [1982], which was anticipated to overcome the problems experienced using the pullout testing device. A prototype confined extension testing device, similar to the in-soil test apparatus, was subsequently developed. The prototype confined extension testing device had an ability to provide: (i) a constant strain rate to a confined specimen; and (ii) maintain a constant aspect ratio during testing.

- *Development of Test Equipment:* On the basis of the success of the prototype confined extension testing device, a test apparatus that could be used for production tests was designed, fabricated, and calibrated. The advantages of the test apparatus otherwise known as the protocol device fabricated for this project include: (i) ease of the test set-up; (ii) well-defined boundary conditions; and (iii) ease of test interpretation. The friction along the soil-geosynthetic interface was minimized by placing the entire confinement box on steel rollers so that a nearly uniform distribution of tension along the specimen length was achieved. Because of this uniform tension distribution, the confined stress-strain response of the geosynthetic was readily obtained from the measured data and used for a direct comparison with the unconfined response of the geosynthetic to evaluate the effect of soil confinement. Tests were conducted under constant strain rate and constant tensile load conditions.

- *Verification of Test Equipment:* There were five test variables identified in the confined extension and confined creep testing program that required verification. These variables were: (i) pretension force; (ii) strain rate; (iii) aspect ratio; (iv) initial rate of loading for the creep tests; and (v) thickness of the confining soil. The first four variables were selected in accordance with ASTM D 4595 (wide-width tensile testing of geotextiles) and ASTM D 5262 (unconfined creep testing of geosynthetics). The effect of soil thickness on the confined response of geosynthetics was investigated through a series of confined extension tests on Geosynthetic PP-10 that was confined by various layers of beach sand with thicknesses ranging from 0.4 to 3 in (10 to 76 mm). The test results indicate that there was little difference when the geosynthetic was confined within 1-to 3-in- (25- to 76-mm-) thick soil layers. However, the effect of soil confinement was reduced when the thickness of the soil layer was reduced to 0.4 in (10 mm) because cracks developed throughout the thickness of the soil layers. A thickness of 3 in (76 mm) was then selected for all production confined extension and confined creep tests to provide full confinement.

- *Production Confined Extension and Creep Tests:* On the basis of the results of verification confined extension and creep tests, production testing was conducted. Results based on the following conclusions can be drawn:

    1. Soil confinement significantly improves the moduli and strength of Geosynthetic PP-10 (i.e., a needle-punched nonwoven geotextile). As the confining pressure increases, the moduli and strength of this material similarly increases.

    2. Under a constant confining pressure for Geosynthetic PP-10, the confined response (i.e., modulus and strength) of the geosynthetic specimen in beach sand is greater than the response of the geosynthetic specimen in silty sand.

    3. There is a noticeable effect of confinement with respect to the confined response for the two woven geotextiles and two geogrids (Geosynthetics PP-11, PP-12, PE-13, and PET-14) when confined in the beach sand and in the silty sand; the increase in confined moduli at 5 percent strain ranged from approximately 5 to 30 percent among Geosynthetics PP-11, PP-12, PE-13, and PET-14 at a normal stress of 20 psi (138 kPa). These increases can be considered significant with respect to unconfined moduli of the same materials although less significant when compared with the increase of the 5 percent moduli for the nonwoven geotextile (Geosynthetic PP-10).

    4. Soil confinement significantly reduced the measured time-dependent total strain of Geosynthetic PP-10; the measured total strain reduced in direct proportion to the increase at higher confining pressures.

    5. Reduction of measured time-dependent total strains resulting from soil confinement for Geosynthetics PP-11, PP-12, PE-13, and PET-14 was less than that for Geosynthetic PP-10.

    6. Improvement of the confined stress-strain properties for a given geosynthetic material is believed to be primarily related to: (i) internal friction between fibers or yarns; (ii) alignment of curved fibers or yarns (i.e., tortuosity); and (iii) interlocking of soil within openings or apertures of geosynthetics.

- *Confined Extension Tests Using a Triaxial-Type Apparatus:* The triaxial-type confined extension testing device developed at Polytechnic was used for evaluating the confined extension responses of Geosynthetic PP-15 and Geosynthetic PP-16. The results of the confined extension tests conducted on Geosynthetic PP-15 are generally consistent with those found for Geosynthetic PP-10 at GeoSyntec in that the effect of soil confinement is significant and quantifiable. A detailed comparison of test results, however, indicates that there is a noticeable difference between the stress-strain properties of the nonwoven geotextiles obtained by the two organizations. The difference is likely due to the following two facts: (i) the strengths of nonwoven geotextiles tested by Polytechnic and GeoSyntec are highly variable, as suggested by the manufacturer's data; and (ii) there are fundamental differences in the test devices. The triaxial-type device works in such a way that friction is developed at the soil-geotextile interface, causing a nonuniform distribution of tension along the geosynthetic specimen length. The response of the geosynthetic in this device is similar to the response in a pullout test. Accordingly, it is difficult to account for the effect of friction on the confined stress-strain properties of geosynthetics through an interpretation procedure. The authors of this report believe that it is premature to adopt the triaxial device for evaluating confined stress-strain properties of geosynthetics.

- *Testing Protocol:* A written testing protocol has been developed in the format of an ASTM standard test method. It is recommended that the testing protocol in its current state be offered to the ASTM D-35 committee on geosynthetics for consideration as a potential new test method.

8.2 DESIGN IMPLICATIONS

In the design of geosynthetic-reinforced soil walls and slopes, it is the state-of-practice to use the unconfined stress-strain properties of geosynthetic materials to evaluate the short-term and long-term stability of the geosynthetic-reinforced structures. The results of this research program indicate that soil confinement imposes beneficial effects on the stress-strain response of the nonwoven geotextiles and the other geosynthetic materials tested in the program; furthermore, results indicate that the use of unconfined stress-strain properties of these geosynthetic materials in the design may be conservative. With specific reference to the nonwoven geotextile, the test results indicate that the stiffness is significantly enhanced as a result of soil confinement. Use of the unconfined stress-strain properties for the nonwoven geotextile in design may be overly conservative. Results of this program indicate that the confined response of geosynthetics can be significant in some cases. Therefore, when using geosynthetic materials in the design, it is recommended that:

- confined extension tests be performed to determine the modulus and peak strength of nonwoven geotextiles and other geosynthetic materials;
- confined creep tests be performed to determine the long-term strength of the nonwoven geotextiles and other geosynthetic materials;
- confined extension and/or confined creep tests be performed to obtain serviceability values for woven geotextiles and geogrids; and
- confined extension and/or confined creep tests be conducted for calibrating instrumentation to be used in field monitoring and for assessing input parameters for numerical analysis.

As discussed and supported in this document, the authors believe that the protocol confined extension test device is appropriate for assessing the confined properties of geosynthetic materials. The testing protocol can be utilized to assess geosynthetic stress-strain characteristics under either fully confined or partially confined conditions. The results of this study indicate that full confinement provides a larger improvement relative to the unconfined response when compared with partial confinement. Depending on the specific design condition assessed by the designer, either a fully or partially confined test can be conducted using the protocol testing device to obtain parameters to be used in the design.

8.3 RECOMMENDATIONS

The test results from this study regarding the short-term and long-term confined response of various geosynthetic materials are encouraging. The test results indicate that soil confinement imposes beneficial effects on the stress-strain response of the nonwoven geotextile and other geosynthetic materials tested in the program. It is recommended that the Federal Highway Administration pursue a more comprehensive study of the confined behavior of geosynthetic materials with the use of the protocol confined extension/creep test device developed, with the ultimate goal of incorporating the confined stress-strain properties into future design procedures. The following recommendations are made to achieve this ultimate goal:

- Confined extension tests are recommended to be performed for a wide range of soil materials.

- Confined extension tests are recommended to be performed on geosynthetics with the use of detailed instrumentation to measure the stiffness (modulus) of the confined geosynthetic materials at low strain levels.

- Confined creep tests are recommended to be performed at different tensile stress levels, especially at high stress levels to evaluate the confined creep rupture strengths.

- Confined creep tests are recommended to be performed for a duration of 10,000 hours.

- Detailed tests are recommended to be performed on geosynthetics that are used primarily for reinforcement.

- Confined extension and confined creep tests should be conducted under both fully or partially confined conditions and the results compared.

- Select geosynthetic materials should be tested using the protocol testing equipment and the more complex UCD test device developed by Boyle [1995] and the APSR test device developed by Whittle et al. [1993] to assess how the confined extension test results relate to the actual response of geosynthetic reinforcement in simulated field conditions.

- It should be noted that the protocols developed will likely still result in fairly conservative confined creep results, although improved economy will be realized.

APPENDIX A
CONFINED EXTENSION TEST RESULTS

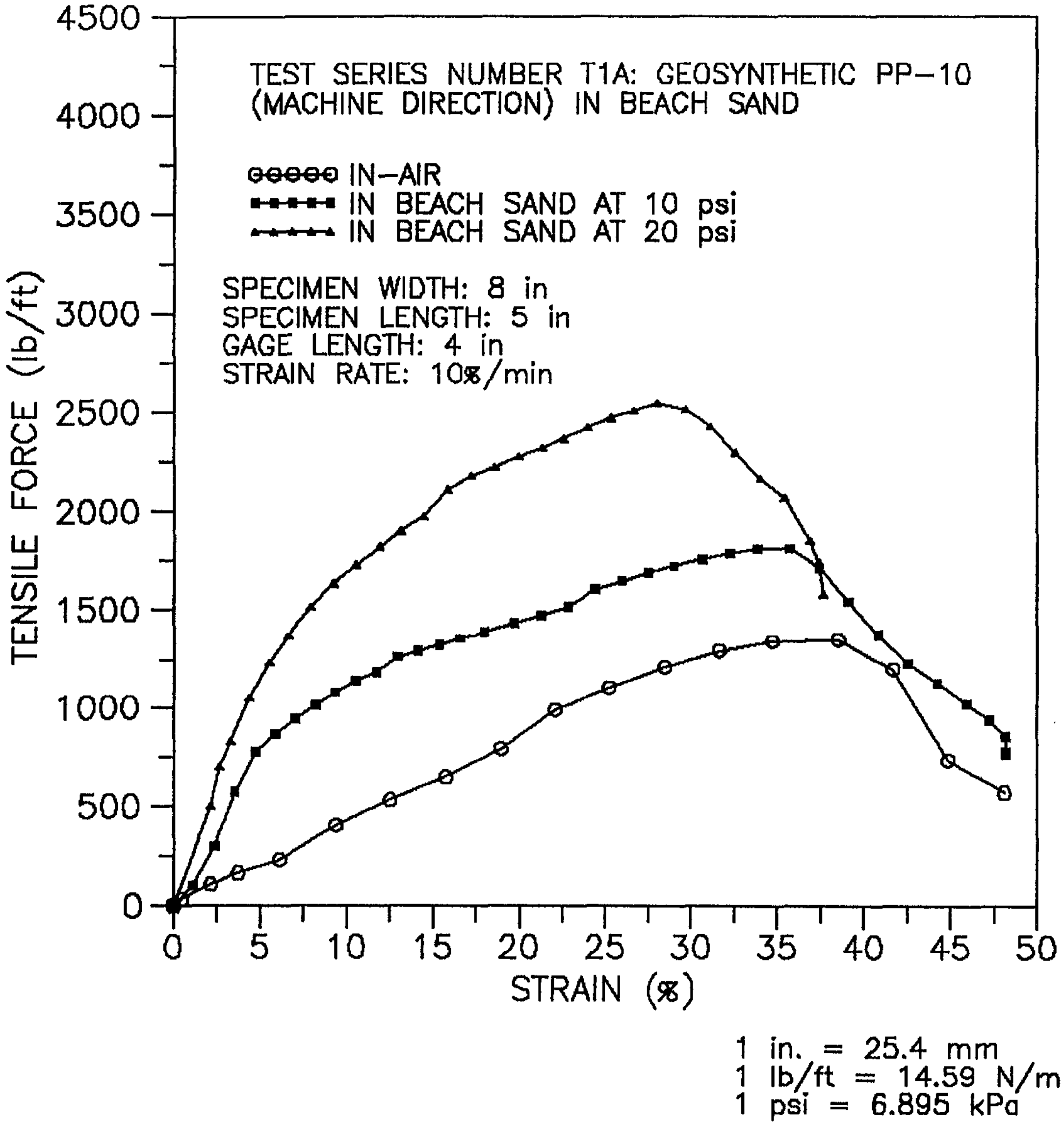


Figure A-1. Tensile force versus strain response for Geosynthetic PP-10 confined in beach sand.

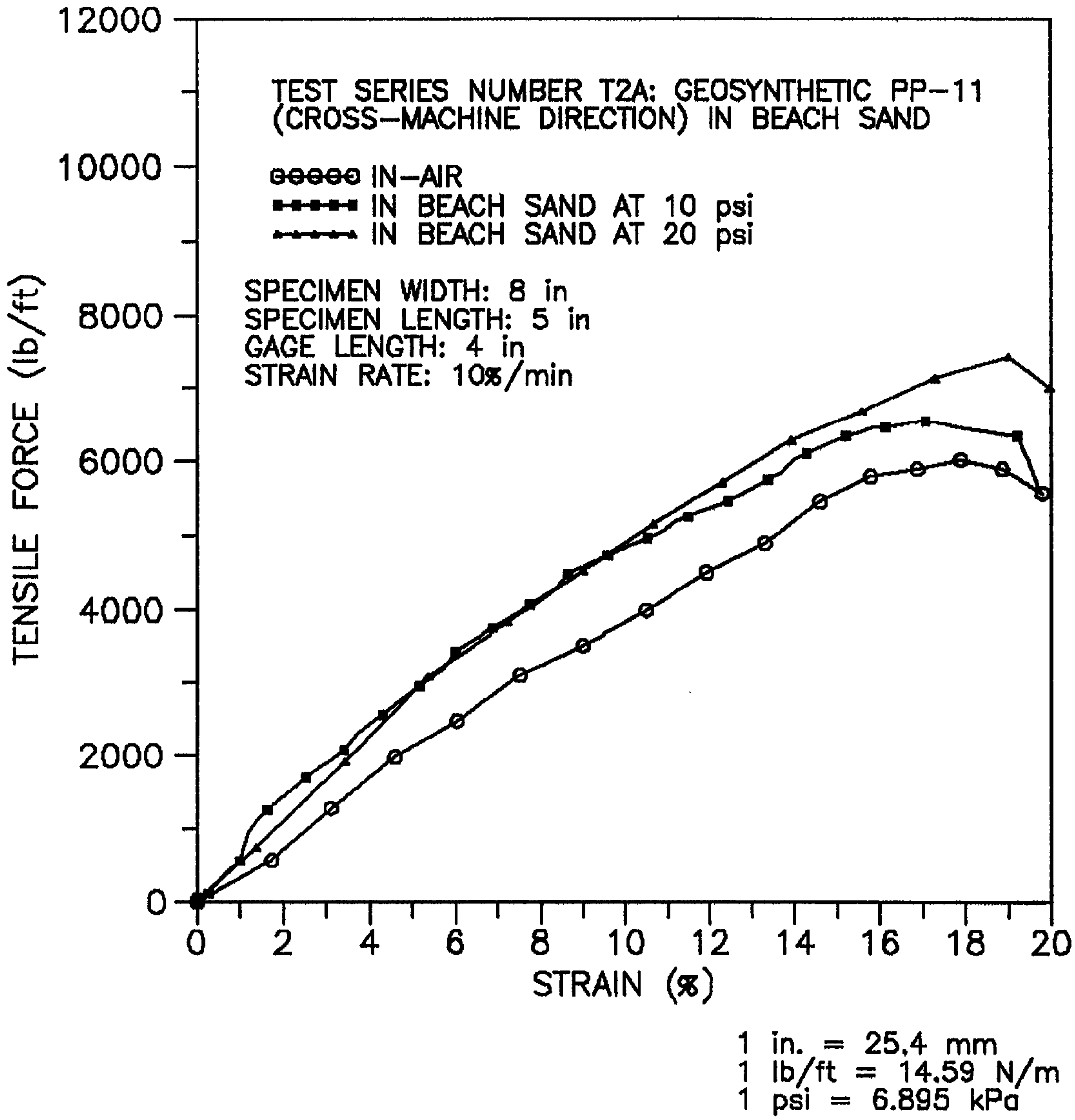


Figure A-2. Tensile force versus strain response for Geosynthetic PP-11 confined in beach sand.

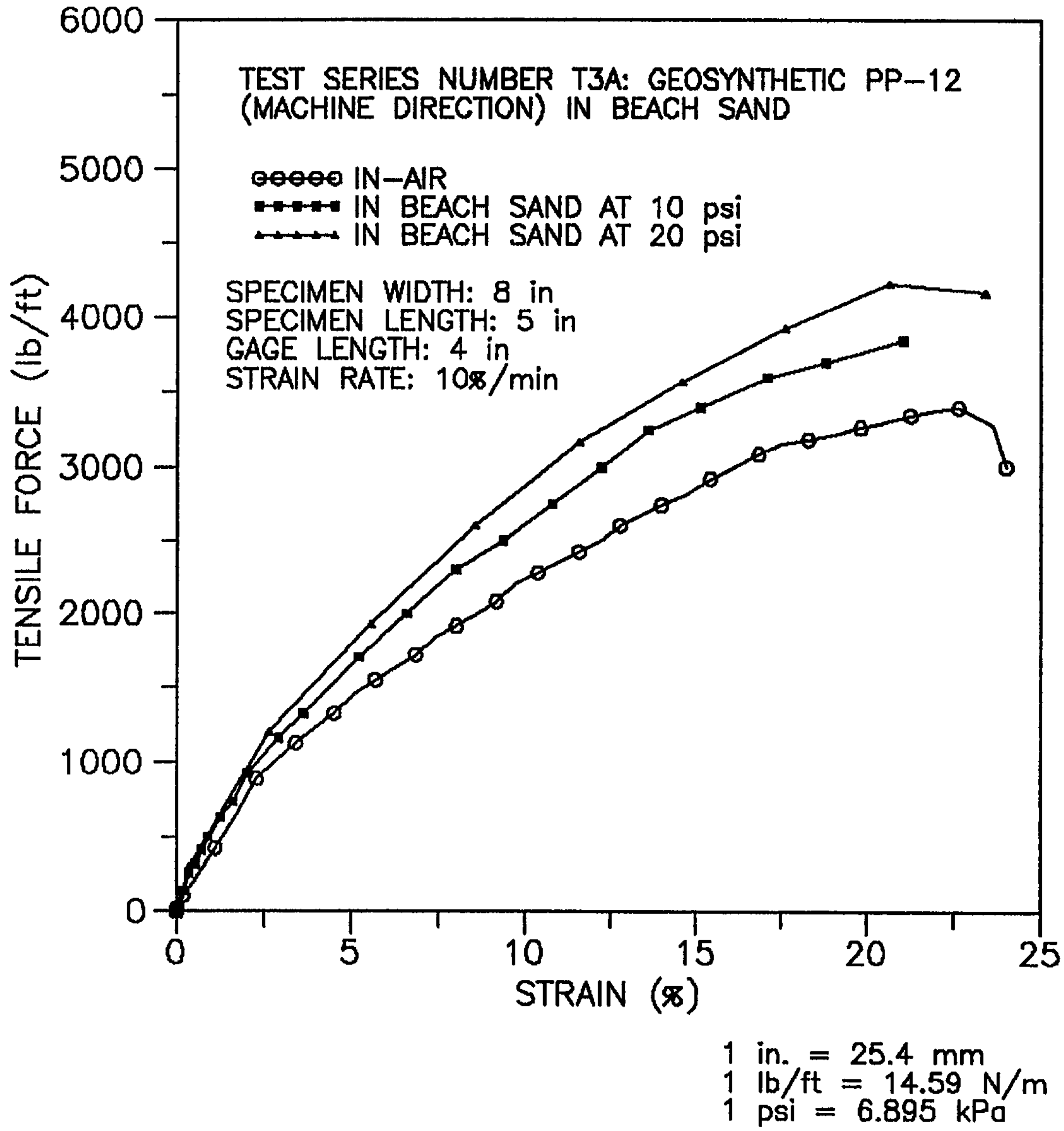


Figure A-3. **Tensile force versus strain response for Geosynthetic PP-12 confined in beach sand.**

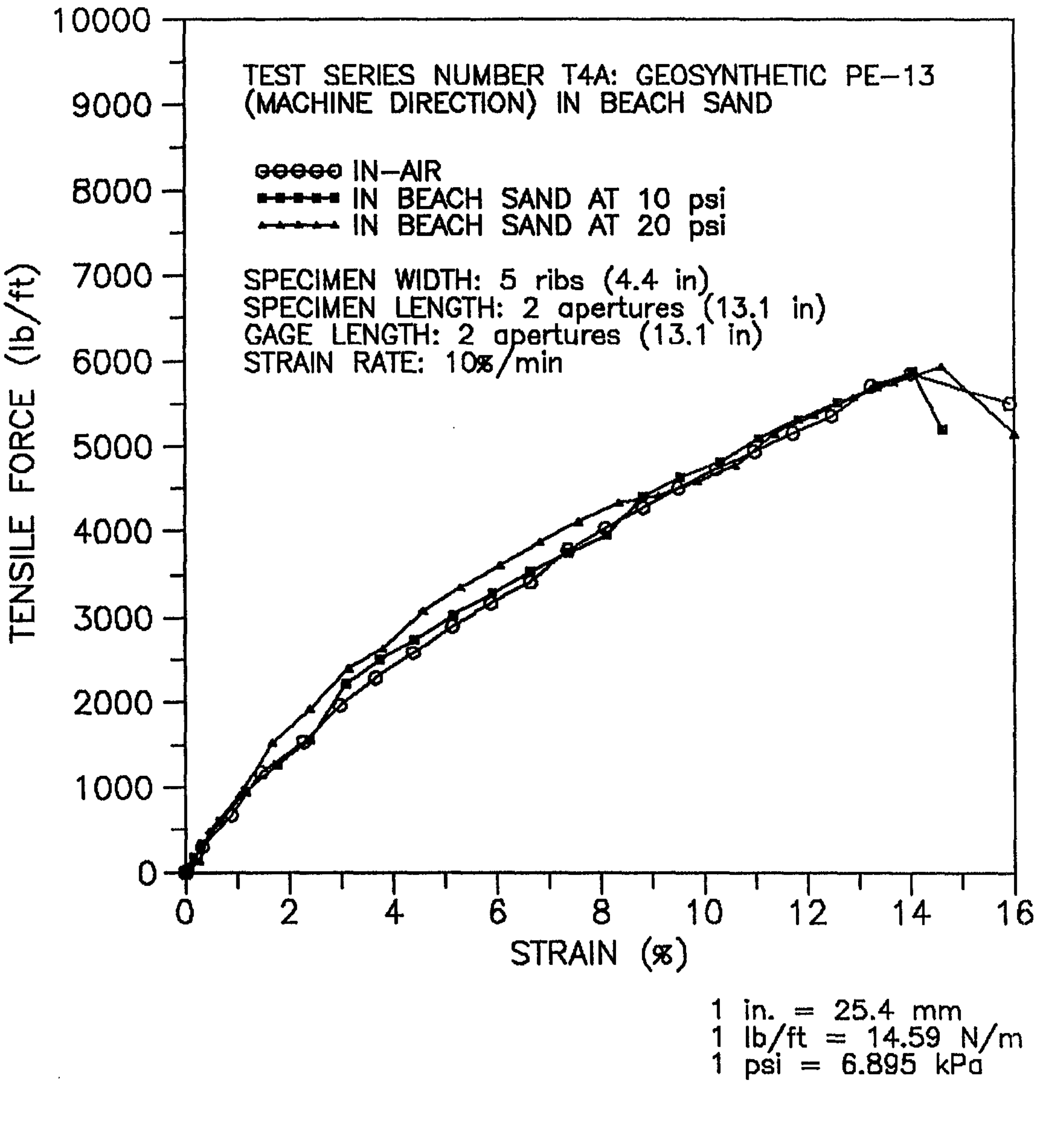


Figure A-4. Tensile force versus strain response for Geosynthetic PE-13 confined in beach sand.

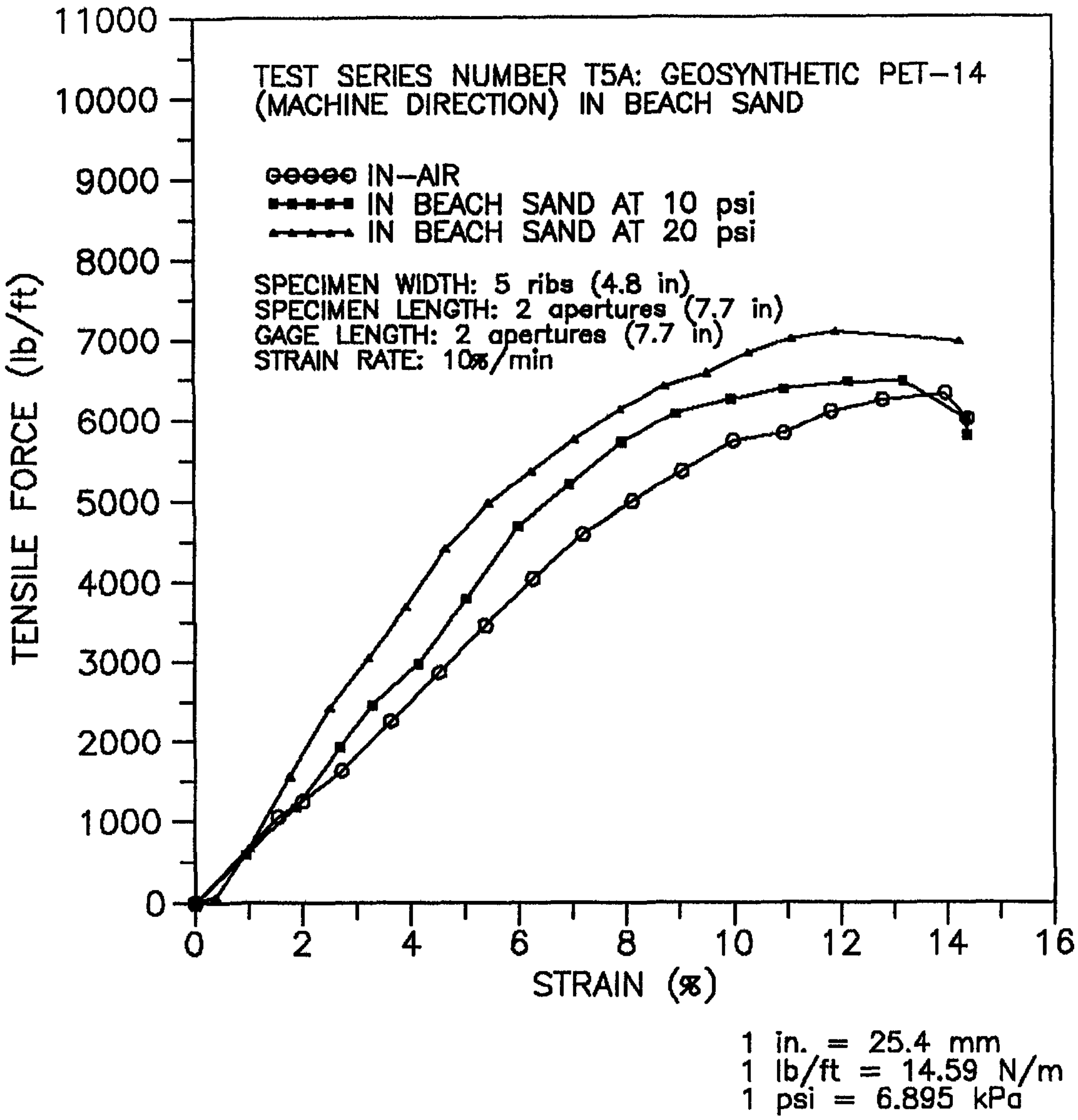


Figure A-5. Tensile force versus strain response for Geosynthetic PET-14 confined in beach sand.

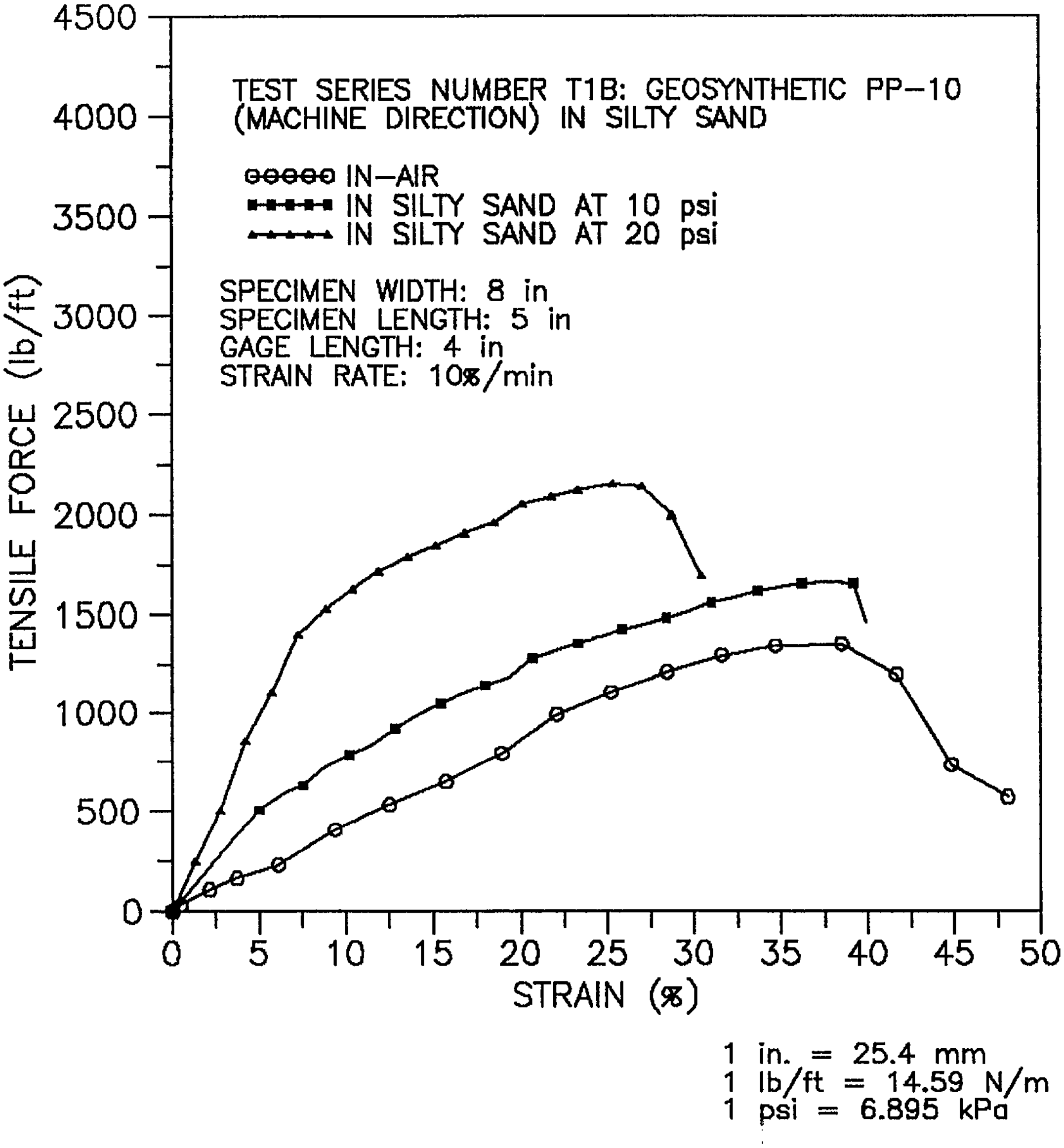


Figure A-6. Tensile force versus strain response for Geosynthetic PP-10 confined in silty sand.

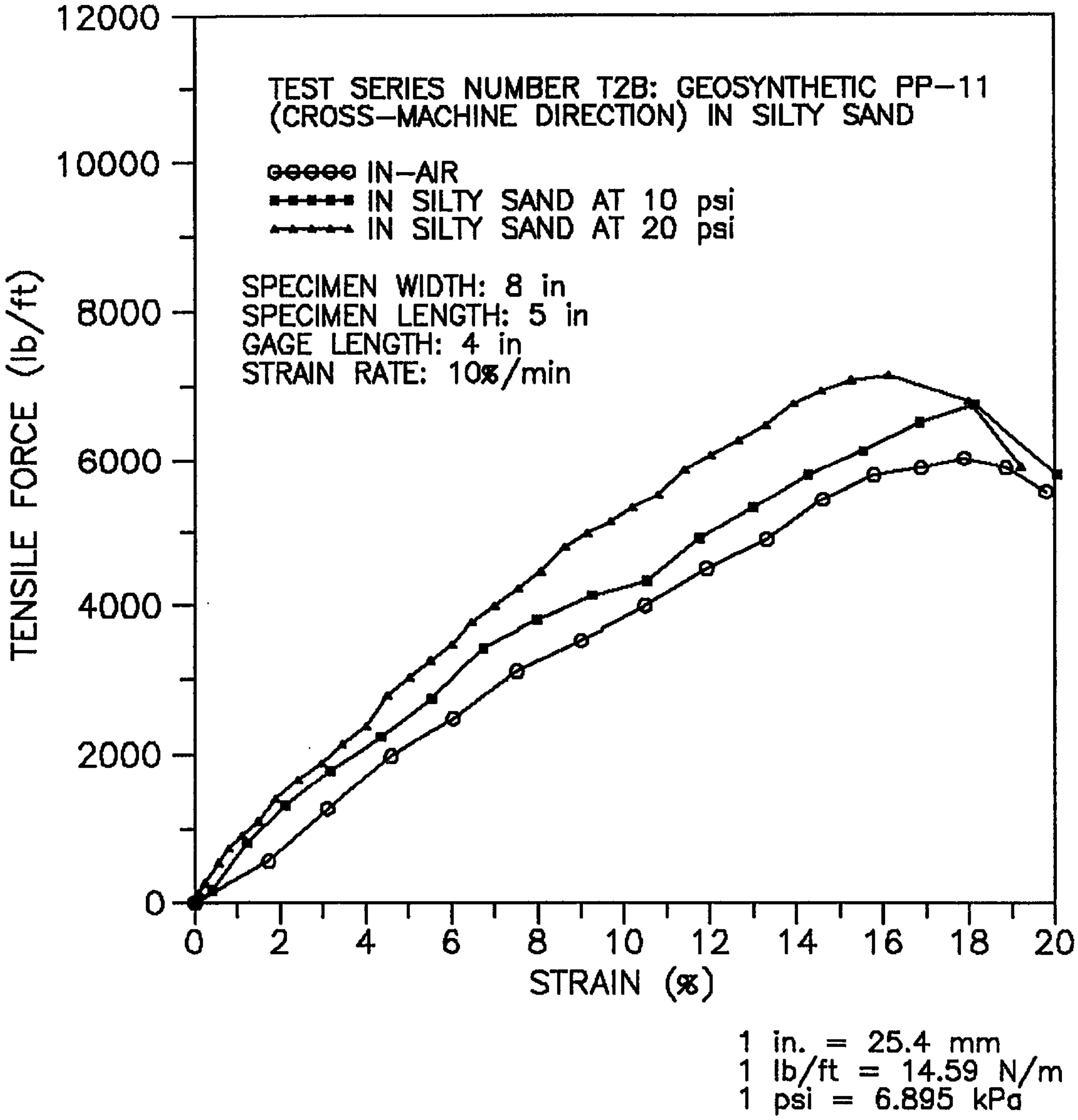


Figure A-7. Tensile force versus strain response for Geosynthetic PP-11 confined in silty sand.

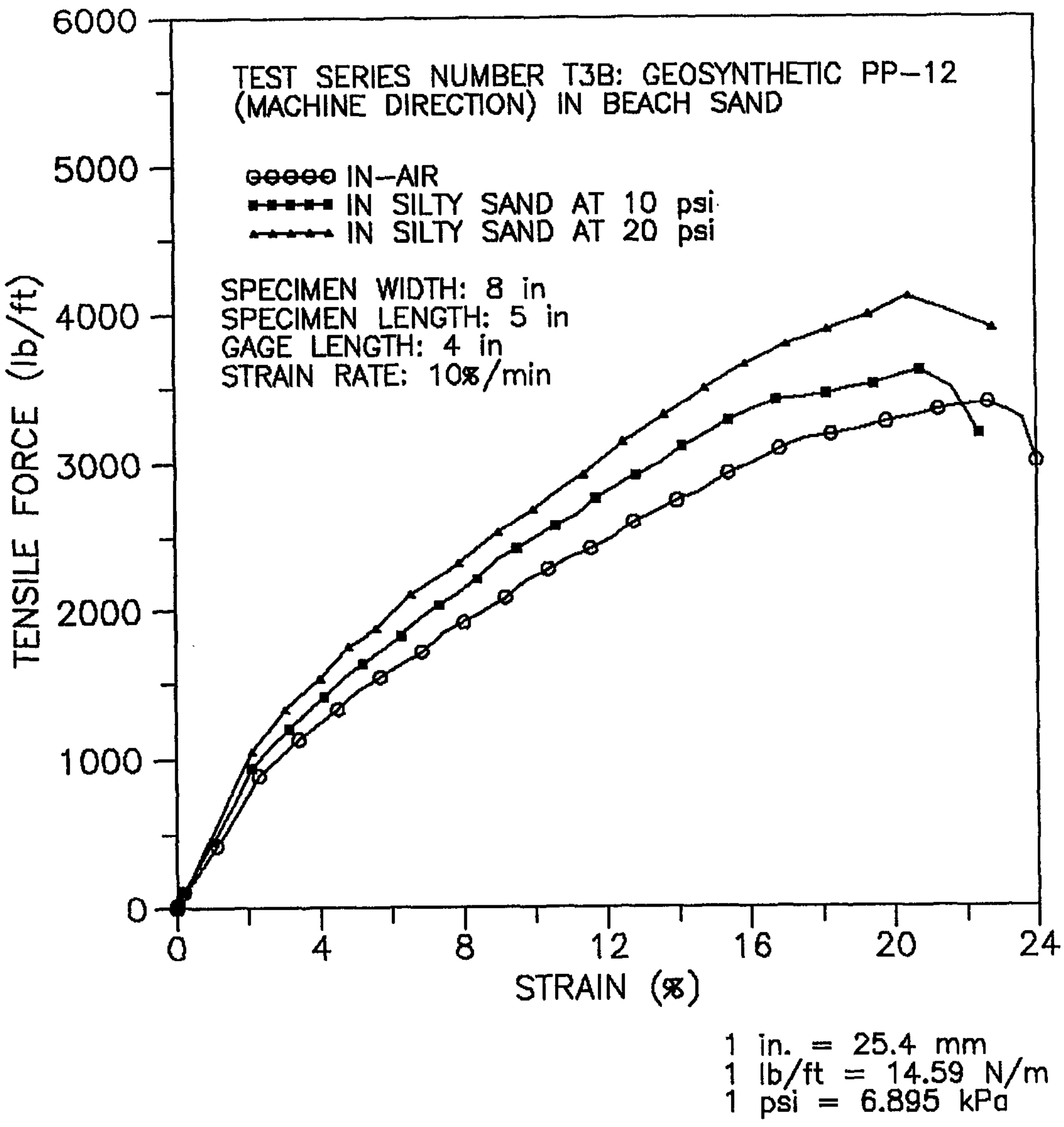


Figure A-8. Tensile force versus strain response for Geosynthetic PP-12 confined in silty sand.

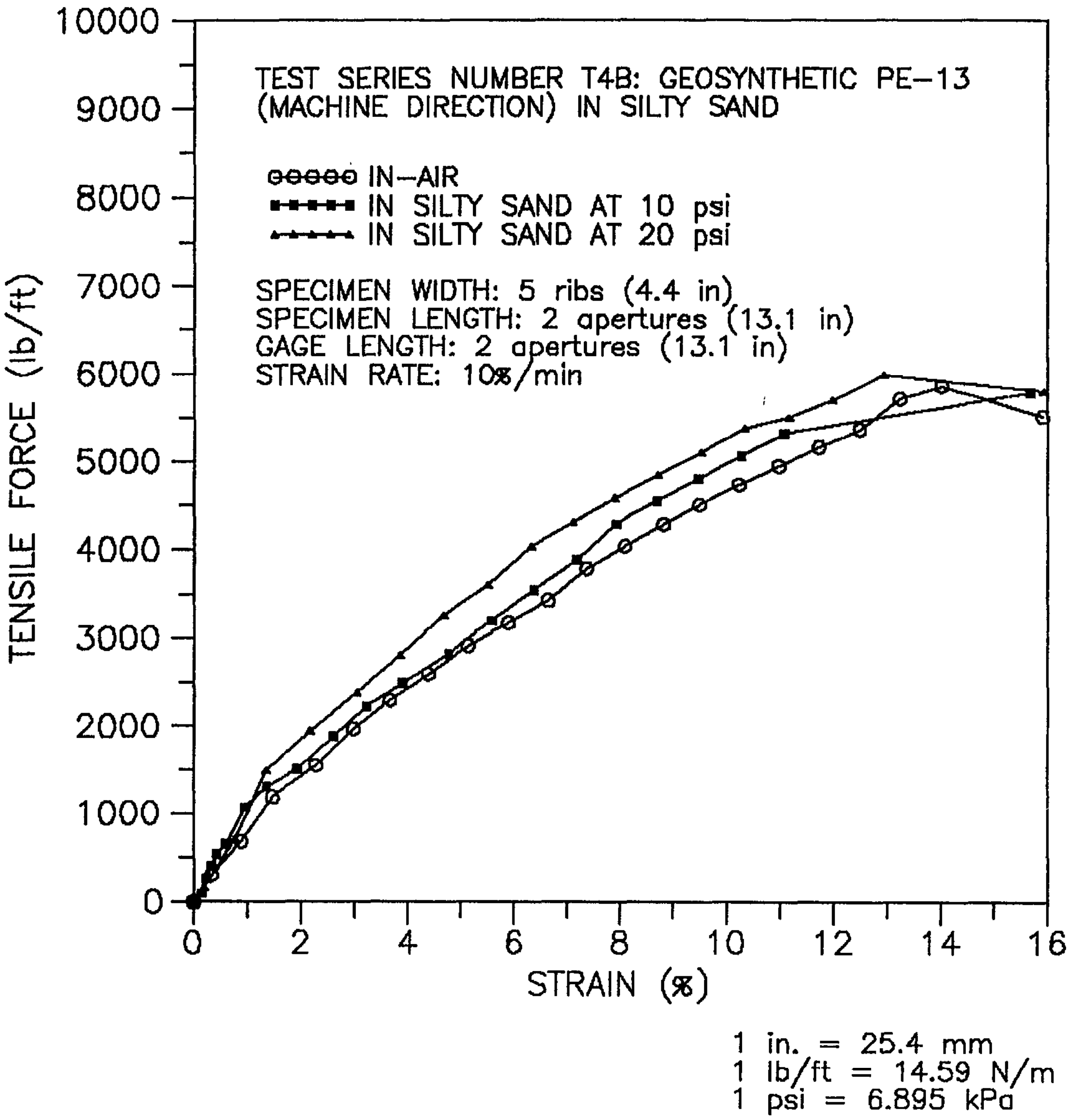
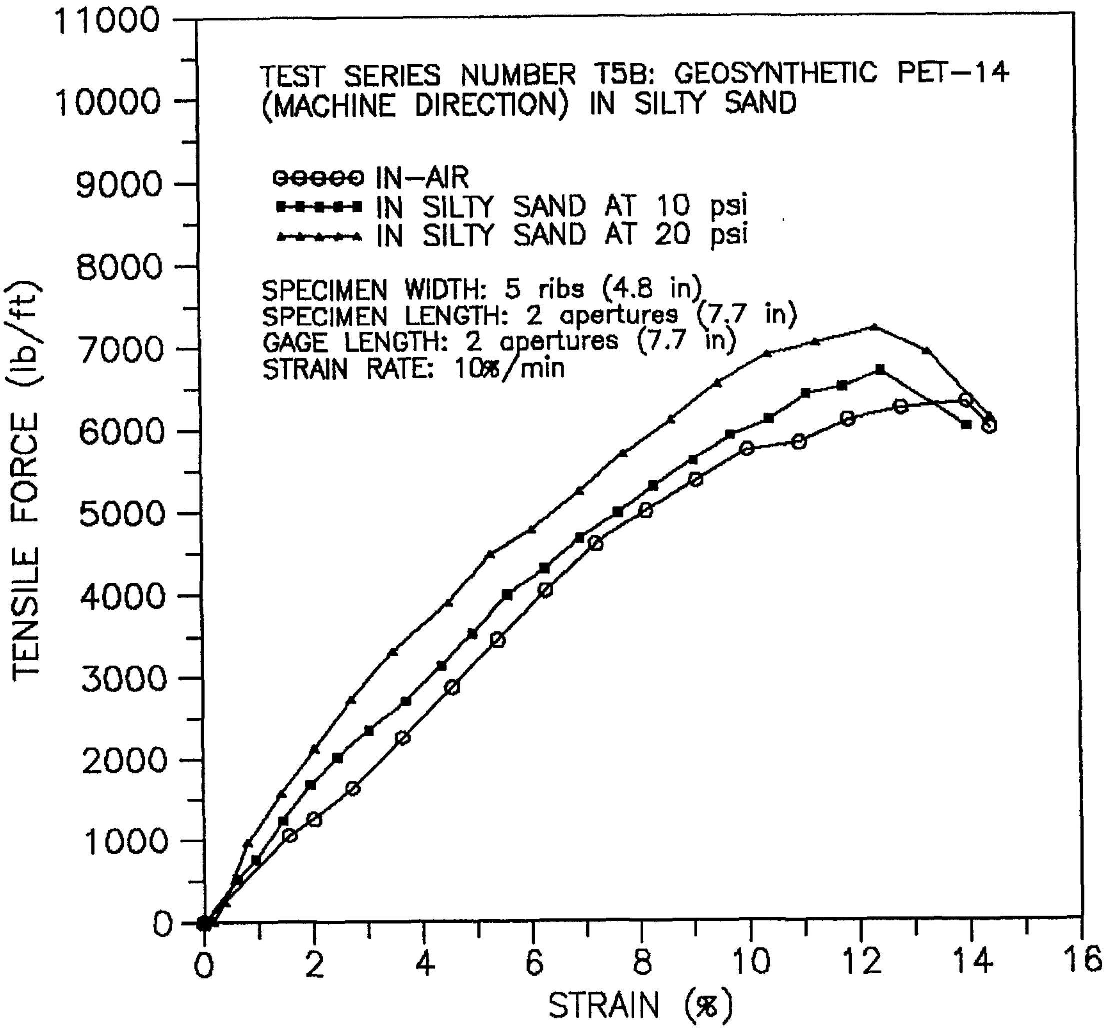


Figure A-9. Tensile force versus strain response for Geosynthetic PE-13 confined in silty sand.



1 in. = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.895 kPa

Figure A-10. Tensile force versus strain response for Geosynthetic PET-14 confined in silty sand.

APPENDIX B
CONFINED CREEP TEST RESULTS

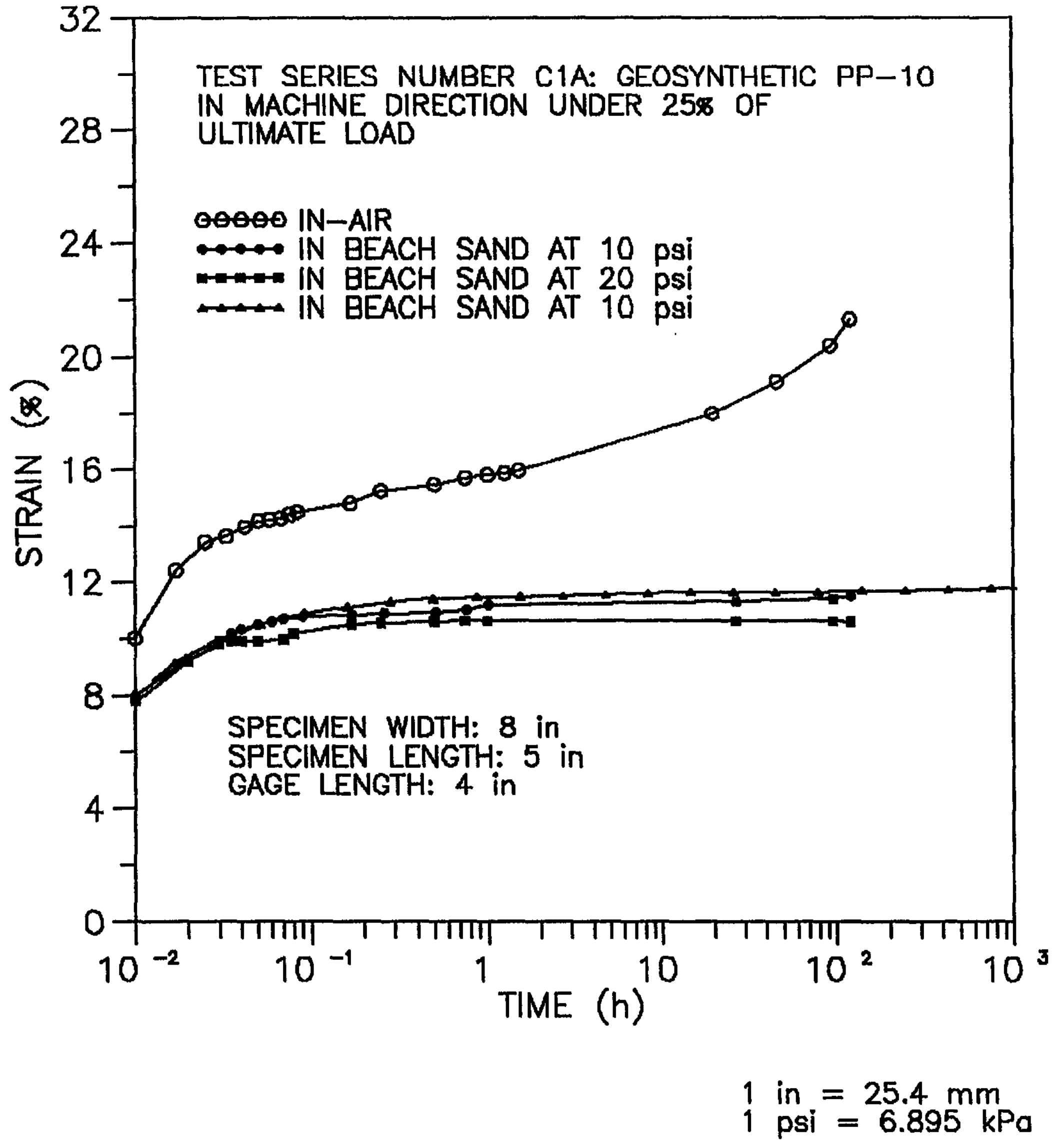


Figure B-1. Strain versus time response for Geosynthetic PP-10 confined in beach sand.

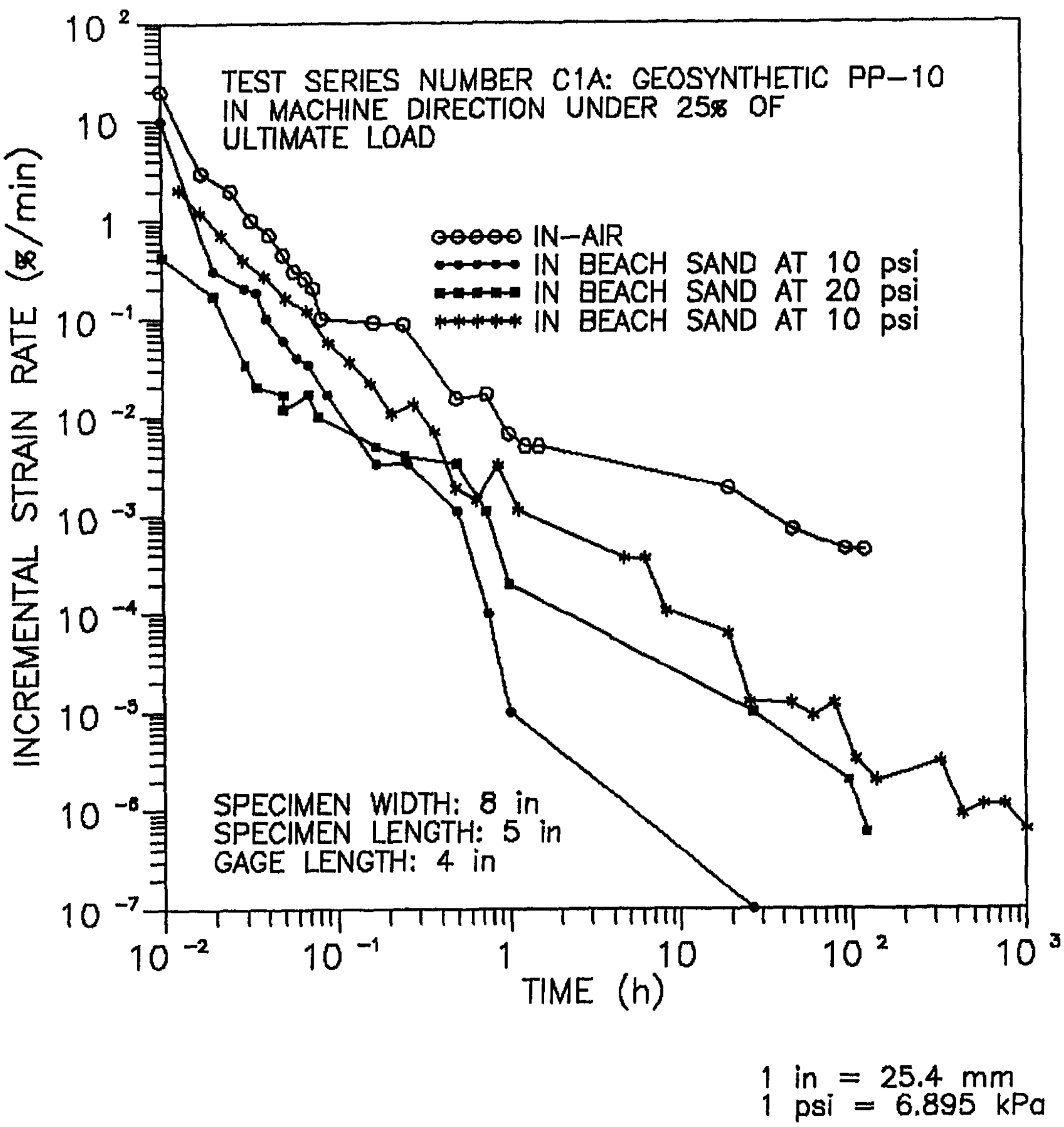


Figure B-2. Incremental strain rate versus time response for Geosynthetic PP-10 confined in beach sand.

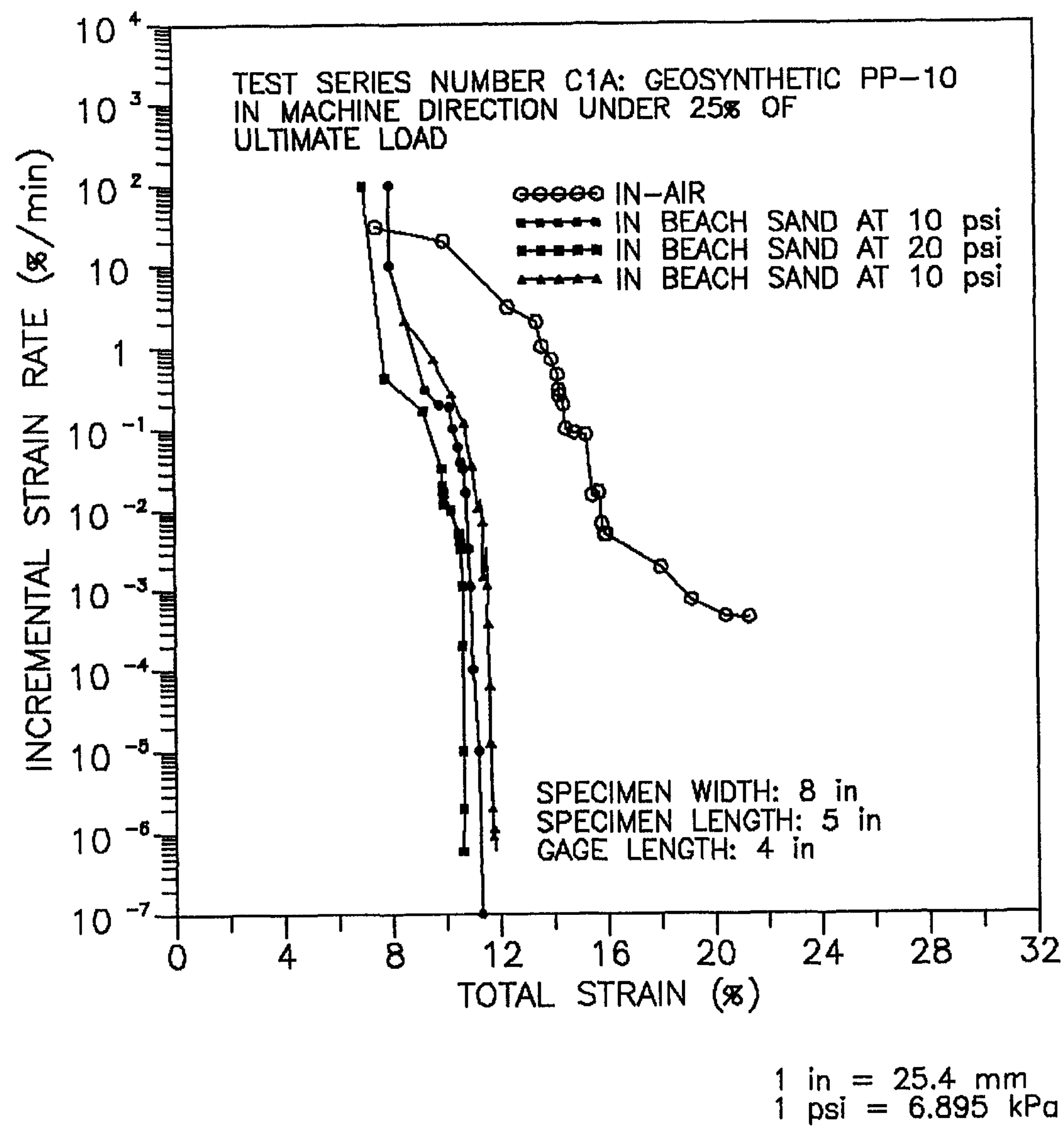
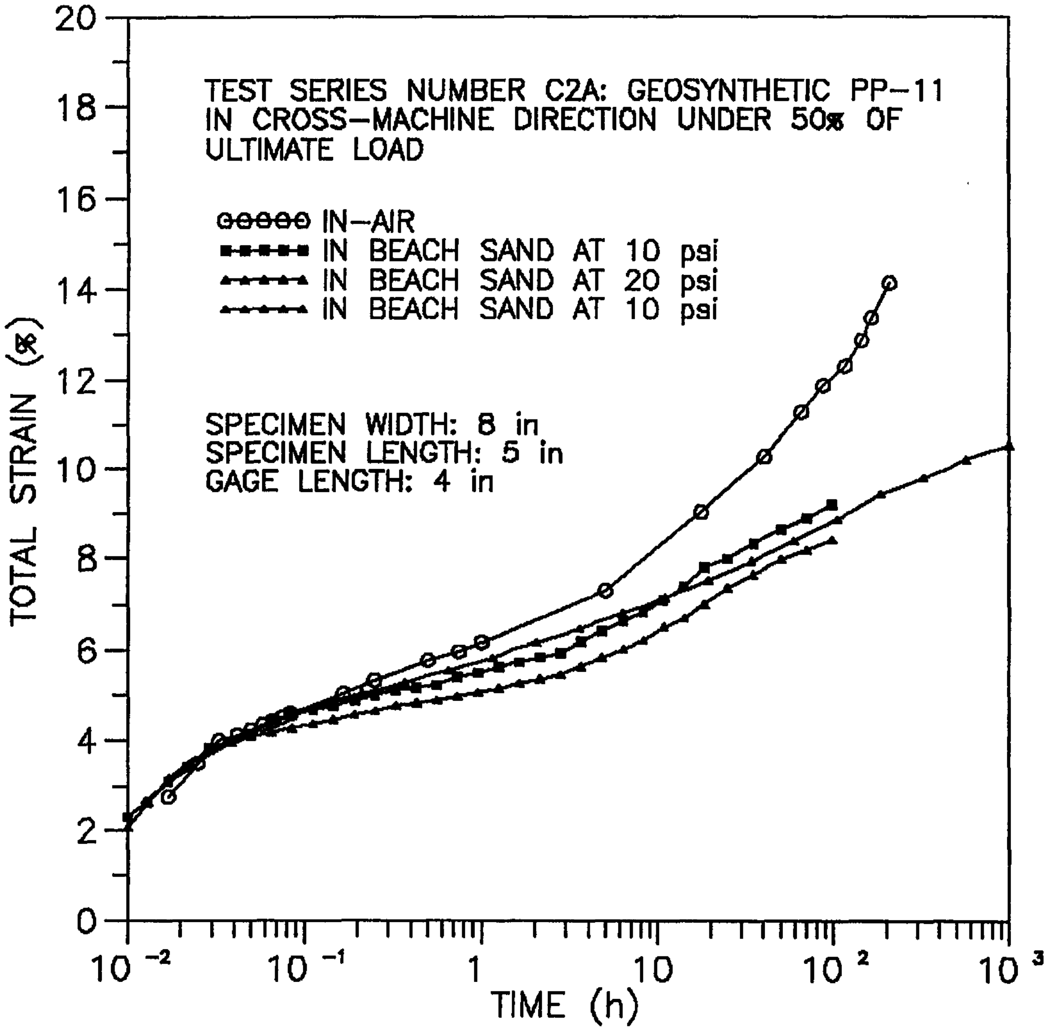


Figure B-3. Incremental strain rate versus strain response for Geosynthetic PP-10 confined in beach sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-4. Strain versus time response for Geosynthetic PP-11 confined in beach sand.

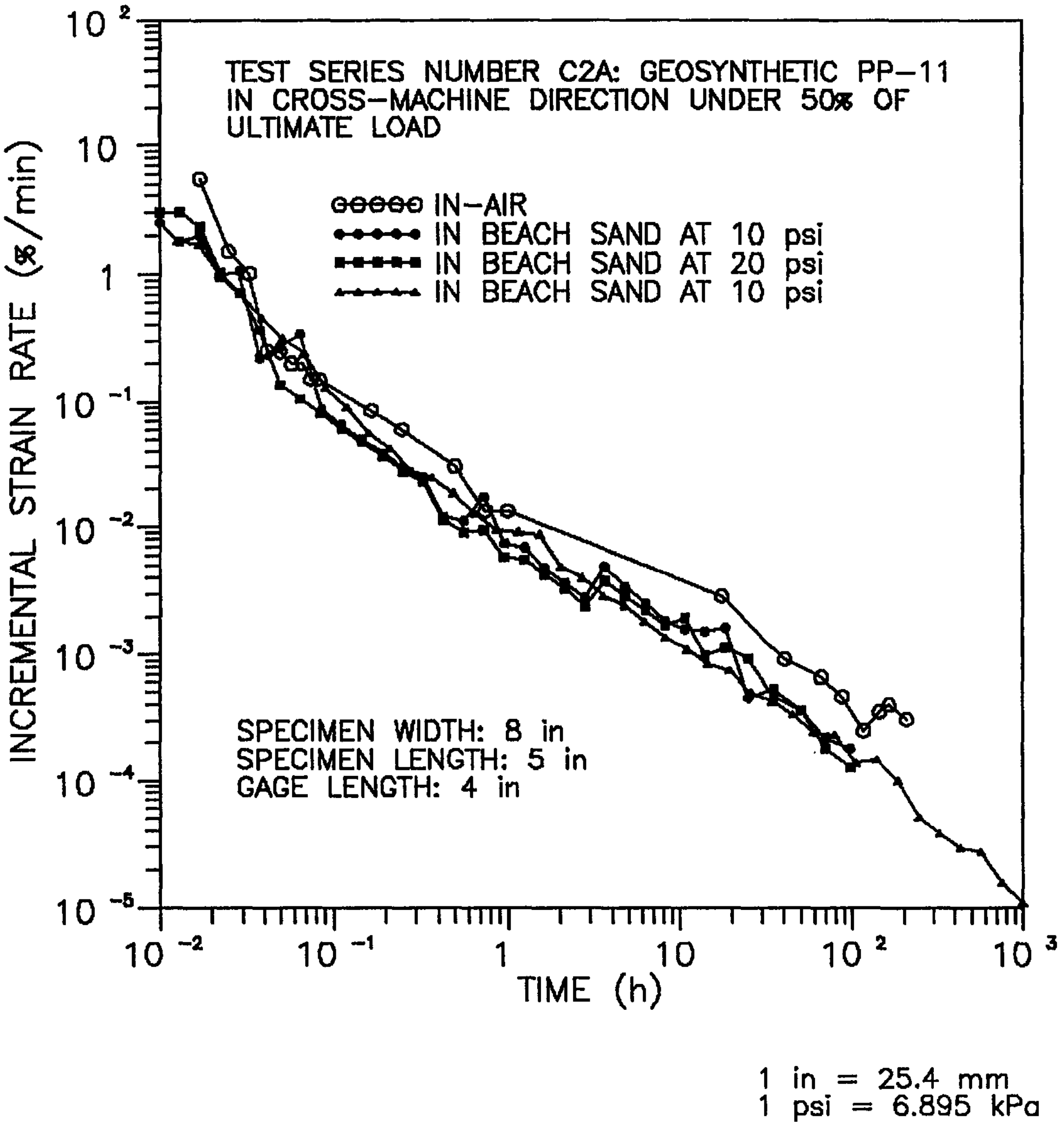


Figure B-5. **Incremental strain rate versus time response for Geosynthetic PP-11 confined in beach sand.**

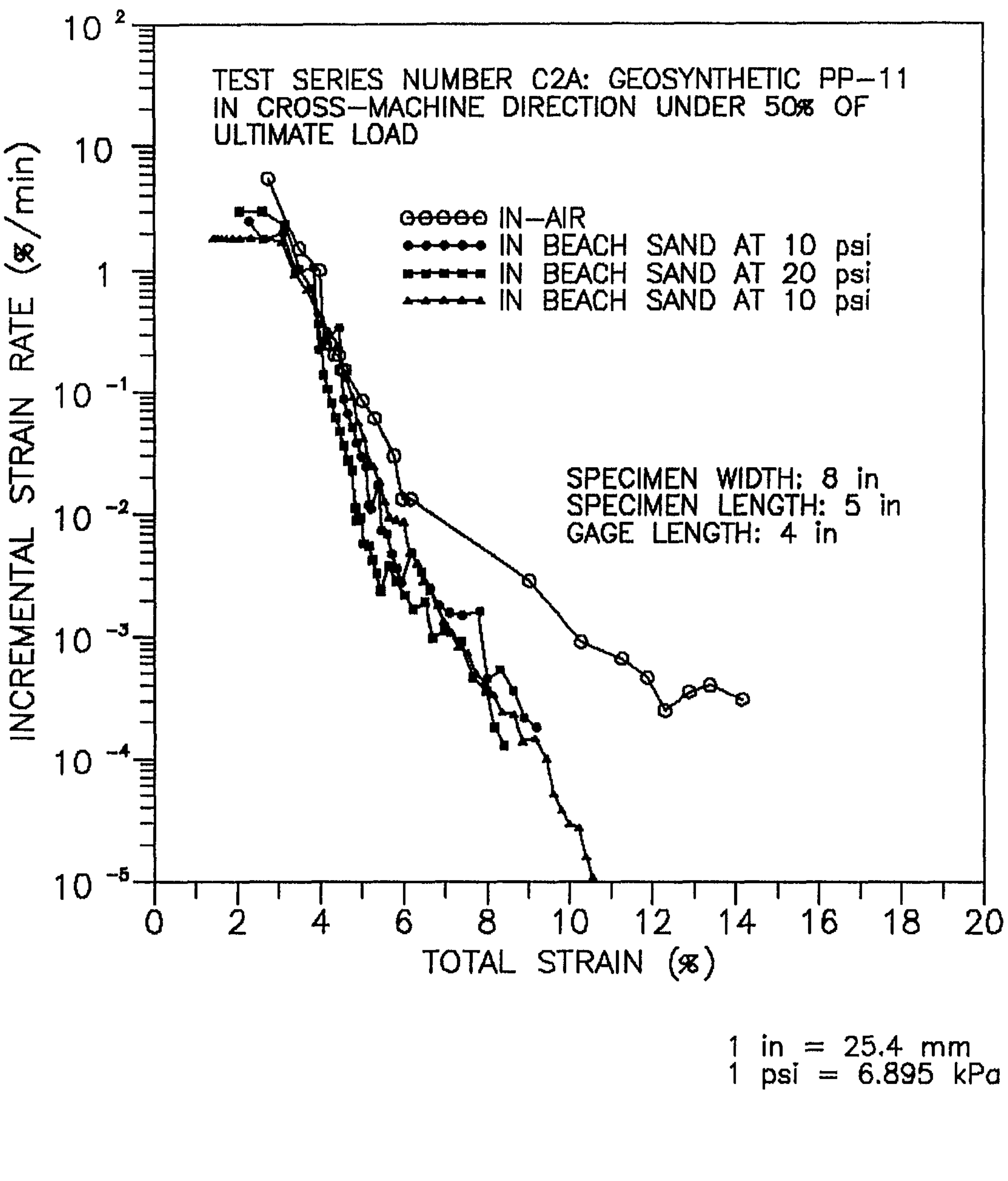
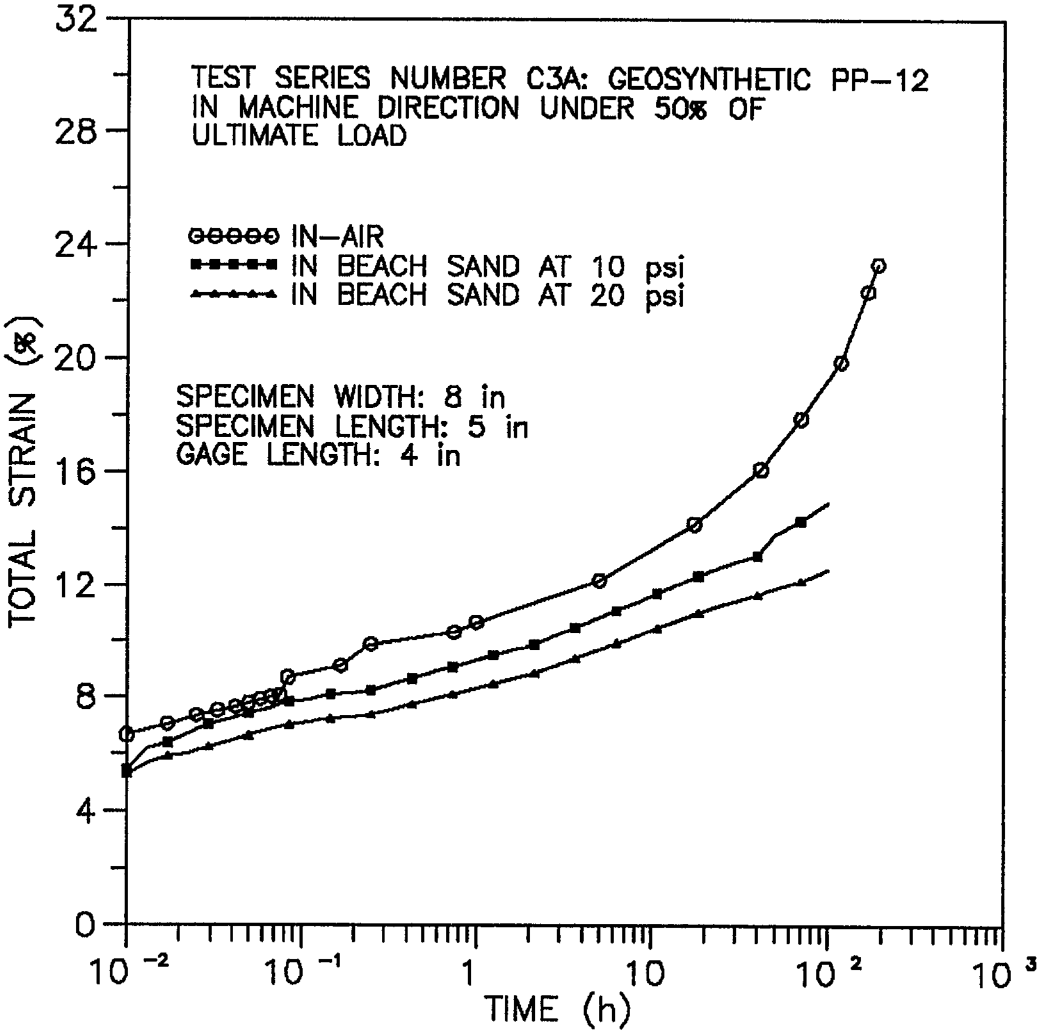
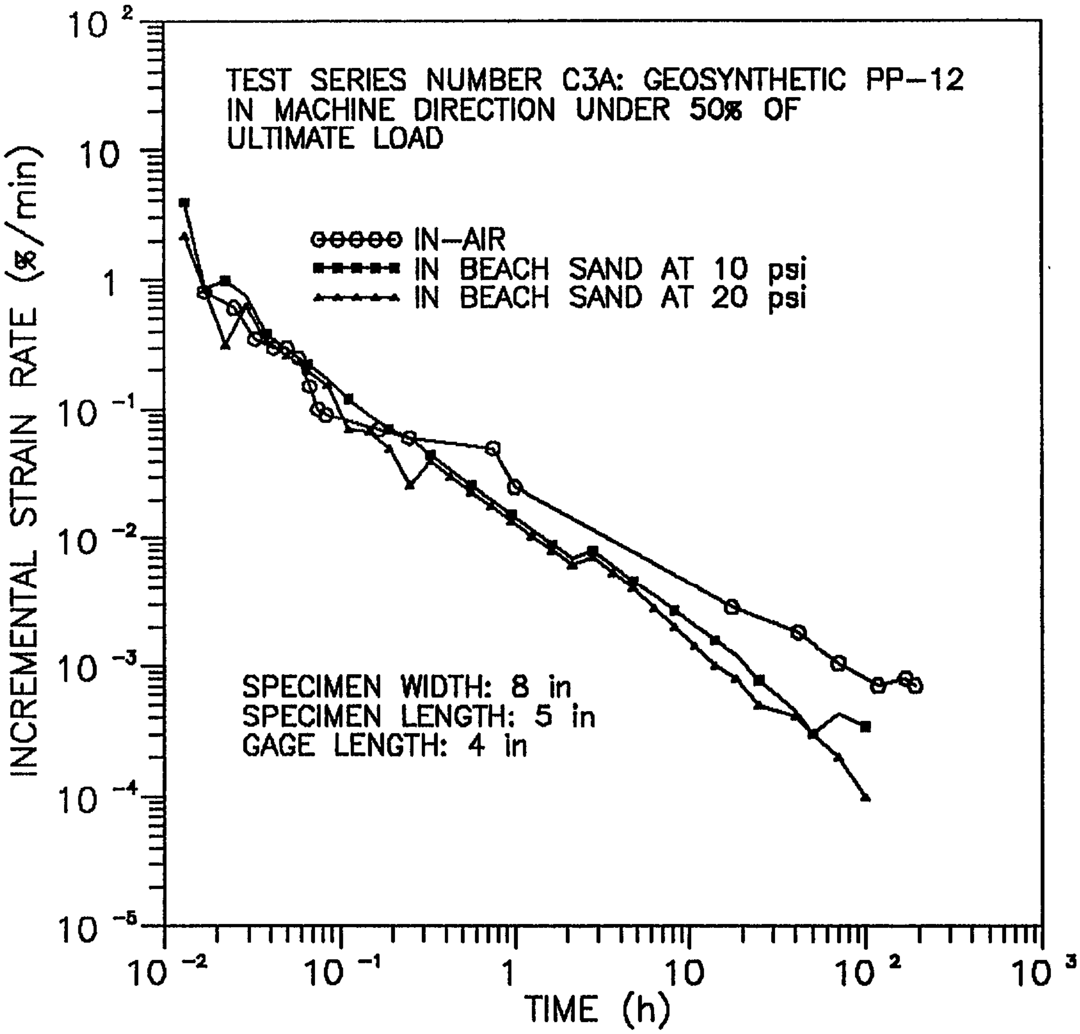


Figure B-6. Incremental strain rate versus strain response for Geosynthetic PP-11 confined in beach sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-7. Strain versus time response for Geosynthetic PP-12 confined in beach sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-8. Incremental strain rate versus time response for Geosynthetic PP-12 confined in beach sand.

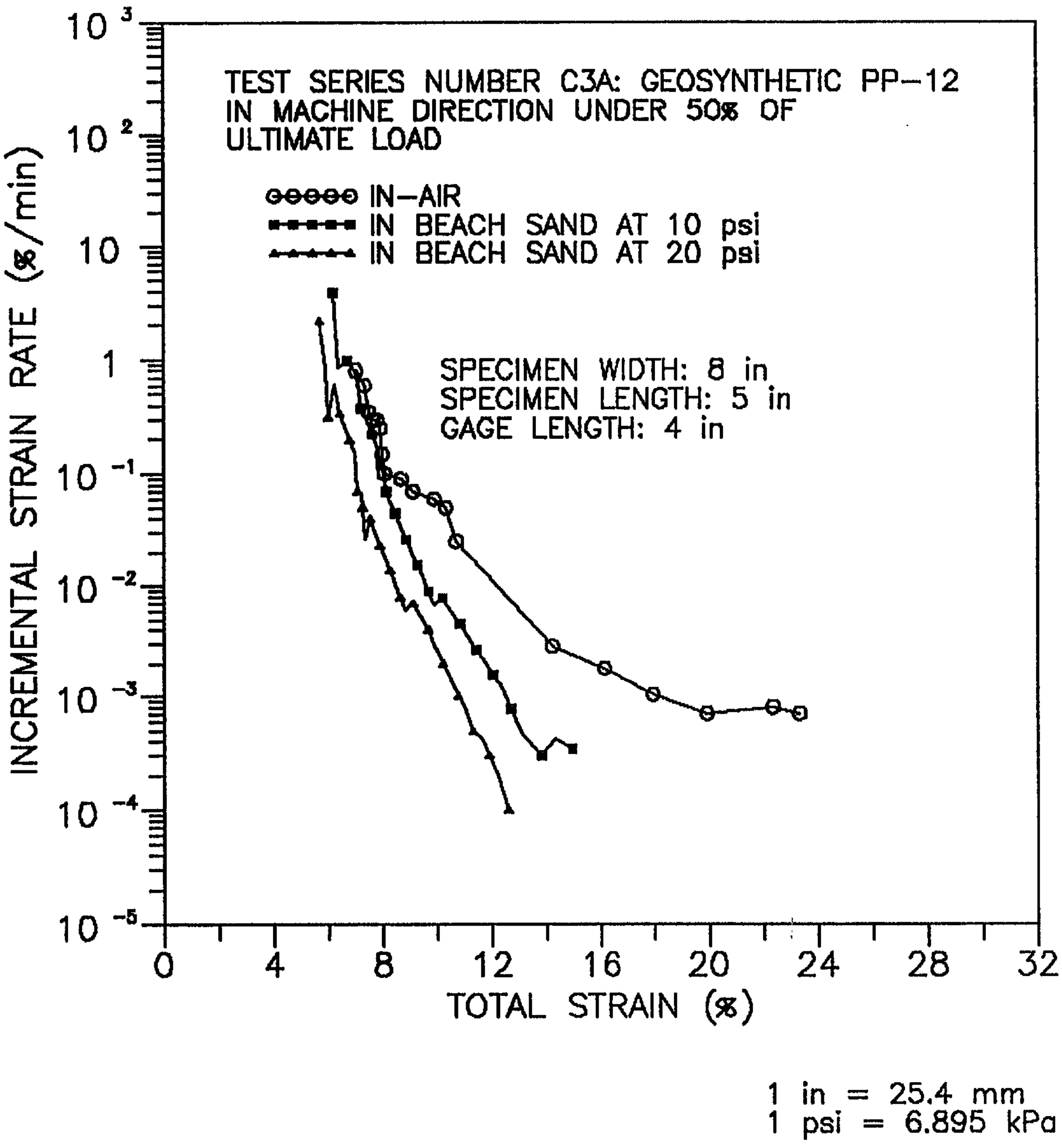
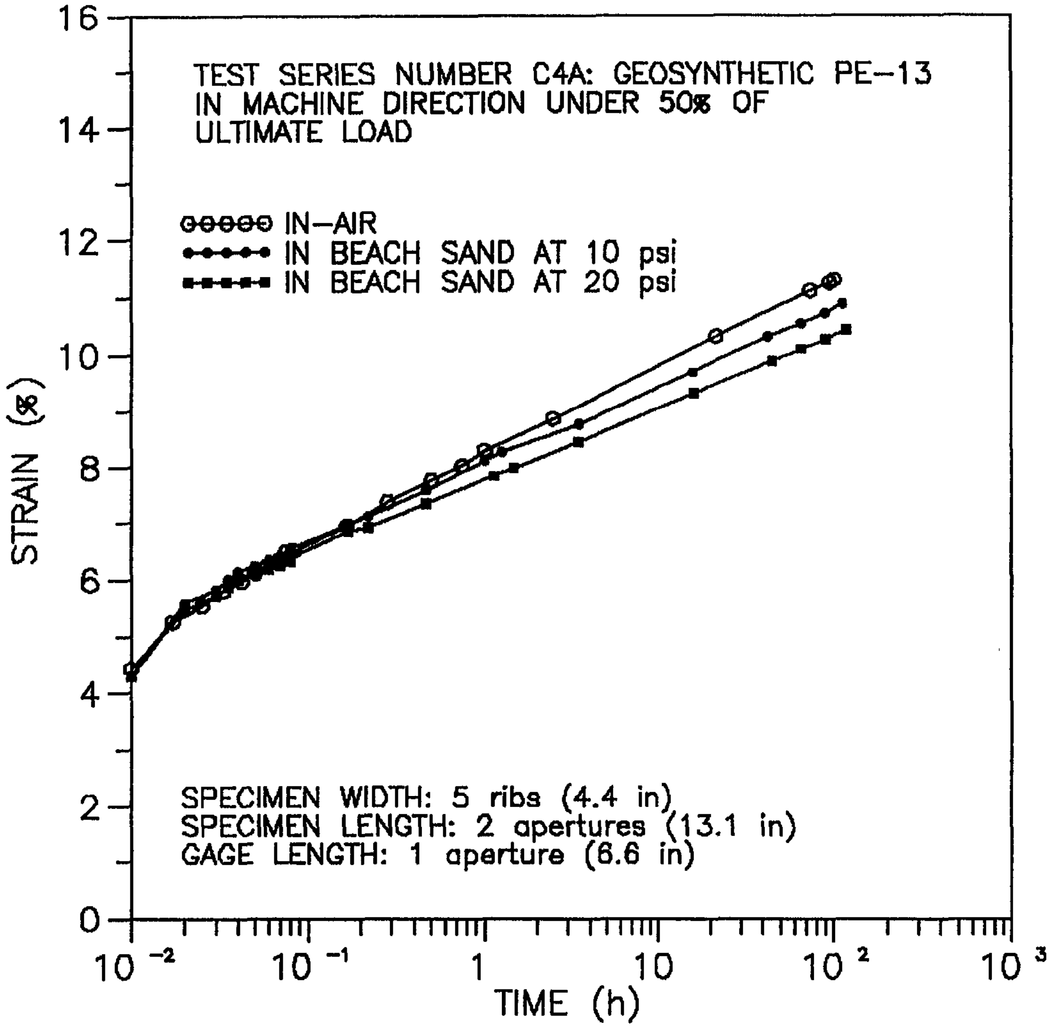
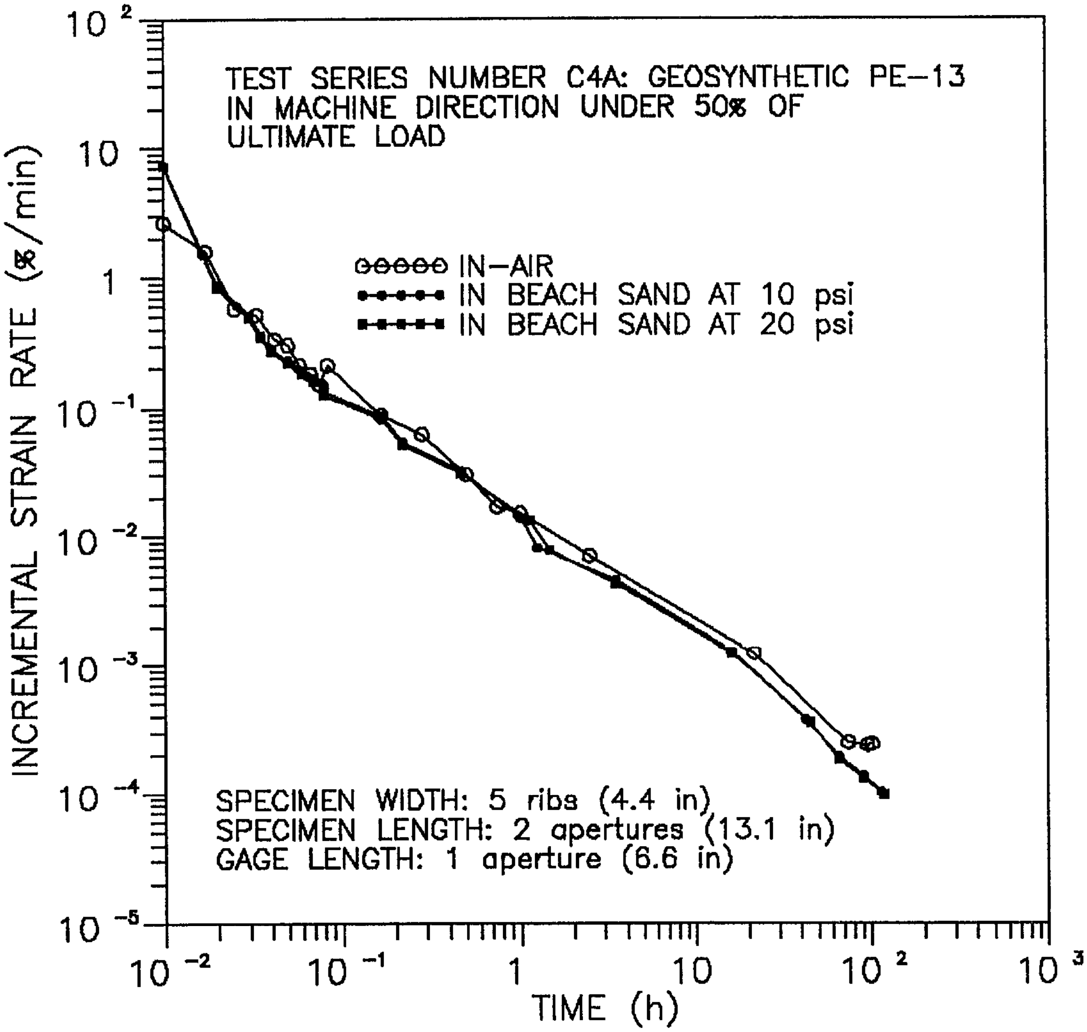


Figure B-9. **Incremental strain rate versus strain response for Geosynthetic PP-12 confined in beach sand.**



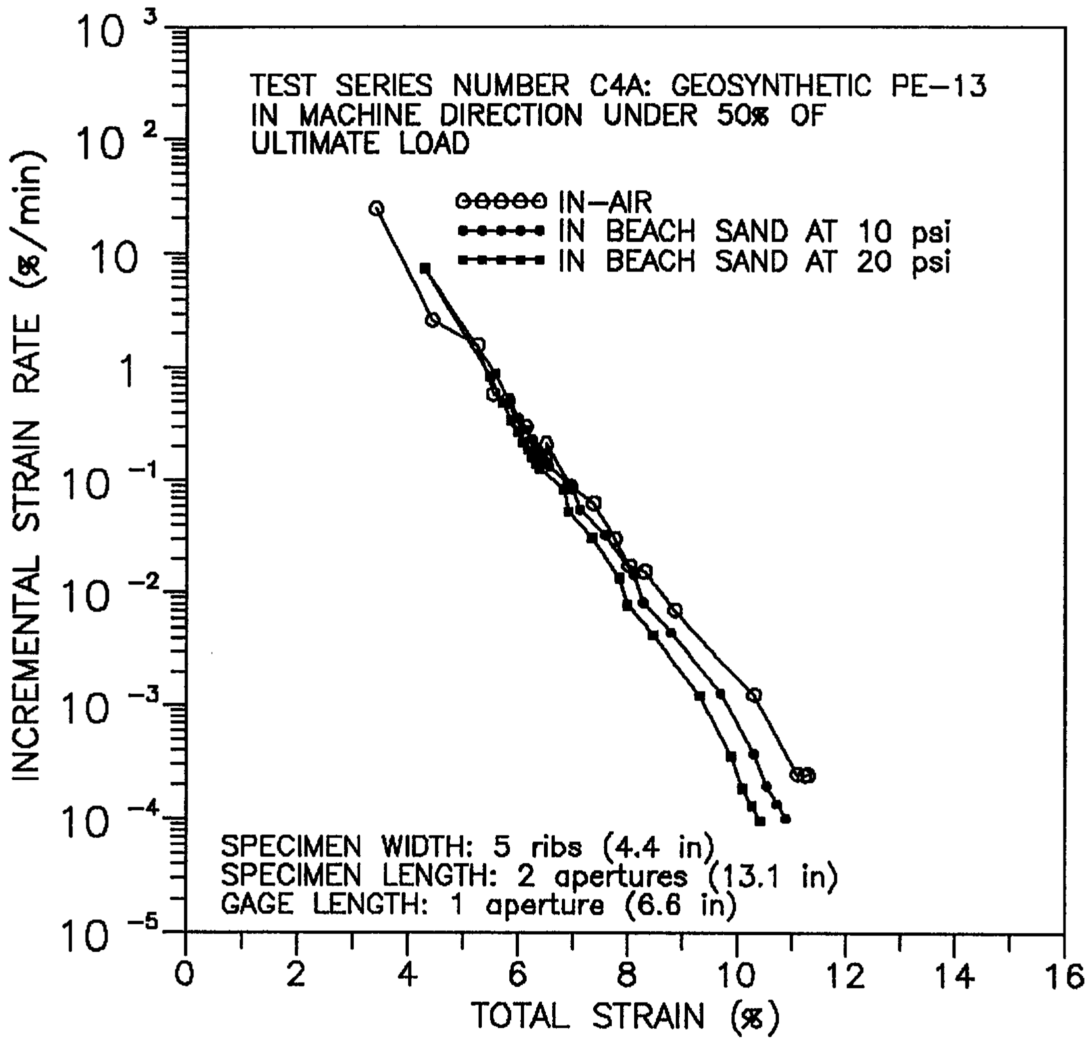
1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-10. Strain versus time response for Geosynthetic PP-13 confined in beach sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-11. Incremental strain rate versus time response for Geosynthetic PE-13 confined in beach sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-12. Incremental strain rate versus strain response for Geosynthetic PE-13 confined in beach sand.

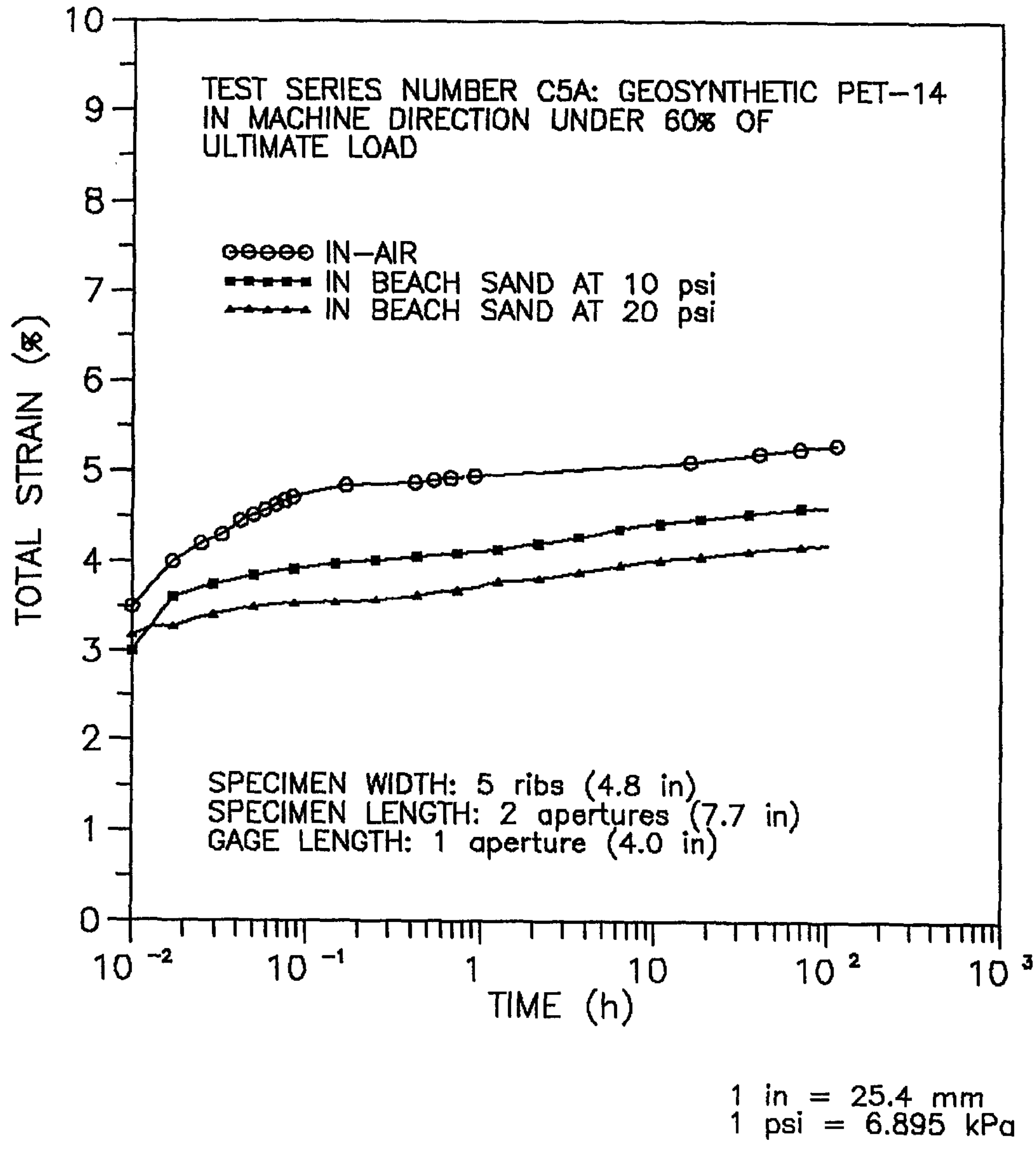
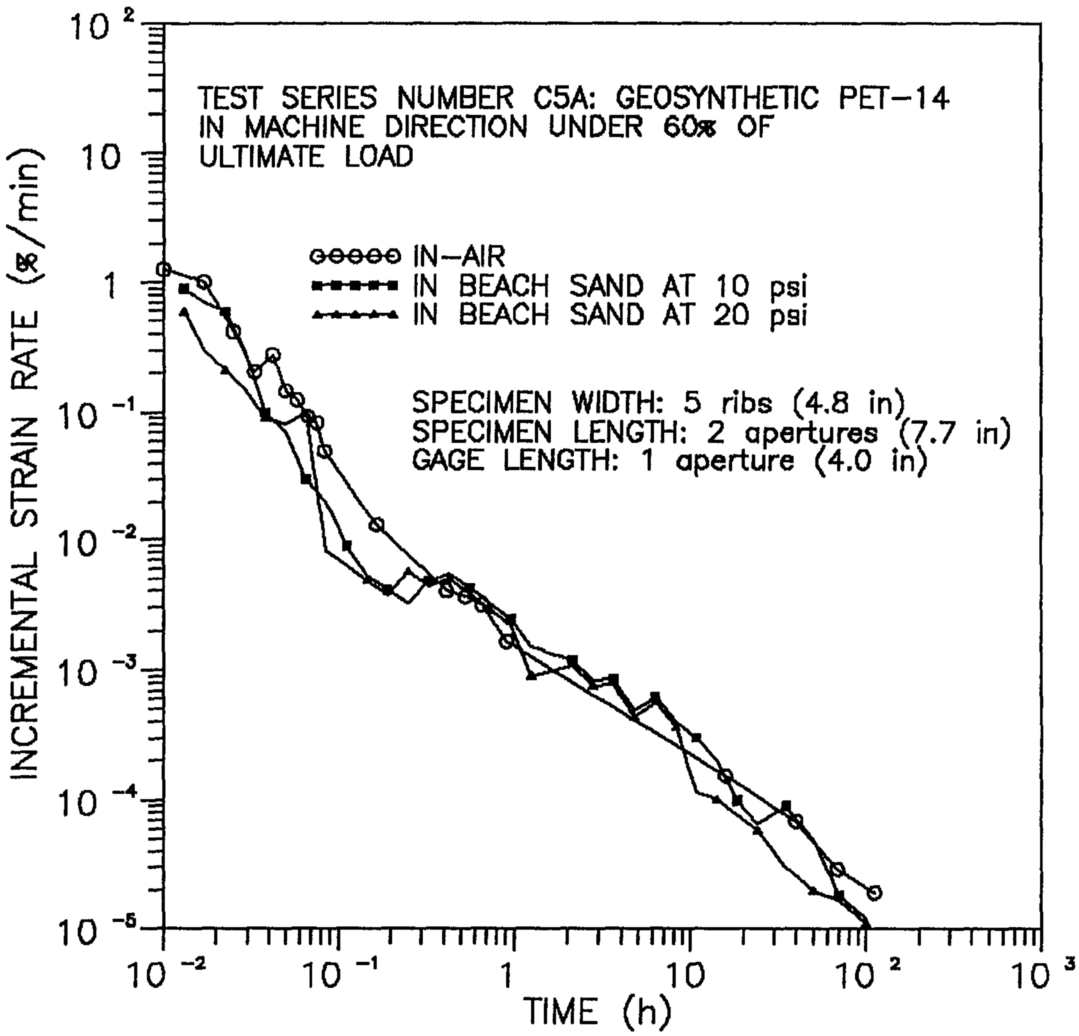


Figure B-13. Strain versus time response for Geosynthetic PET-14 confined in beach sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-14. Incremental strain rate versus time response for Geosynthetic PET-14 confined in beach sand.

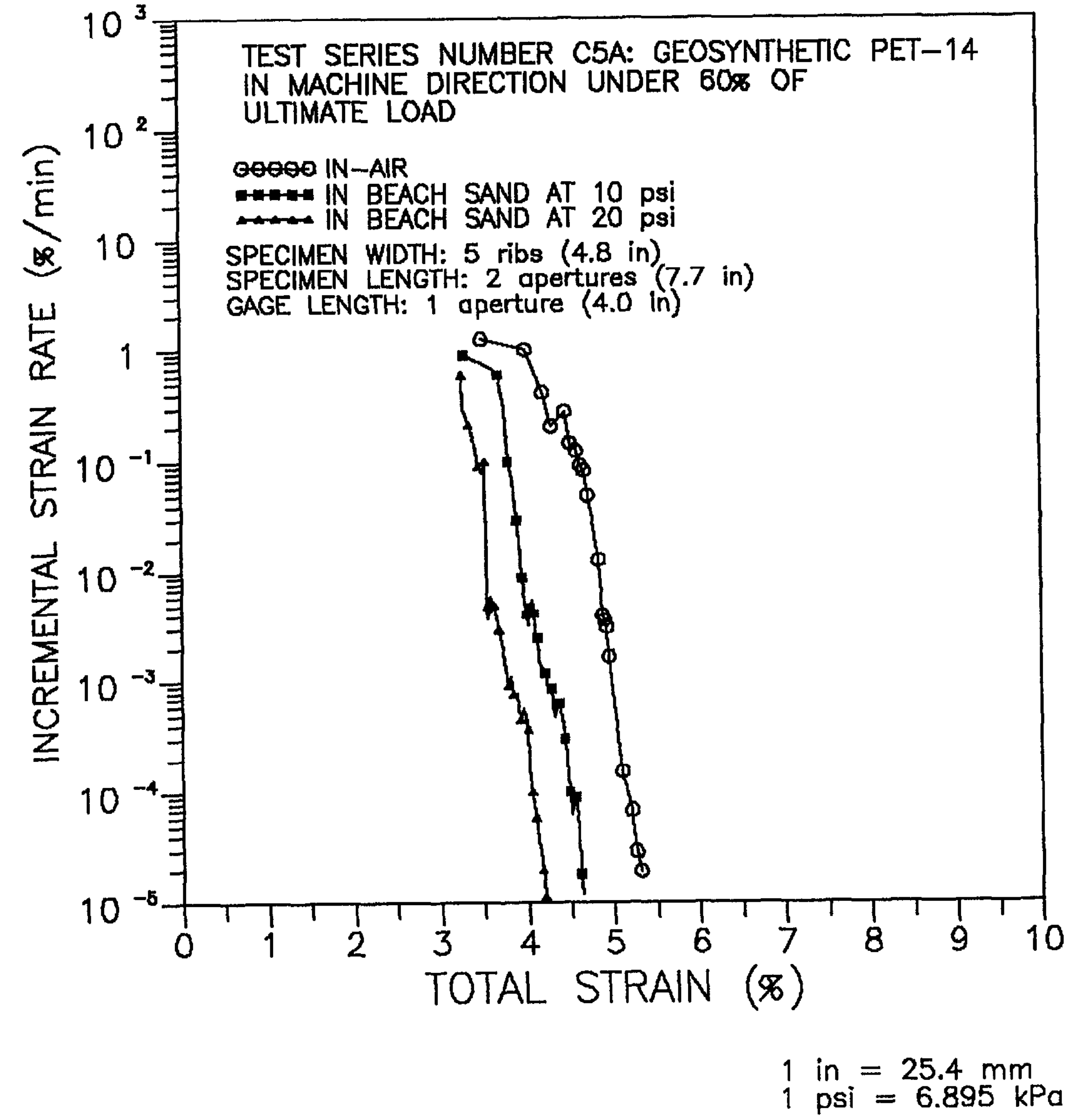


Figure B-15. Incremental strain rate versus strain response for Geosynthetic PET-14 confined in beach sand.

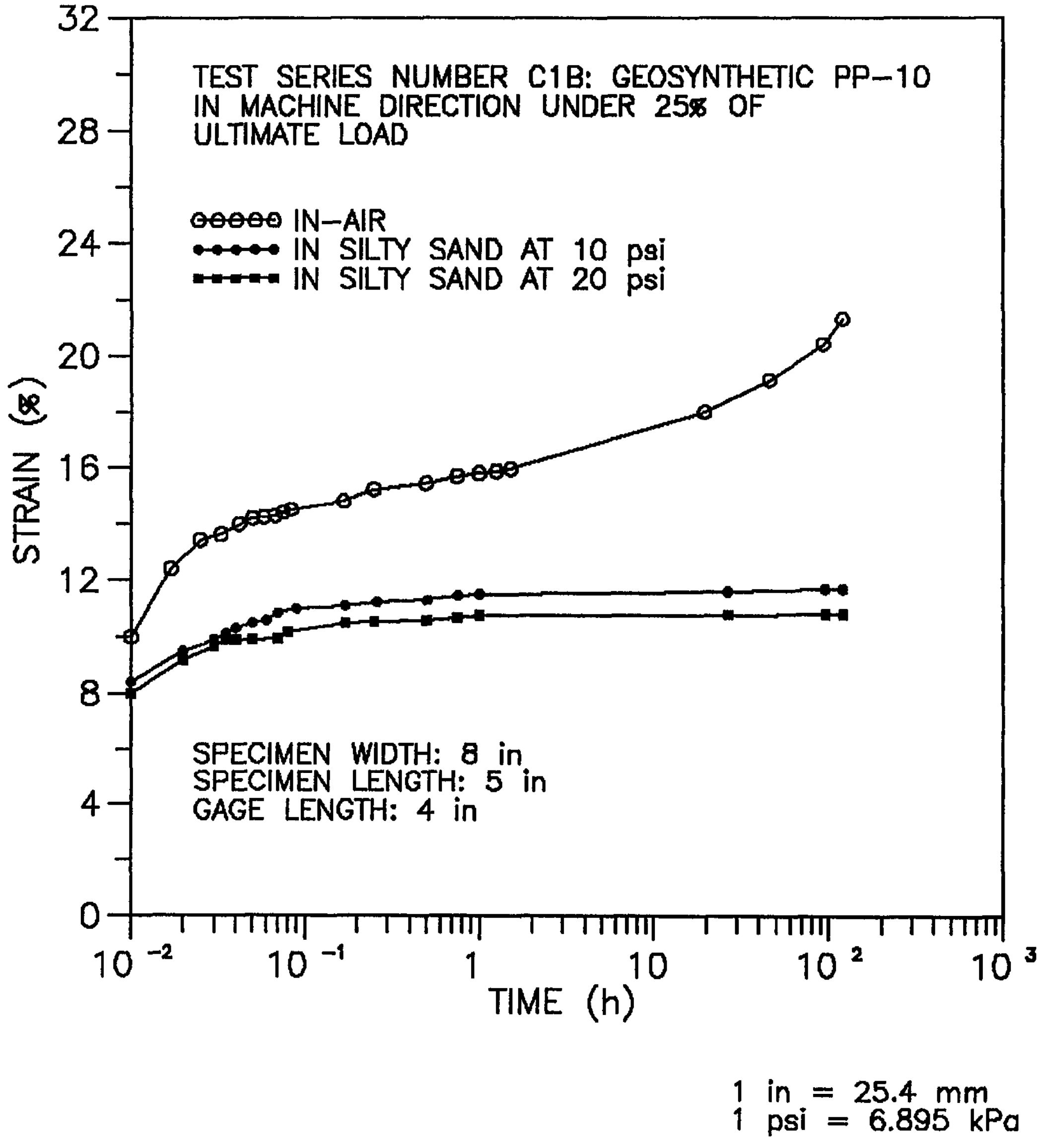


Figure B-16. Strain versus time response for Geosynthetic PP-10 confined in silty sand.

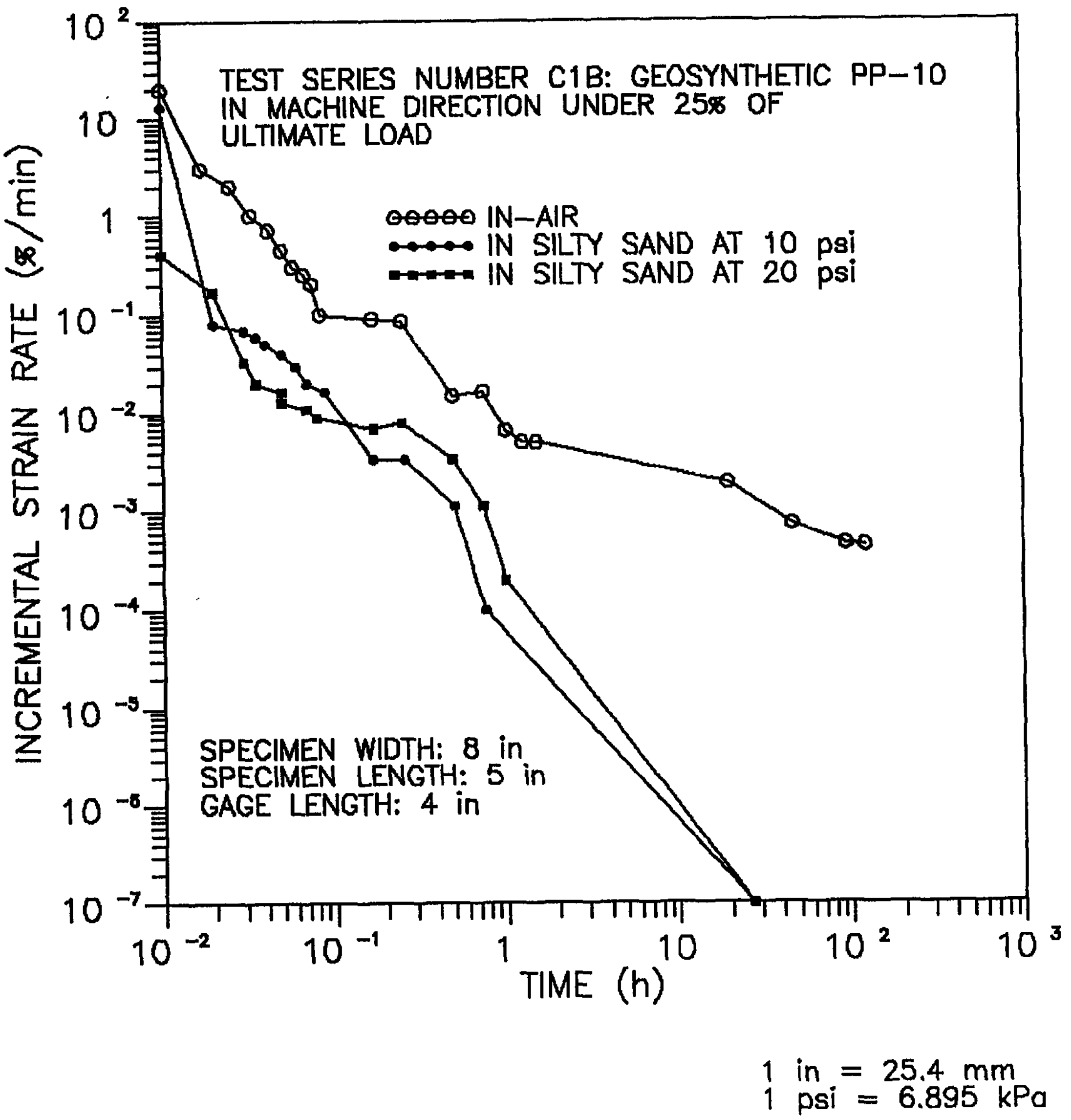


Figure B-17. Incremental strain rate versus time response for Geosynthetic PP-10 confined in silty sand.

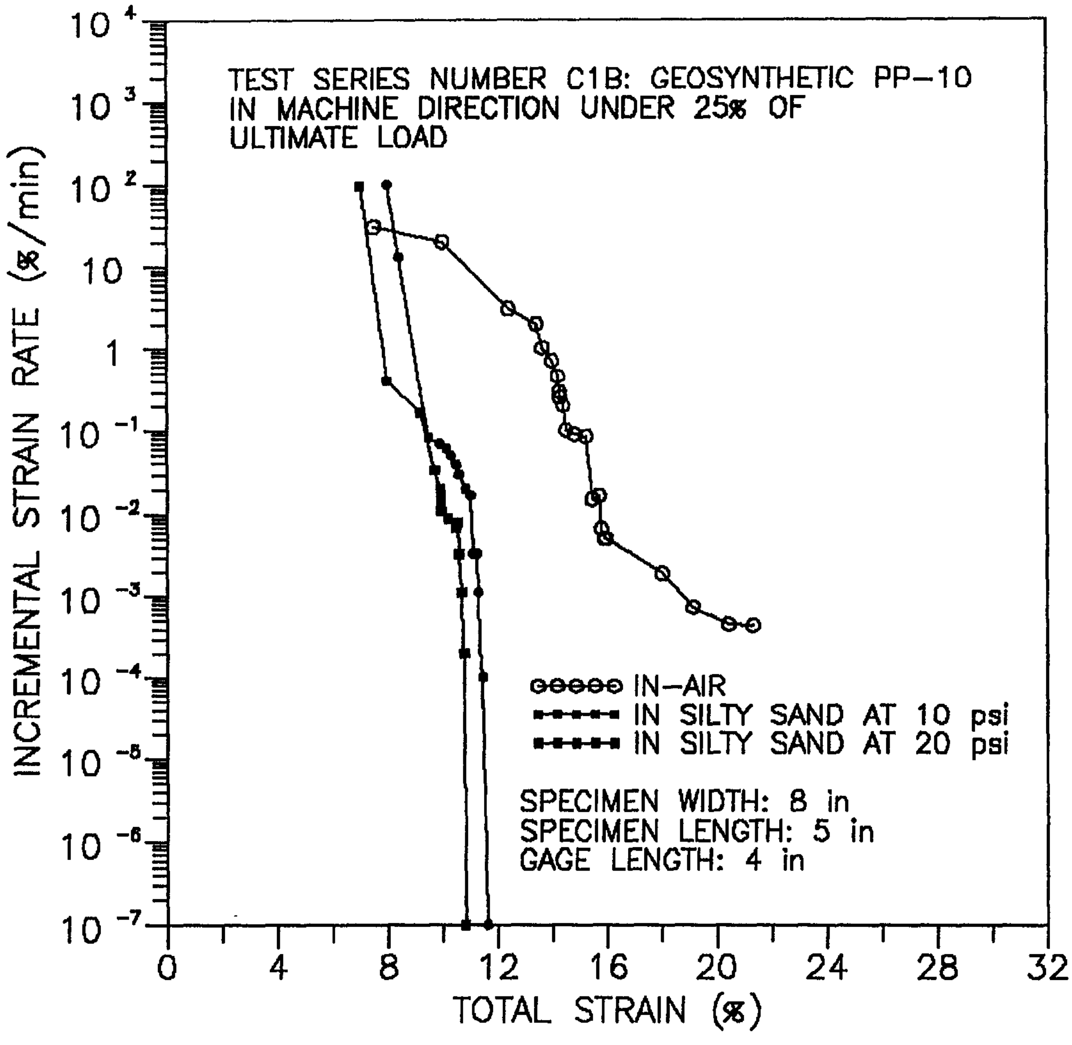
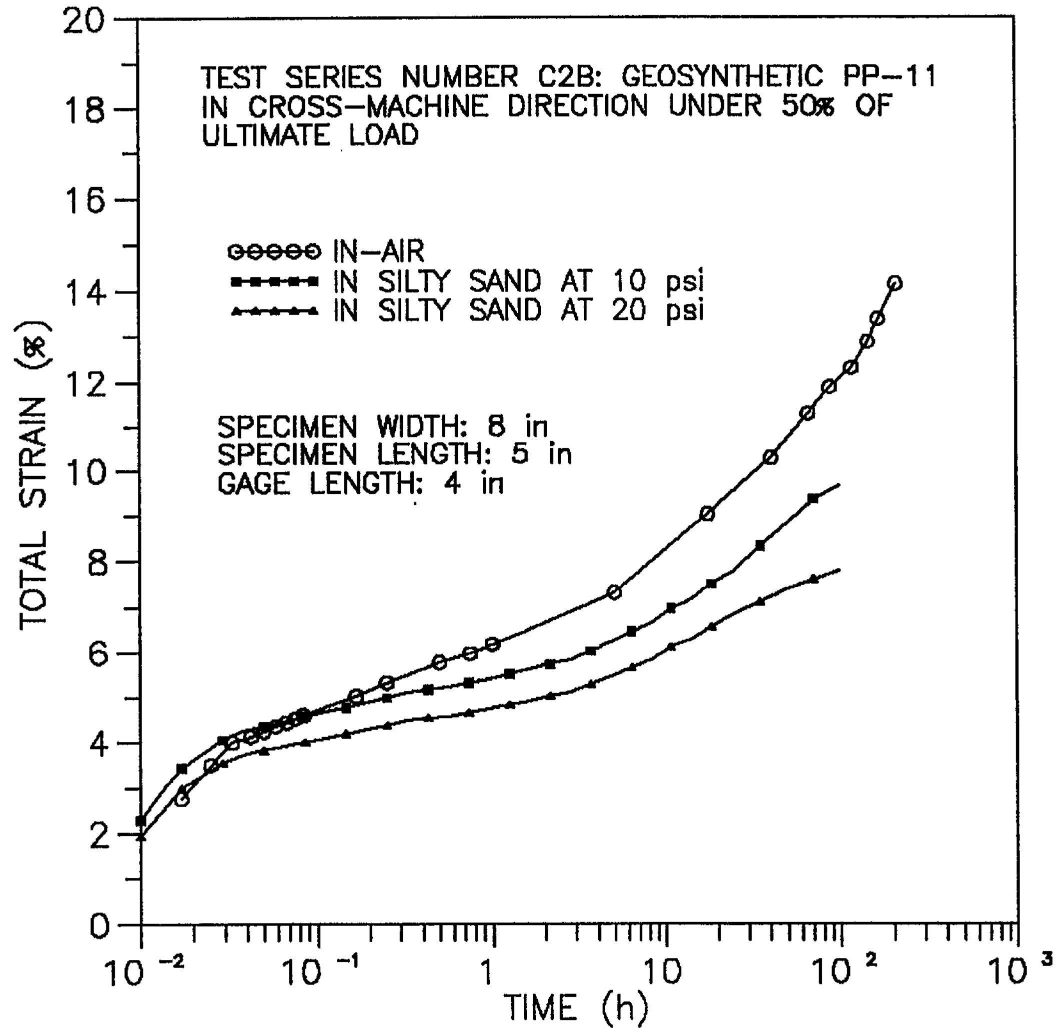
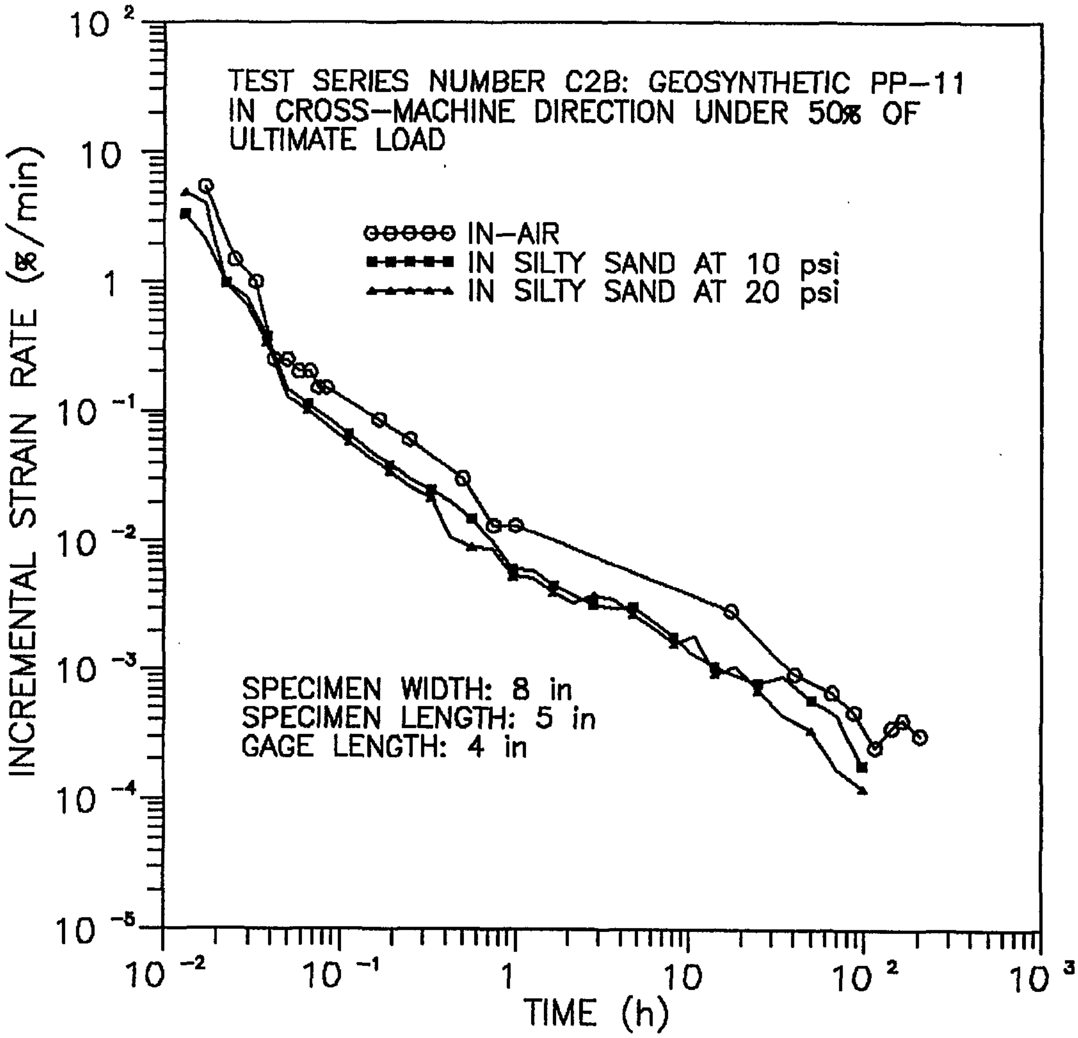


Figure B-18. Incremental strain rate versus strain response for Geosynthetic PP-10 confined in silty sand.



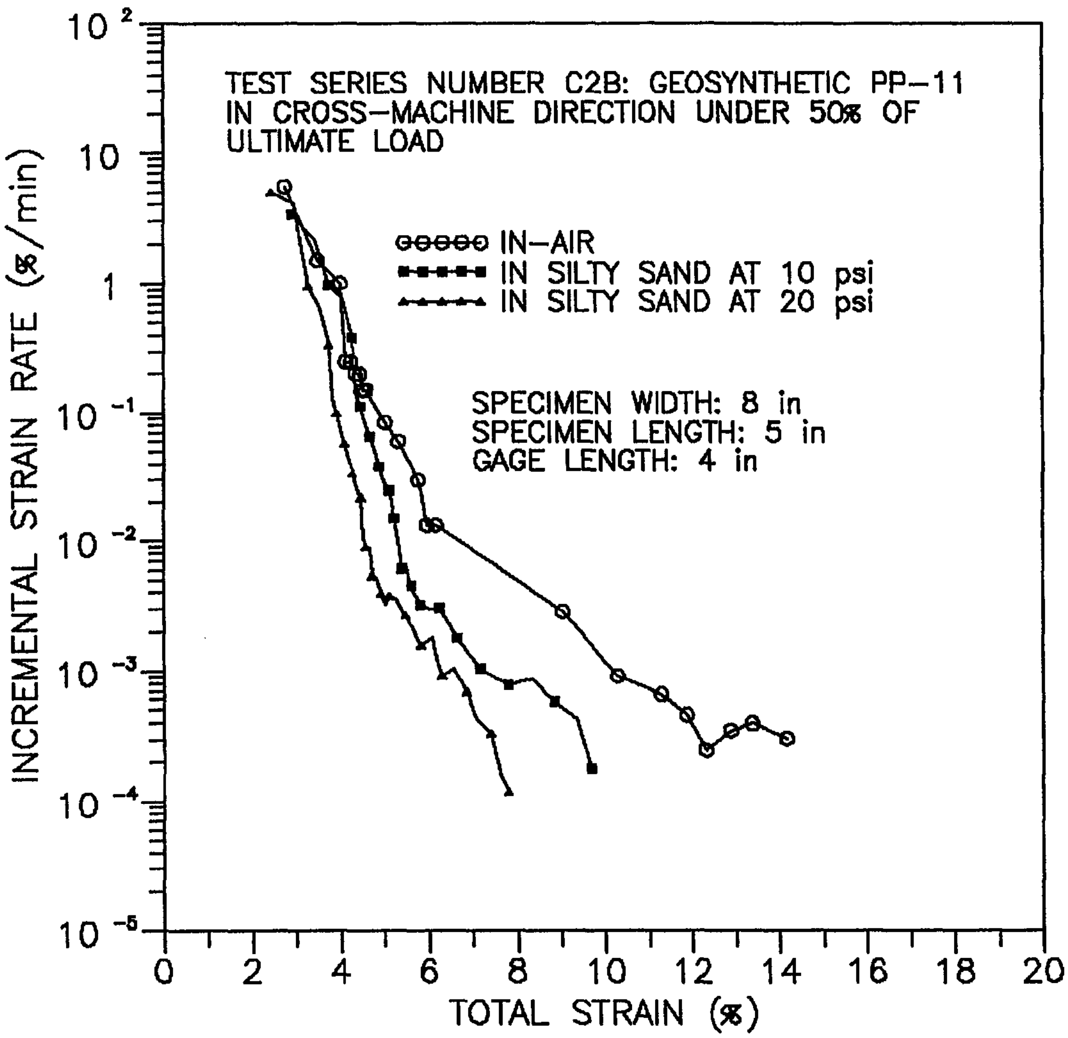
1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-19. Strain versus time response for Geosynthetic PP-11 confined in silty sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-20. Incremental strain rate versus time response for Geosynthetic PP-11 confined in silty sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-21. Incremental strain rate versus strain response for Geosynthetic PP-11 confined in silty sand.

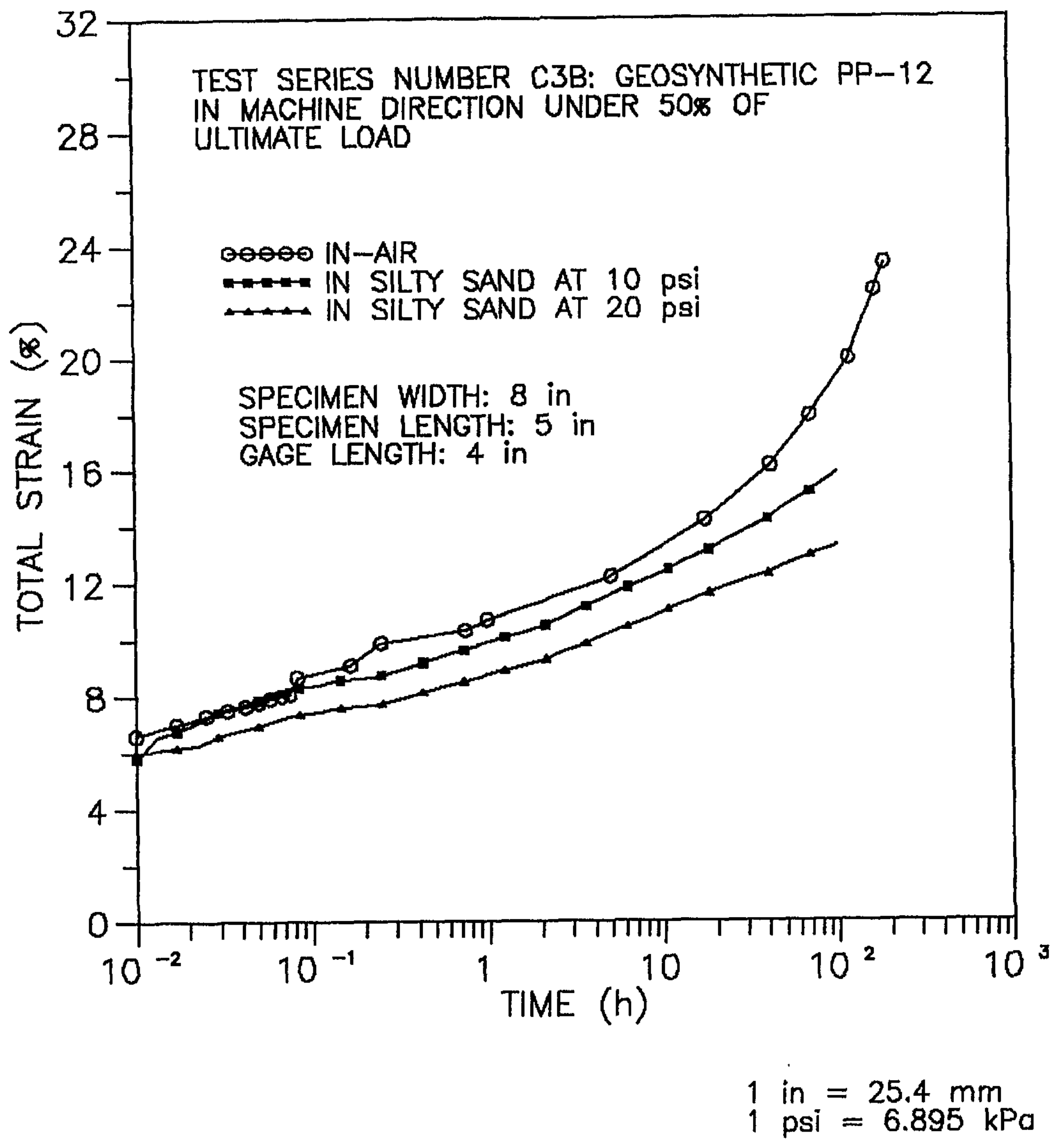


Figure B-22. Strain versus time response for Geosynthetic PP-12 confined in silty sand.

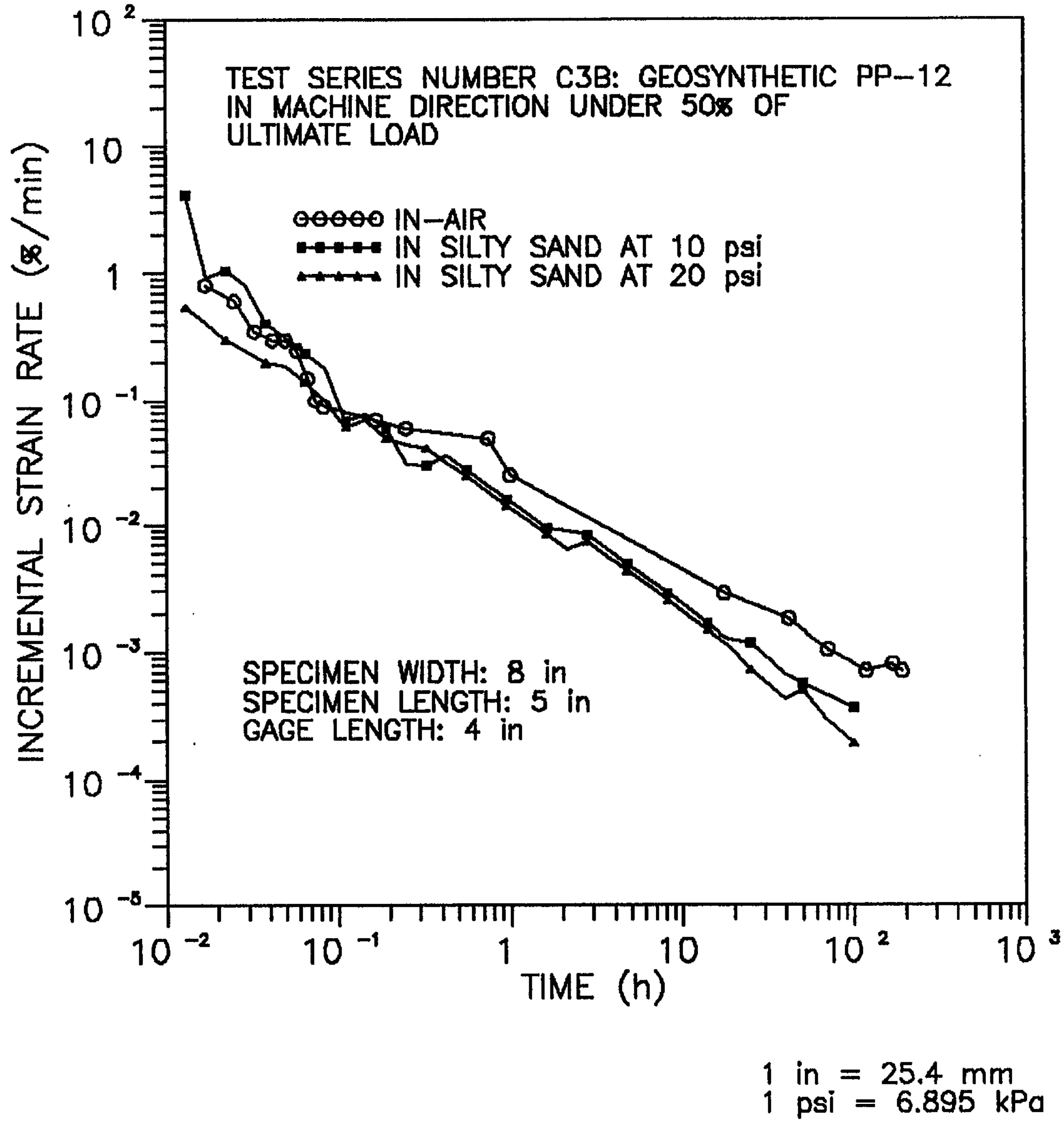


Figure B-23. Incremental strain rate versus time response for Geosynthetic PP-12 confined in silty sand.

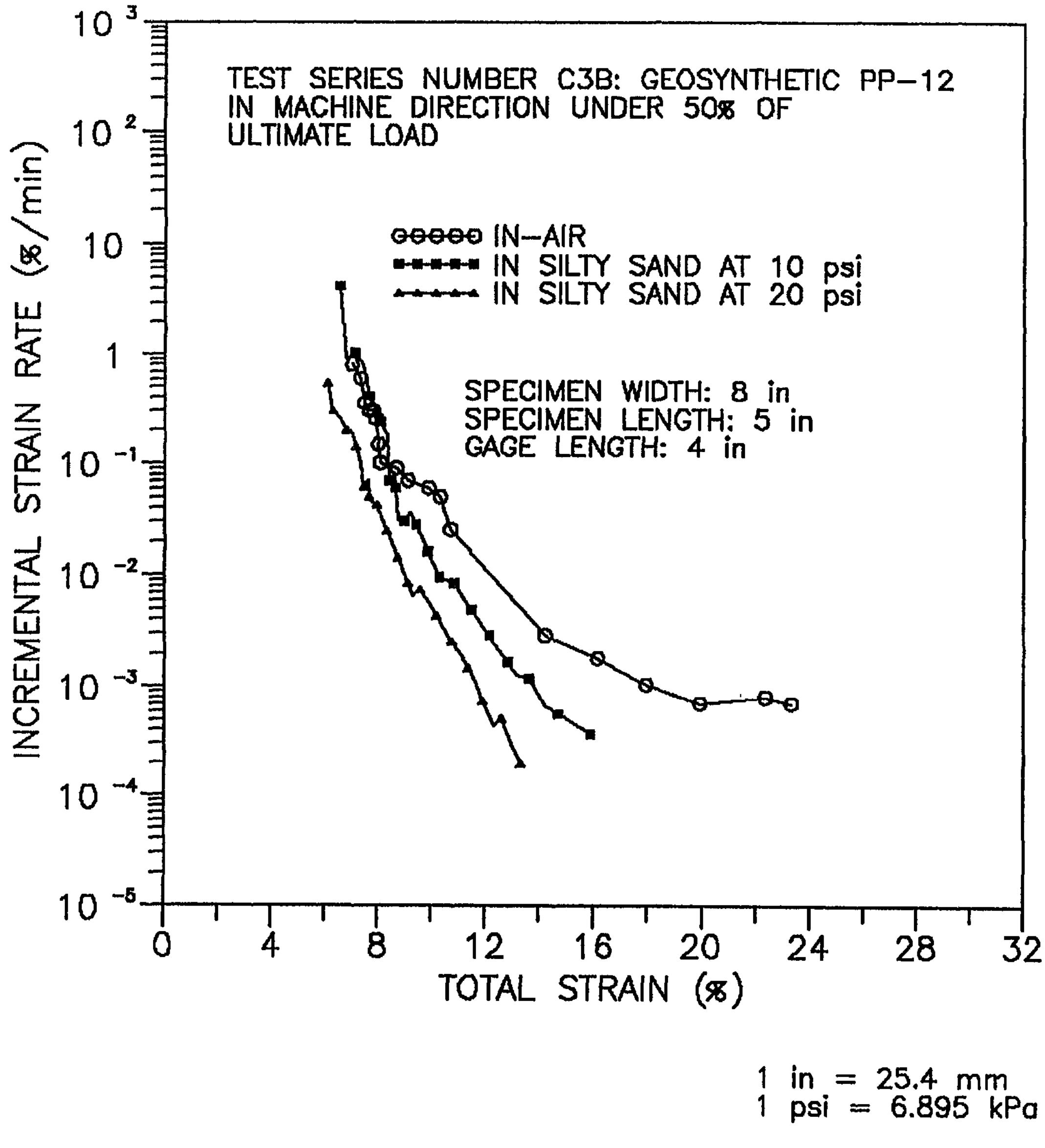
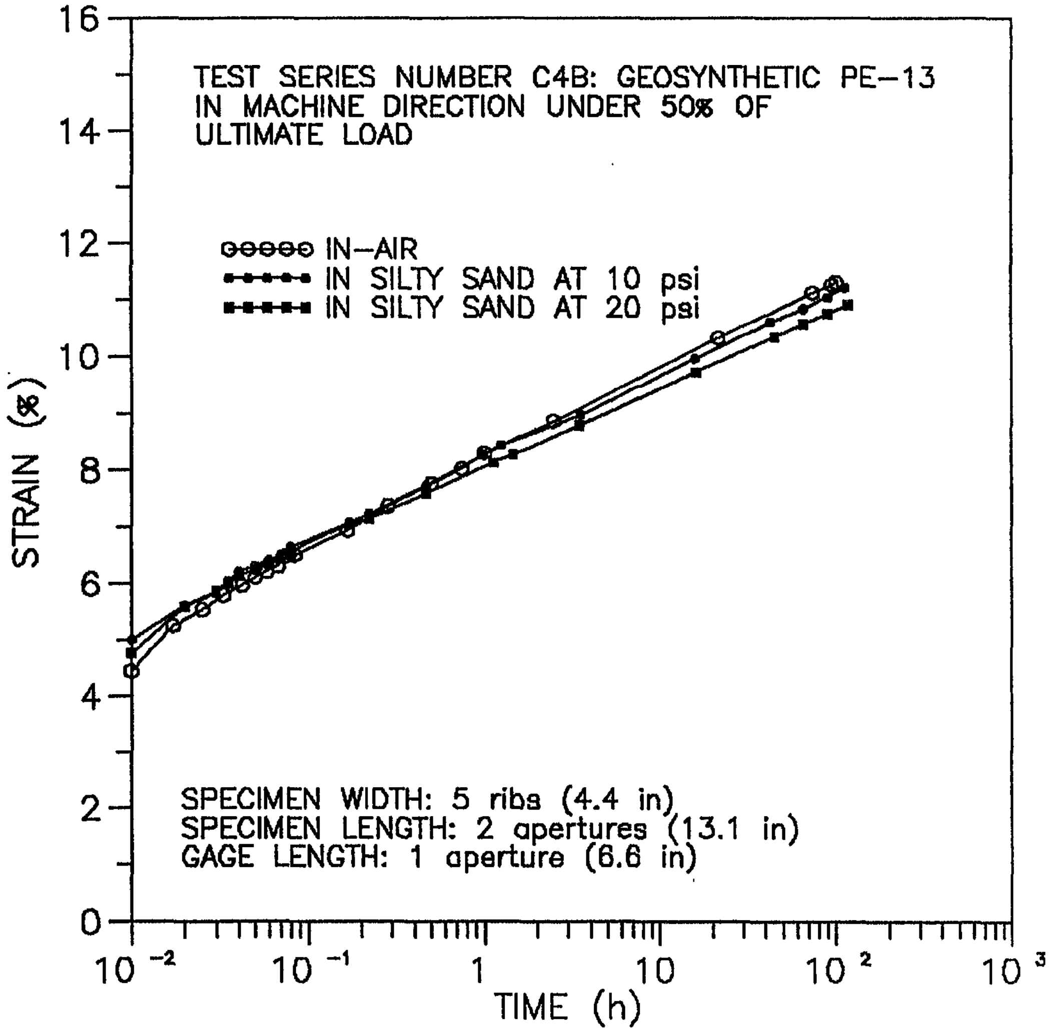
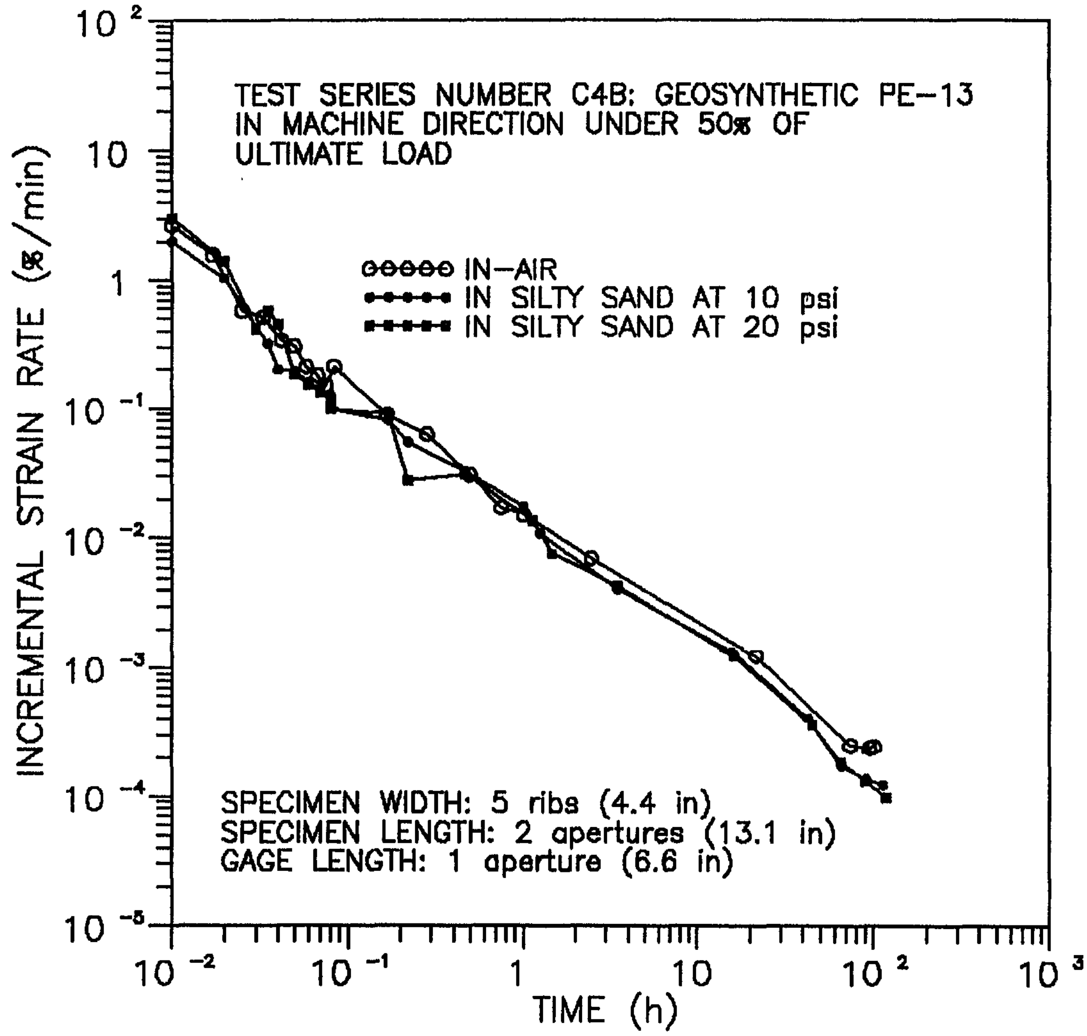


Figure B-24. Incremental strain rate versus strain response for Geosynthetic PP-12 confined in silty sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-25. Strain versus time response for Geosynthetic PE-13 confined in silty sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-26. Incremental strain rate versus time response for Geosynthetic PE-13 confined in silty sand.

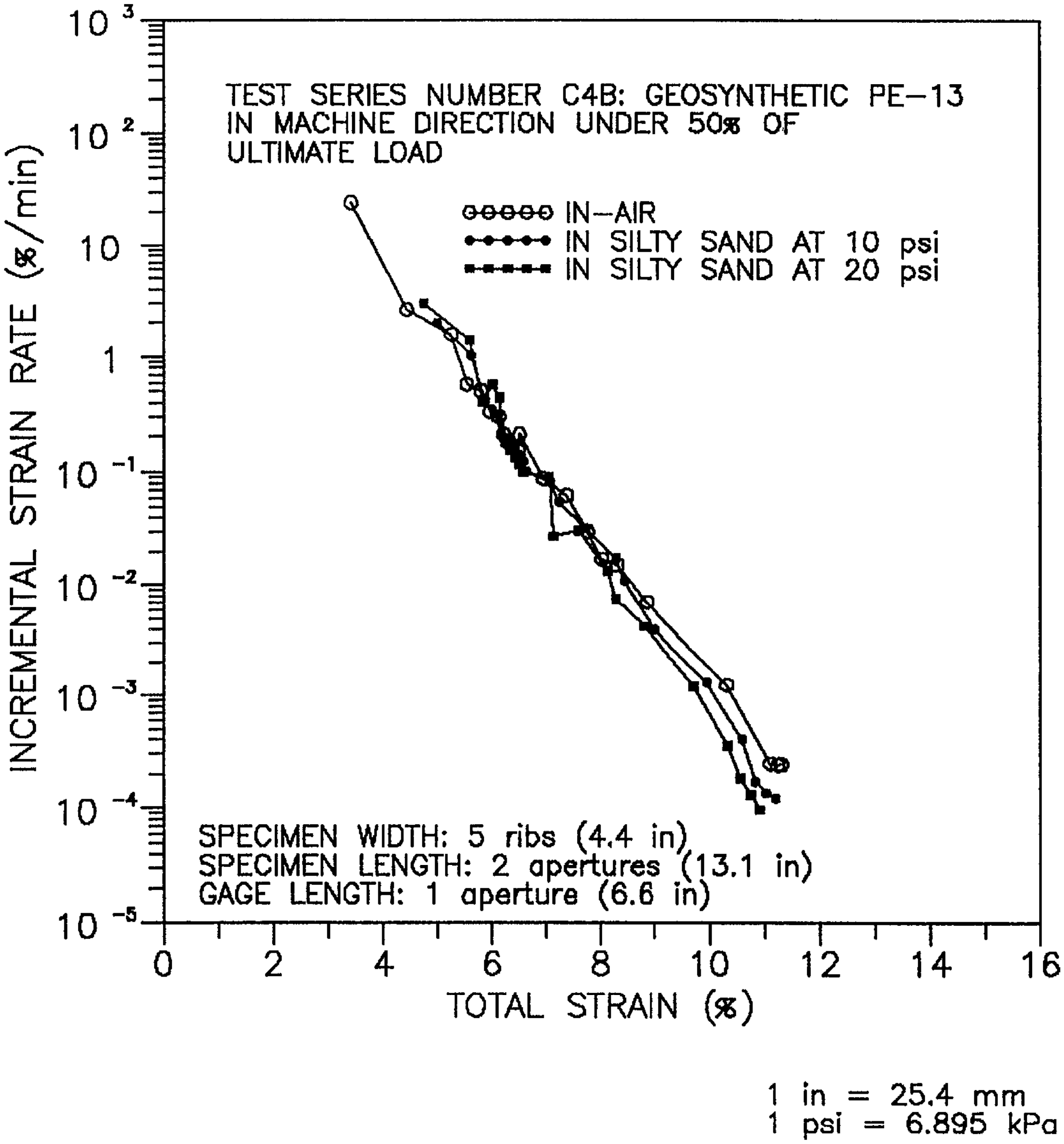


Figure B-27. Incremental strain rate versus strain response for Geosynthetic PE-13 confined in silty sand.

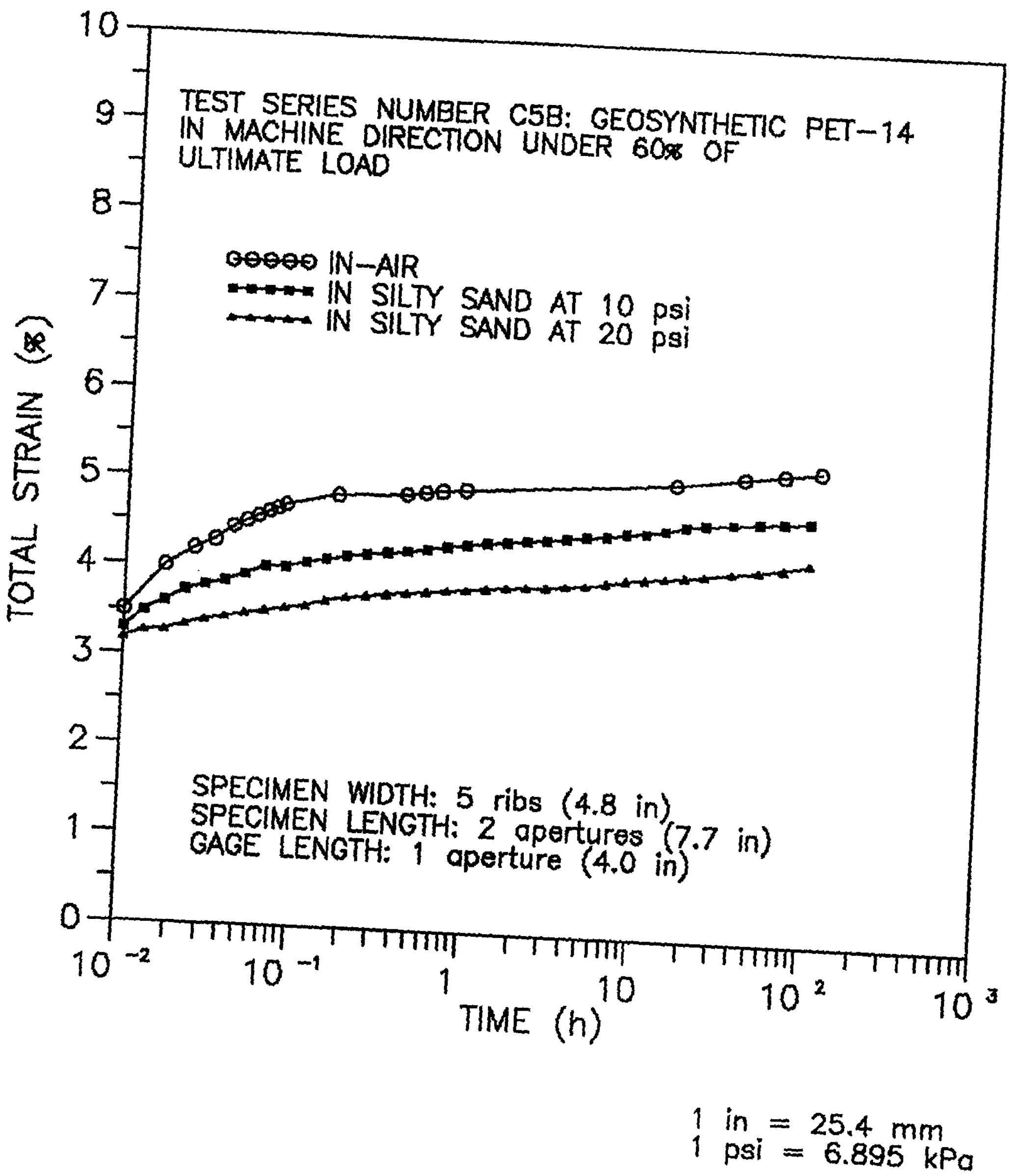
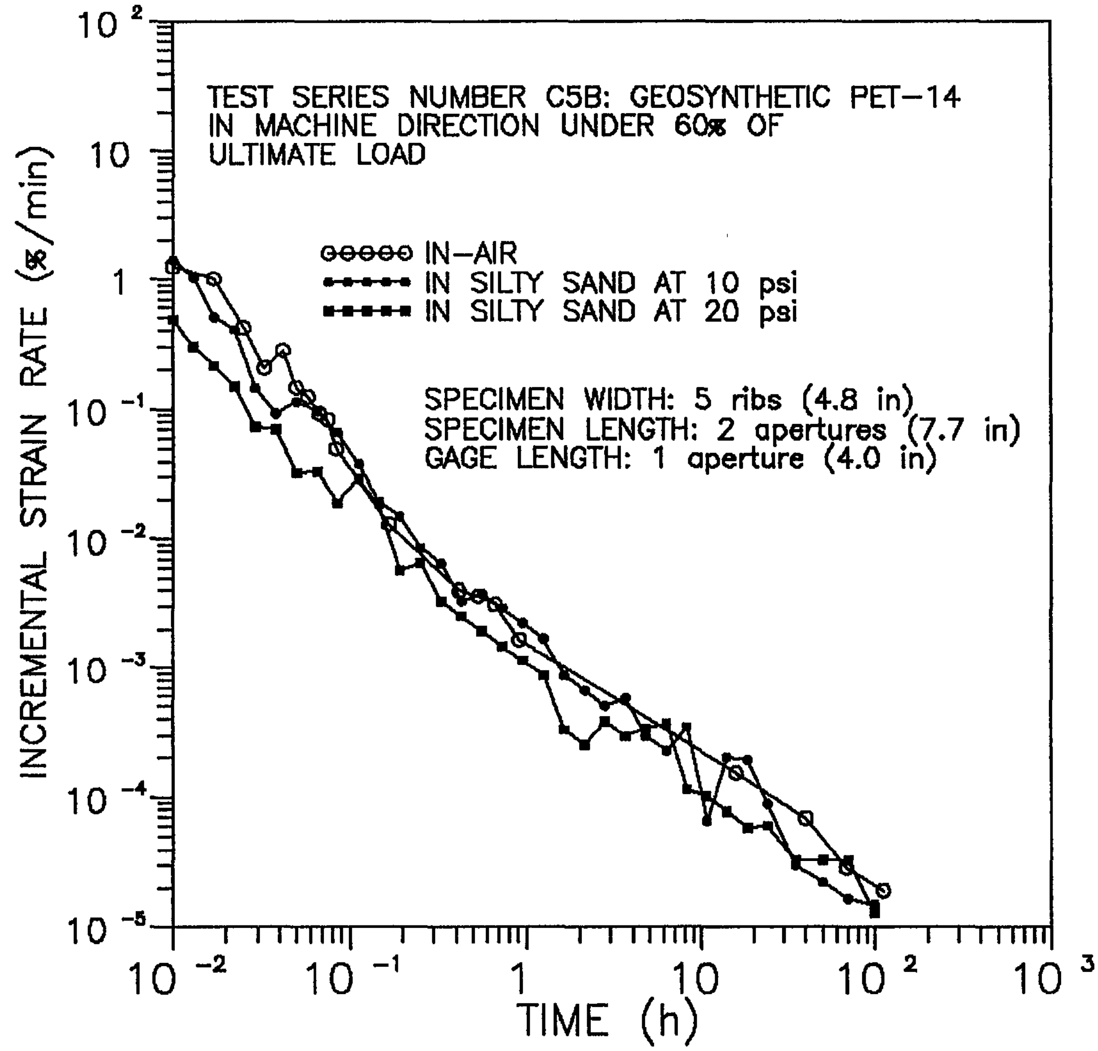


Figure B-28. Strain versus time response for Geosynthetic PET-14 confined in silty sand.



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure B-29. Incremental strain rate versus time response for Geosynthetic PET-14 confined in silty sand.

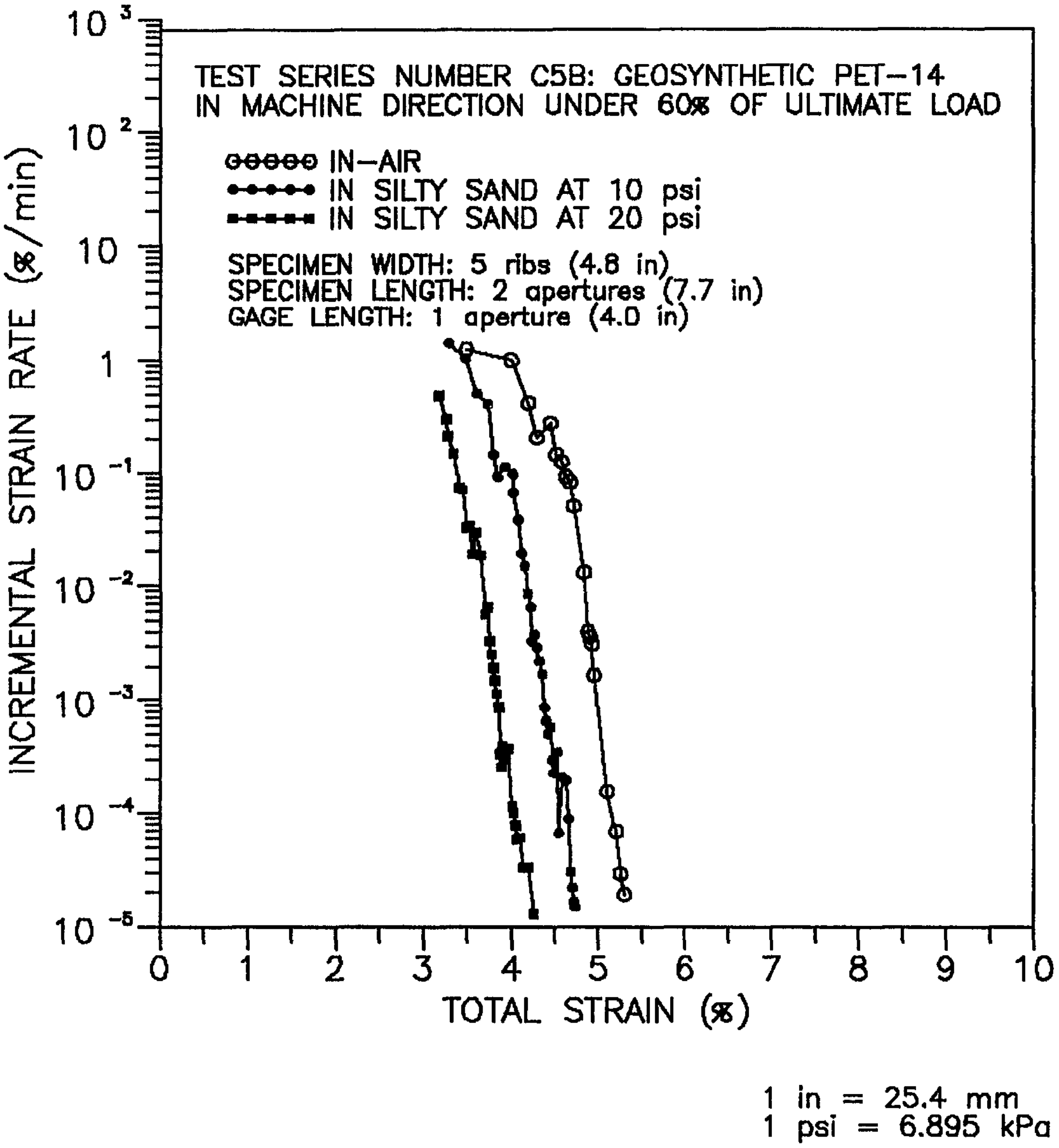


Figure B-30. Incremental strain rate versus strain response for Geosynthetic PET-14 confined in silty sand.

APPENDIX C
PROTOCOL FOR CONFINED EXTENSION/CREEP TESTING

TEST PROTOCOL
EVALUATING THE CONFINED EXTENSION/CREEP BEHAVIOR OF GEOSYNTHETICS FOR HIGHWAY APPLICATIONS

1. Scope

1.1 This test method is intended for use in determining the confined extension and/or confined creep behavior of geosynthetics used in highway applications when subjected to a sustained normal stress and tensile stress loading. This test method is applicable for geotextiles and geogrids.

1.2 The test method can be used to measure the tensile force and strain properties of a geosynthetic specimen confined and tested at a constant deformation (i.e., strain) rate; the test method can also be used to measure the total strain of the geosynthetic test specimen tested under a constant sustained tensile load.

1.3 The test method includes procedures for measuring the extension and creep behavior of a geosynthetic under two different confinement conditions. The selection of the test procedure should be based on the designer's selected design approach. Procedure A provides full confinement to the soil and the geosynthetic by using a thick soil specimen and a nonlubricated interface between the soil and the confining air bladder; Procedure B provides partial confinement to the soil and the geosynthetic by using a thin soil specimen and a lubricated interface between the soil and the confining air bladder.

1.4 The test method also provides guidance on the calculation and presentation of test data. In the extension test, data are used to calculate tensile strength, strain, tensile modulus (i.e., initial tensile modulus, offset tensile modulus, and secant tensile modulus), and force versus strain curves. In the creep test, data are used to calculate total strain, incremental strain rate, total strain versus time curves, incremental strain rate versus time curves, and incremental strain rate versus total strain curves.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only. Within this protocol, the use of the term *strain* is considered as standard.

1.6 This test protocol may involve hazardous materials and equipment. This test protocol does not address all of the health and safety problems associated with its use when hazardous materials are involved. It is the responsibility of the user of this test protocol to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D 123	Terminology Relating to Textile Materials
D 653	Standard Terminology Relating to Soil, Rock, and Contained Fluids
D 1776	Practice for Conditioning Textiles for Testing
D 1909	Table of Commercial Moisture Regains for Textile Fibers
D 2435	Standard Test Method for One-Dimensional Consolidation Properties of Soils
D 2990	Test Methods for Tensile, Compressive, and Flexural Creep and Creep Rupture of Plastics
D 4354	Practice for Sampling of Geotextiles for Testing
D 4439	Terminology for Geosynthetics
D 4595	Test Method for Tensile Properties of Geotextiles by the Wide Width Strip Method
D 5262	Standard Test Method for Evaluating the Unconfined Tension Creep Behavior of Geosynthetics
E 6	Terminology Relating to Methods of Mechanical Testing

3. Terminology

3.1 Definitions - For definitions of other terms used in this standard, refer to Terminology D 123, D 653, D 4439, and E 6.

3.2 Descriptions of Terms Specific to This Standard:

3.2.1 *atmosphere for testing geosynthetics, n.* - air maintained at a relative humidity between 50 to 70 percent and temperature of 21° ±2°C (70° ±4°F).

3.2.2 *confined extension tensile test, n.* - an extension test in which a geosynthetic material is stretched in one direction while under confinement to determine the force versus strain characteristics, the tensile strength, tensile modulus (i.e., initial, offset, and/or secant), and the total strain.

3.2.3 *creep, n.* - the time-dependent increase in accumulated strain in a material resulting from an applied constant force while under confinement (i.e., a confined creep test).

3.2.4 *creep strain, n.* - the total strain (i.e., extension divided by gage length) at any given time produced by the applied tensile load during a confined creep test.

3.2.5 *corresponding force, n.* - the force associated with a specific strain on the force per unit width strain curve.

3.2.6 *design load, n.* - the load at which the geosynthetic is required to operate in order to perform its intended function.

3.2.7 *extension, n.* - the change in the initial gage length of the geosynthetic specimen during the confined extension or confined creep test.

3.2.8 *failure, n.* - the point during a confined extension or confined creep test at which a material ceases to be functionally capable of its intended use.

3.2.9 *gage length, n.* - the initial length of the portion of the specimen over which strain (or creep strain) is to be measured.

3.2.10 *geogrid, n.* - a geosynthetic formed by a regular network of integrally connected elements with apertures greater than 6.35 mm (1/4 in) to allow interlocking with surrounding soil, rock, earth, and other materials to function primarily as reinforcement.

3.2.11 *geosynthetic, n.* - a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a man-made project, structure, or system.

3.2.12 *geotextile, n.* - a permeable geosynthetic comprised solely of textiles. Current manufacturing techniques produce nonwoven geotextiles, knitted (nontubular) geotextiles, and woven geotextiles.

3.2.13 *initial tensile modulus, n.* - the ratio of the change in tensile force per unit width to a change in strain for the initial portion of a force per unit width strain curve.

3.2.14 *offset tensile modulus, n.* - the ratio of the change in force per unit width to a change in strain below the proportional limit point and above the tangent point on the force per unit strain curve.

3.2.15 *proportional limit, n.* - the greatest stress that a material is capable of sustaining without any deviation from linear proportionality of stress to strain (Hooke's Law).

3.2.16 *rate of creep, n.* - the slope of the creep versus time curve at a given time.

3.2.17 *secant tensile modulus, n.* - the ratio of the change in force per unit width to a change in strain between two points on a force per unit width strain curve. One of the two points will be the origin (or the offset of the origin). The second point will be the point on the curve corresponding to a specified strain.

3.2.18 *strain, n.* - the total extension divided by the gage length produced by the applied tensile load during a confined extension or confined creep test. (*Syn.* total strain)

3.2.19 *tangent point, n.* - the first point of the force versus strain curve at which a major increase in slope occurs. The tangent point is determined by extending the line on the force versus strain curve where Hooke's Law is valid (see proportional limit) to the zero force axis. The point where the force versus strain curve first touches this line is the tangent point.

3.2.20 *tensile creep rupture strength, n.* - for geosynthetics, the force per unit width that will produce failure by rupture in a confined creep test in a given time in a specified constant environment.

3.2.21 *tensile creep strain, n.* - the total strain at any given time during a confined creep test.

3.2.22 *tensile modulus, n.* - the ratio of the change in tensile force per unit width to a corresponding change in strain.

3.2.23 *tensile strength, n.* - the maximum resistance to deformation developed for a specific material when subjected to tension by an external force. Tensile strength of geosynthetics is the characteristic of a sample as distinct from a specimen and is expressed in force per unit width.

3.2.24 *wide-width strip tensile test, n.* - for geosynthetics, a tensile test in which the entire width of a 200-mm (8.0-in) wide geosynthetic specimen incorporating a gage length of 100 mm (4.0 in) is gripped in the clamps.

4. Summary of Test Method

4.1 Both ends of a relatively wide geosynthetic specimen are gripped across the entire specimen width in clamps. The specimen is placed in a confinement box between layers of a specified soil. Confining pressures are applied at the boundaries of soil to provide normal stress to the geosynthetic specimen.

4.2 For both the confined extension and confined creep test, the thickness of soil adjacent to the geosynthetic can be controlled to provide either partial or full confinement to the geosynthetic.

4.3 For a confined extension test, a constant rate of extension (CRE) type tensile testing machine is operated at a prescribed rate of extension to apply a tensile force to the confined geosynthetic specimen until the specimen ruptures. Tensile strength, strain, and initial, offset, and secant tensile modulus of the test specimen can be calculated from machine scales, dials, recording charts, or an interfaced computer.

4.4 For a confined creep test, the tension creep behavior of a confined geosynthetic specimen is measured by applying an initial load in one step and sustaining the load for the duration of the test. The total strain and creep strain of the test specimen as a function of time are measured while maintaining a specified confining stress and sustained tensile load.

5. Significance and Use

5.1 This test method is developed for use in the determination of tensile force and strain properties or creep properties that may occur in geosynthetics while under confined conditions.

5.1.1 The test data can be used in conjunction with interpretive methods to evaluate tensile force versus strain and the creep strain at design loads.

5.2 This test method is not intended for routine acceptance testing of geosynthetics. This test method should be used to characterize geosynthetics intended for use in reinforcement applications in which the confined stress-strain and creep behavior of the geosynthetic are of concern. Test Method D 4595 for the determination of the wide-width strip tensile properties of geotextiles should be used for the acceptance testing of commercial shipments of geosynthetics.

5.3 The determination of the confined extension tensile force versus strain properties of geosynthetics under a confining stress provides design parameters for soil reinforcement applications. Example applications include reinforced embankments over soft subgrades, reinforced soil retaining walls, and reinforced slopes.

5.4 Most geotextiles and geogrids can be tested by this test method. Some modification of clamping techniques may be necessary for certain geosynthetics depending on the structure of the geosynthetic. Special clamping adaption may be necessary for high-strength geosynthetics (i.e., tensile strength greater than approximately 100 kN/m (600 lbf/in)) or geosynthetics made from glass fibers to prevent them from slipping in the clamps or being damaged as a result of being gripped in the clamps. Specimen clamping may be modified at the discretion of the individual laboratory provided that a representative tensile strength is obtained. In any event, the procedure described in section 11 of this test method for obtaining confined extension/confined creep behavior must be maintained.

6. Apparatus

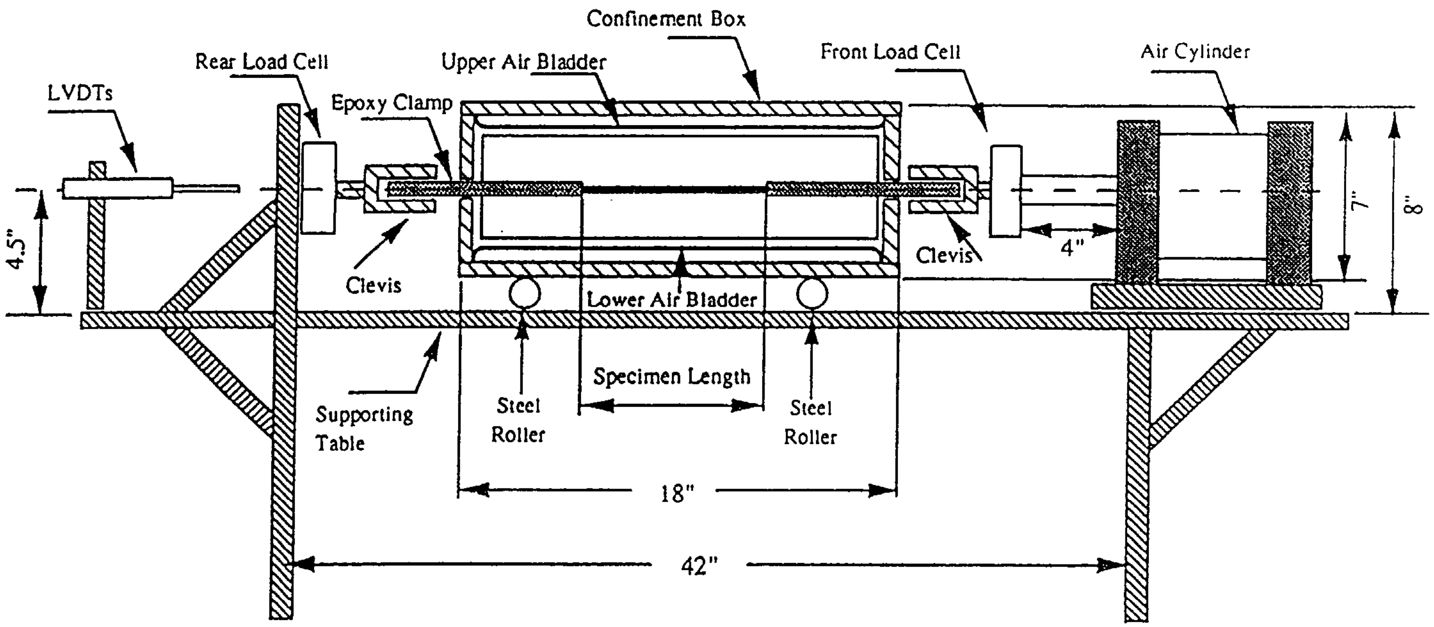
6.1 *Test Setup* - The confined extension and/or confined creep test setup is similar to that described in ASTM D 4595 and ASTM D 5262 for unconfined testing, respectively. For confined testing, the specimen is placed within a horizontally aligned containment box that incorporates the use of two air pressure bladders such that normal stress can be applied to the test specimen from above and below the geosynthetic. Figure 1 shows the horizontal orientation of the test setup.

6.1.1 For Procedure A, the setup consists of the geosynthetic test specimen mounted in suitable grips within the containment box, with a layer of soil having an approximate thickness of 75 -mm (3 -in) on both sides. The air bladders that are fitted to receive compressed air at a specified sustained pressure are contained within the confinement box, above and below the soil layers. The two air bladders interface directly onto the soil surfaces as shown in figure 2A.

6.1.2 For Procedure B, the setup consists of the geosynthetic test specimen mounted in suitable grips within the containment box, with a thin layer of soil having an approximate thickness of 10 -mm (0.4 -in) on both sides. Covering each soil layer are two layers of thin lubricated latex membranes and a relatively thick rubber rub-sheet. Each of the two air bladders interface directly onto each of the rub-sheets, as shown in Figure 2B. Depending on the design of the air bladder systems, rigid spacers may be required, as discussed in note 1.

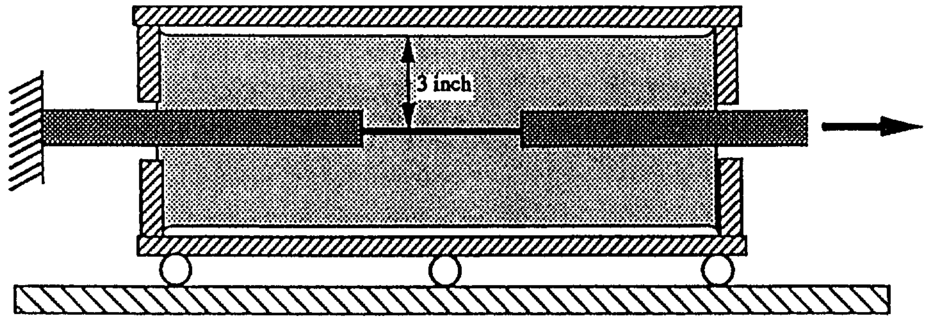
> Note 1 - It should be noted that rigid spacers may be required to be placed between the air bladder systems and soil confining layers, depending on the design of the air bladder systems and the selected test procedure (i.e., Procedure A or Procedure B), in order to fill the containment box to the proper level.

6.2 *Containment Box* - An open rigid box is used as the containment box. It is constructed of 13-mm- (0.50-in-) thick steel plates, consisting of two smooth parallel sides, front and back walls containing horizontal split adjustable doors at their center line (i.e., mid-section of the wall), and a removable bottom and top plate. The internal dimensions of the containment box should have minimum dimensions of 430 mm (17 in) long by 305 mm (12 in) wide by 150 mm (6 in) deep. The air bladder systems used to provide the confining stress should be designed to be incorporated into the top and bottom of the containment box.



1 in = 25.4 mm

Figure 1. Test setup configuration.



1 in - 25.4 mm

Figure 2A. Cross-section for Procedure A with full confinement to the soil and the geosynthetic by using a thick soil specimen and a nonlubricated interface between the soil and the confining air bladder.

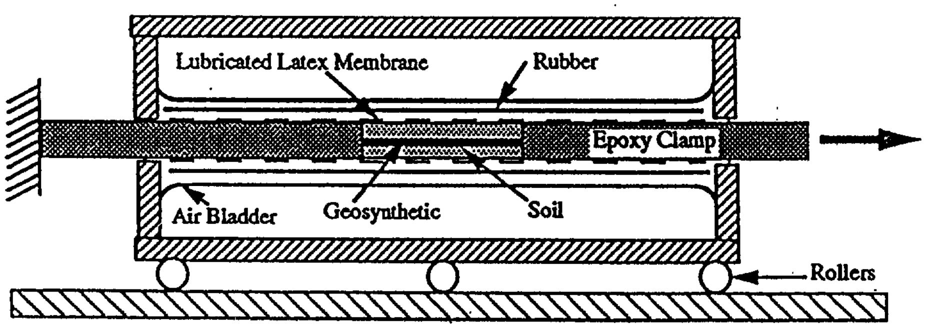


Figure 2B. Cross-section for Procedure B with partial confinement to the soil and the geosynthetic by using a thin soil specimen and a lubricated interface between the soil and the confining air bladder.

6.3 *Rigid Supporting Table* - A rigid supporting table consisting of a reaction frame with a smooth and polished tabletop should be constructed of structural steel tubing and a minimum 13-mm- (0.5-in-) thick steel plate rigidly attached to the frame to form the table. The overall minimum plan dimensions of the supporting table should be 1065 mm (42 in) in length and 710 mm (28 in) in width. The structural frame should incorporate the tensile loading system and a very low friction bearing surface. As presented in this document, the table allows two 25-mm- (1-in-) diameter steel rollers to be placed between the bottom of the containment box and the polished surface of the tabletop. This setup is required to allow the containment box to move together with the geosynthetic specimen in the horizontal direction during the confined extension and confined creep tests. Other means of providing very low friction are acceptable, but are not required by this standard.

6.4 *Test Grips* - The test grips must be smooth-surfaced thin steel plates measuring 200-mm (8.0-in) wide and of a length to extend out of each side of the containment box. The test specimen is held within these grips by a resin/epoxy to allow full and uniform tension to be applied during the test. The resin/epoxy should exit the grips within the containment box to leave, for geotextiles a minimum 100-mm- (4.0-in-) long gage length of test specimen or, for geogrids, a minimum of two complete apertures of the test specimen exposed for stress application.

6.5 *Normal Pressure Loading System* - To maintain a uniform normal stress, a flexible pneumatic diaphragm loading device (air bladder) that is continuous over the entire containment box should be used. Air pressure within the upper and lower air bladders is used to simulate the normal stresses anticipated in the field. The magnitude of this pressure must be agreed upon by the parties using the test results. Air pressure in equal amounts above and below the specimen is applied before the testing tension force is applied. The normal pressure loading system should have an operating capacity of up to 345 kPa (50 psi).

> Note 2 - It is generally recognized that there can be a reduction of confining pressure applied to the specimen because of side wall friction for thick soil specimens. This reduction from side wall friction can be on the order of 5 to 10 percent of the applied normal pressure. It is believed that the effect of side wall friction on the soil-geosynthetic interface is minimized by maintaining a minimum distance of 50 -mm (2 -in) between the geosynthetic specimen and the side walls of the containment box. By maintaining this minimum distance, the confining pressure transmitted to the geosynthetic specimen in a confined extension or confined creep test is expected to be the same as the air pressure applied to the air bladders.

6.6 *Tensile Loading System* - The tension force is to be applied to the grips exiting the containment box. As shown in figure 1, a horizontally deployed test setup uses a loading system consisting of a "moving grip" and a "fixed grip." A large-capacity hydraulic cylinder incorporating an electronic load cell is mounted on the front of the supporting table and placed in line with the center line of the horizontal containment box. This hydraulic cylinder is used to load the moving grip. The fixed grip is attached to the rear of the supporting table through the use of a second electronic load cell placed in line with the center line of the horizontal containment box. For a confined extension test, a constant rate of strain can be achieved by manually adjusting the rate of fluid flow into the hydraulic cylinder. For a confined creep test, a constant load can be maintained by applying a constant pressure into the hydraulic cylinder. The tensile loading system should have an operating capacity of at least 45 kN (10,000 lbf). Testing can be conducted using air or hydraulic fluid, although higher system capacity is generally available for tests conducted using hydraulic fluid.

Note 3 - Even if specimens of the proper aspect ratio are used for testing, the tensile load applied to the front of the geosynthetic specimen may not be fully transferred to the rear of the geosynthetic specimen. The difference between the front and rear loads is mainly caused by the mobilized friction between the soil and geosynthetic specimen and the specimen clamp, as well as friction developing between the supporting table, steel rollers, and the containment box. The use of Procedure B can help to reduce the mobilized friction between the soil and geosynthetic specimen. The overall friction loss should be measured through calibration, and the total friction should be controlled to within 2 percent of the anticipated maximum load in the confined extension test or the applied creep load in the confined creep test.

6.7 *Extension Measurement* - Extension of the geosynthetic specimen is measured at the moving grip and at several locations along the gage length of the confined portion of the geosynthetic specimen. Extensometers are preferred for the measurement of strain in geosynthetics when confined in soil. One such device utilizes tell-tail wires attached to the specimen and to externally mounted extensometers. The wires are protected from the influence of normal stress by a small-diameter tube surrounding the wire, which runs from a location on the test specimen to the extensometer mounted outside of the containment box. Whenever possible, other means of measuring strain should be calibrated against extensometers (see appendix X1). In any case, the device chosen shall be capable of measuring deformations to an accuracy of at least ± 0.03 mm (± 0.001 in). The means of measuring strain should be indicated clearly in the report.

6.8 *Vibration Control* - Confined creep tests are sensitive to shock and vibration. The location of the apparatus, test equipment, and mounting shall be designed so that the specimen is isolated from vibration.

6.9 *Time Measurement* - The accuracy of the time measuring device shall be ±1 percent of the elapsed time of each creep measurement load increment.

6.10 *Temperature Control* - The temperature in the containment box, especially that close to the gage length of the specimen, shall be maintained within +2°C (+4°F) of the targeted value by a suitable automatic device and shall be stated in the report.

6.11 *Temperature Measurements* - Temperature measurements shall be recorded at frequent intervals, or recorded continuously, in order to ensure an accurate determination of the average test temperature and compliance with 6.10.

6.12 *Environmental Control* - The test environment shall be maintained constant throughout the test. Safety precautions should be taken to avoid personal contact during the test. The area should be isolated adequately and fenced such that only the test operator has access to the test station.

6.13 *Soil Preparation Equipment* - Use equipment as necessary for the placement of soils at desired conditions. This may include compaction devices such as vibratory or "jumping-jack" type compaction or hand compaction hammers. Soil containers or hoppers, leveling tools, and soil placement/removal tools may be required.

6.14 *Miscellaneous Equipment* - Measurement and trimming equipment as necessary for geosynthetic preparation, a timing device, and soil property testing equipment are necessary for testing, but are considered to be routine components of a geosynthetic testing laboratory.

7. Sampling

7.1 *Lot Sample* - For the lot sample, rolls of geosynthetics should be obtained as directed in an applicable material specification, or as agreed upon between the purchaser and the supplier.

7.2 *Laboratory Sample* - For the laboratory sample, a full-width swatch approximately 1-m- (40-in-) long in the machine direction should be obtained from each roll in the lot sample. The sample may be taken from the end portion of a roll, provided there is no evidence that it is distorted or different from other portions of the roll. In general, and particularly in cases of dispute, it is recommended that a sample be obtained that will exclude material from the outer wrap of the roll or the inner wrap around the core.

7.3 *Test Specimens:*

7.3.1 *Geotextiles* - For tests in the machine and cross-machine directions, respectively, the number of specimens as directed in section 9.1 should be taken from each sample. The specimens should be taken along a diagonal across the width of the sample, with no specimens closer than 1/10 the width of the roll or 150- mm (6- in) from the edge of the sample, whichever is smaller.

7.3.2 *Geogrids* - For tests in the machine and cross-machine directions, respectively, the number of specimens as directed in section 9.1 should be taken from each sample. The specimens should be taken at random locations from the laboratory sample. Machine direction samples should be obtained from locations independent from the cross-machine samples. The test specimens should exclude the outermost longitudinal and transverse ribs. No specimens should be taken closer to the edge than 1/10 the width of the roll or 150 mm (6 in) from the edge, whichever is smaller.

8. Test Specimen Preparation

8.1 *Test Specimen Preparation*:

8.1.1 *Geotextiles* - An aspect ratio of 2:1 should be used for all geotextile specimens. Prepare each finished specimen to 200-mm (8.0-in) wide by at least 200-mm (8.0-in-) long, with the length dimension being designated and accurately cut parallel to the direction for which the confined extension or confined creep behavior is being measured. Draw two parallel lines near the center of each specimen length that are separated by 100 mm (4.0 in) and that extend the full width of the specimen. These lines should be exactly perpendicular to the length of the specimen.

8.1.1.1 The length of the specimen depends on the type of clamps being used. The specimen must be long enough to extend through the full length of both clamps, as determined for the direction of the test. When specimen integrity is not affected, the specimen may be cut initially to the finished width.

8.1.2 *Geogrids* - Prepare each finished specimen to contain a width of at least five ribs in the cross-test direction (i.e., typically the cross-machine direction) by a length of at least two complete apertures in the direction of testing (i.e., typically the machine direction), with the length dimension being designated and accurately cut parallel to the direction for which the confined extension or confined creep behavior is being measured.

8.1.3 This test method may not be suitable for some woven geotextiles or geogrids that exhibit breaking strengths in excess of 100 kN/m (600 lbf/in), due to clamping and equipment limitations. In such cases, 100-mm- (4.0-in-) wide specimens may be substituted for 200-mm- (8.0-in-) wide geotextile specimens. For geogrids, a minimum of three ribs in the cross-test direction may be substituted for the five ribs in the cross-test direction to ensure proper load distribution.

9. Number of Tests

9.1 *Confined Extension Tests* - Unless otherwise agreed upon, confined extension tests shall be conducted at normal stress levels as specified by the designer. Three different normal stress levels are recommended for characterization of the interaction of the geosynthetic material and the confining soil.

9.2 *Confined Creep Tests* - To evaluate design creep strains, it is recommended that a minimum of two different normal stress conditions be evaluated to cover the range of normal stresses anticipated in the design. For each normal stress condition, applied tensile loads shall be selected at intervals of approximately 10 to 20 percent of the maximum load per unit width, that is, 20, 30, 40 and 60 percent, as determined by applicable ASTM test methods.

Note 4 - To properly characterize the confined behavior of a geosynthetic involves identification of the load levels at which there is no creep (no increase in strain with the log of time), low to moderate creep (linear increase in strain with the log of time), and high creep (exponential increase in strain with log of time). Therefore, a minimum of three tests are recommended for each normal stress.

10. Conditioning and Testing Atmosphere

10.1 The specimens should be brought to moisture equilibrium in the atmosphere for testing geosynthetics. Equilibrium is considered to have been reached when the increase in mass of the specimen, in successive weighing, made at intervals of not less than 2 hours, does not exceed 0.1 percent of the mass measured at the previous time period.

> Note 5 - Geosynthetic materials are frequently not weighed to determine when moisture equilibrium has been reached. While such a procedure cannot be accepted in cases of dispute, in routine testing, it may be sufficient to expose the material to the standard atmosphere for testing for a reasonable time period before the specimens are tested. A period of 24 hours has been found acceptable in most cases. However, certain fibers may exhibit slow moisture equilibrium rates from the as-received wet side. When this is known, a preconditioning cycle, as prescribed in ASTM D 1776, may be agreed upon between contractual parties.

11. Procedure

11.1 Adequately conditioned specimens should be tested. Test are conducted at a temperature of 21° ±2°C (70° ±4°F) and relative humidity of 50 to 75 percent.

11.2 Procedure A or Procedure B should be selected on the basis of the designer's design approach. The test setup is then constructed as discussed in section 6.1.

11.3 The amount of soil should be determined to achieve the desired dry unit weight of the soil when placed in the lower half of the containment box above the lower air bladder system. The selected soil material is then compacted into the lower half of the confinement box to form the lower confining layer. The soil should be compacted by hand tamping or by some other means to the desired unit weight under the specified moisture condition. The upper surface of the lower confining layer should be placed so that it is level with the center line of the loading harness, (i.e., the hydraulic cylinder and the rear load cell).

11.4 A test specimen should be obtained as described in section 8. The end of each geosynthetic specimen should be cast in a low-temperature curing epoxy, resin which should be reinforced using layers of impregnated nonwoven geotextile to facilitate clamping of each geosynthetic. The epoxy resin should be prepared by mixing the components of the resin compound and curing agent as directed by the manufacturer. During the curing period, typically 24 -hours, each end of the specimen should be confined between smooth steel plates under a minimum normal stress of 1 kPa (0.15 psi) to ensure a uniform casting that facilitates clamping.

11.5 After preparation of the geosynthetic specimen, the test specimen is then placed on top of the lower confining soil layer. The two cast ends of the geosynthetic specimen are then connected to the front moving grip through a clevis and the rear fixed grip through a clevis on the tensile loading system as shown in figure 1.

11.6 At least two in-soil extension monitoring devices (typically tell-tail wires attached to extensometers) should be used to monitor displacement of the geosynthetic specimen within the containment box. When only two tell-tail wires are used, they should be connected to the two ends of the geosynthetic specimen gage length. The tell-tail wire gages can be attached by hooking the wire to a glued-on tab or by tying them directly onto the specimen. Care should be taken to ensure that any slack in the wire is eliminated and that the geosynthetic specimen is not damaged. The other end of each wire can then be connected to the extensometer mounted to the rear of the supporting table outside the containment box. See appendix X.1 for information about extensometers.

Note 6 - It is recommended that additional in-soil extension monitoring devices be used during testing to confirm that there is uniform strain distribution along the gage length of the confined portion of the geosynthetic specimen.

11.7 A pretension force should be applied to the geosynthetic specimen to eliminate slack within the geosynthetic specimen. The amount of pretension force is preselected for each test in accordance with the procedure established in ASTM D 4595 for in-air tensile testing of geosynthetics. A total pretension force equal to 1.25 percent of the expected breaking force should be applied to each geosynthetic specimen. However, the total pretension force should not be less than 45 N (10 lb) or greater than 222 N (50 lb) in any case. The pretension force should be applied to the geosynthetic specimen prior to placement of the upper confining soil layer. This allows examination of the geosynthetic specimen to assess whether the geosynthetic is in uniform contact with the top of the lower confining soil layer.

11.8 Additional soil should now be placed above the geosynthetic in the upper half of the containment box and compacted by hand tamping or by some other means to form the upper confining layer above the geosynthetic specimen. The soil should be compacted to the same unit weight and at the same specified moisture content as the lower confining soil layer.

11.9 The test setup is completed with the installation of the upper lubricated interface if Procedure B is used, upper air bladder system, and top plate (see note 1).

11.10 A normal stress is then applied to the test specimen by pressurizing the upper and lower air bladder loading systems. The desired predetermined source pressure should be applied simultaneously through the lower and upper air bladders.

11.11 For a *confined extension test*, the geosynthetic specimen should be loaded under a constant rate of strain of 10 percent/min as measured on the front specimen clamp. The selection of this constant rate of strain is based on the standard loading rate specified in ASTM D 4595 for conducting unconfined wide-width strip tension tests on geosynthetics. For a *confined creep test*, a load should be applied to the test specimen at an initial loading strain rate of 10 percent/min until the selected test load is achieved. Selection of this initial loading rate is based on the standard loading rate in ASTM D 5262 for conducting unconfined tension creep tests on geosynthetics. The variation of the applied constant load should be within ± 1 percent of the desired load to be applied to the test specimen throughout the duration of the test. Readings should be taken regularly and, at a minimum at the same time the extension of the test specimen is measured, as discussed in section 11.11.1.

11.11.1 During the *confined creep test*, the extension of the specimen should be measured in accordance with the following approximate time schedule: 1, 2, 6, 10, and 30 min; and 1, 2, 5, 10, 30, 100, 200, 500, and 1000 hours. For creep tests longer than 1000 hours, extension readings should be recorded every 500 hours until testing is complete.

> Note 7 - In design, it is generally accepted that creep data should not be extrapolated for time periods beyond one order of magnitude of the test time. In many cases, a test period of 1000 hours may not reflect the long-term creep behavior of the material accurately, as this reflects an extrapolation limit of approximately 10,000 hours or approximately 14 months. For such cases, creep tests should be conducted for more than 10,000 hours.

11.11.2 Test results should be plotted on a graph as discussed in section 12.2. Results should be plotted regularly during the test. Readings should be recorded more frequently if discontinuities in the creep strain versus log of time plot are suspected or encountered. To avoid such discontinuities, the use of automatic monitoring and measuring equipment is recommended.

11.12 The test should be terminated when the specimen ruptures or at the end of the agreed upon time period. If the specimen ruptures, the type of failure, the location, and time to failure should be recorded.

12. Calculations

12.1 *Confined Extension Tests:*

12.1.1 *Tensile Strength* - Calculate the tensile strength of individual specimens by reading the maximum force per unit width to cause a specimen to rupture from the testing instrument. Tensile strength is expressed in N/m (lbf/ft) of width, using Eq 1, as follows:

$$\alpha_f = F_f/W_s \tag{1}$$

where:

α_f = tensile strength, N/m (lbf/ft) of width,
F_f = observed breaking force, N (lbf), and
W_s = initial specimen width, m (ft).

12.1.1.1 For geogrids, the equivalent tensile strength is determined by the use of Eq 2:

$$a = (F/N_r) \times N_t \tag{2}$$

where:

a = equivalent tensile strength, N/m (lbf/ft) of width,
F = observed breaking force, N (lbf),
N_r = number of ribs tested, and
N_t = number of ribs per unit width.

12.1.2 *Strain* - Calculate the strain of individual specimens, expressed as the percentage increase in length, relative to the initial nominal gage length of the specimen, using Eq 3, as follows:

$$\epsilon = (\Delta L \times 100)/L_g \tag{3}$$

where:

ϵ = strain, %,
L_g = initial nominal gage length, mm (in), and
ΔL = the unit change in length (extension) of the gaged portion of the specimen from zero force to the corresponding measured force, mm (in).

12.1.3 *Tensile Modulus:*

12.1.3.1 *Initial Tensile Modulus* - Calculate the initial tensile modulus using the initial straight portion of the force versus strain curve by drawing a line tangent to this curve. At any point on this tangent line, measure the slope by measuring the change in force and the corresponding change in strain. Calculate initial tensile modulus in N/m (lbf/ft) of width using Eq 4 (See appendix X2 and figure X2.1), as follows:

$$J_i = (F \times 100)/(\epsilon \times W_s) \tag{4}$$

where:

J_i = initial tensile modulus, N/m (lbf/ft) of width,
F = determined force on the drawn tangent line, N (lbf),
ϵ = corresponding strain with respect to the drawn tangent line and determined force, %, and
W_s = initial specimen width, m (ft).

12.1.3.2 *Offset Tensile Modulus* - Calculate the offset tensile modulus by determining the location where modulus is to be assessed and drawing a line tangent to the force versus strain curve between the tangent point and the proportional limit and through the zero force axis. Measure the force and the corresponding strain with respect to the force axis. Calculate offset tensile modulus in N/m (lbf/ft) of width using Eq 5 (See appendix X2 and X3 and figures X2.1 and X3.1), as follows:

$$J_o = (F \times 100)/(\epsilon \times W_s) \tag{5}$$

where:

J_o = offset tensile modulus, N/m (lbf/ft) of width,
F = determined force on the drawn tangent line, N (lbf),
ϵ = corresponding strain with respect to the drawn tangent line and determined force, %, and
W_s = initial specimen width, m (ft).

12.1.3.3 *Secant Tensile Modulus* - Calculate the secant tensile modulus by determining the force for a specified strain, ϵ_2, and label that point on the force versus strain curve as P_2. It is typical to report secant modulus for 2, 5, and/or 10 percent strain. Accordingly, P_2 would be located on the force versus strain curve at either 2, 5, and/or 10 percent strain. Likewise, label a second point, P_1 at a specified strain, ϵ_1, usually 0 percent strain. Draw a straight line (secant) through points P_1 and P_2 intersecting the zero force axis. The typical values are 0 and 10 percent strain for points P_1 and P_2, respectively, although other values may be used when required in an applicable material specification. The secant tensile modulus is calculated in N/m (lbf/ft) of width using Eq 6 (See appendix X4 and figure X4.1), as follows:

$$J_s = (F \times 100)/(\epsilon \times W_s) \tag{6}$$

where:

J_s = secant tensile modulus, N/m (lbf/ft) between specified strains per m (ft) of width,
F = determined force on the constructed line, N (lbf),
ϵ = corresponding strain with respect to the constructed line and determined force, %, and
W_s = initial specimen width, m (ft).

12.1.4 *Force Versus Strain Curve* - The standard confined extension curve is a graph of the force versus strain as measured on the geosynthetic while under a specified confining stress. A typical plot is presented in figure 3 and should be provided in the report if requested.

12.2 *Confined Creep Tests:*

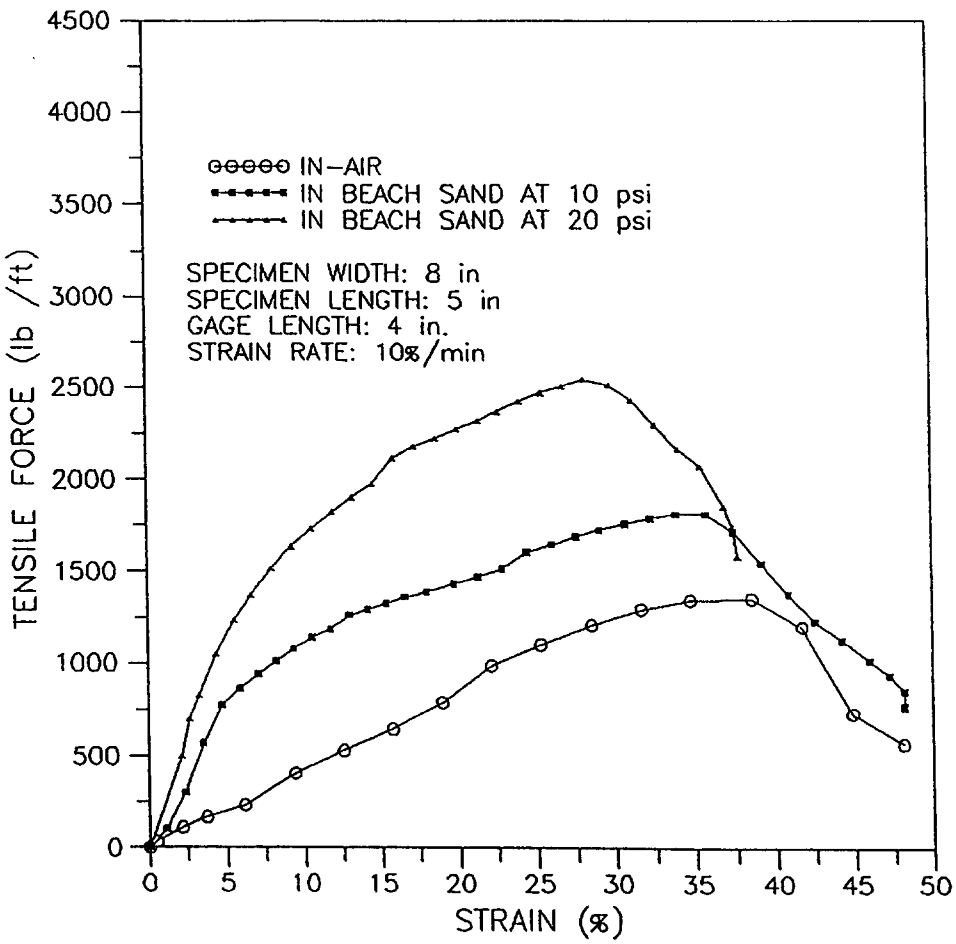
12.2.1 *Creep Curves* - There are three standard confined creep curves, a graph of total strain versus log of time, a graph of log of incremental strain rate versus log of time, and a graph of log of incremental strain rate versus total strain. Typical plots of these three curves are presented in figures 4, 5, and 6. The data are prepared by use of the following calculations:

12.2.1.1 *Time* - Elapsed time intervals are converted to hours and converted to the log of time (in hours).

12.2.1.2 *Total Strain* - The accumulated total strain at each interval is calculated (to the nearest 0.03 mm (0.001 in) of extension) using Eq 3.

12.2.1.3 *Incremental Strain Rate* - The incremental strain rate at each time interval is calculated as the change in strain, ϵ, with respect to time between two successive monitoring periods.

12.2.2 The data are then plotted as: (i) percent total strain as ordinate versus log of time as abscissa, (ii) log of incremental strain rate as ordinate versus log of time as abscissa and (iii) log of incremental strain rate as ordinate versus total strain as abscissa, see figures 4, 5, and 6). If several loads are used for testing, each plot shall be labeled clearly with the appropriate loading or force per unit width, expressed in N/m (lb/ft).



1 in = 25.4 mm
1 lb/ft = 14.59 N/m
1 psi = 6.89 kPa

Figure 3. Typical force versus strain response for a geosynthetic material during confined extension testing.

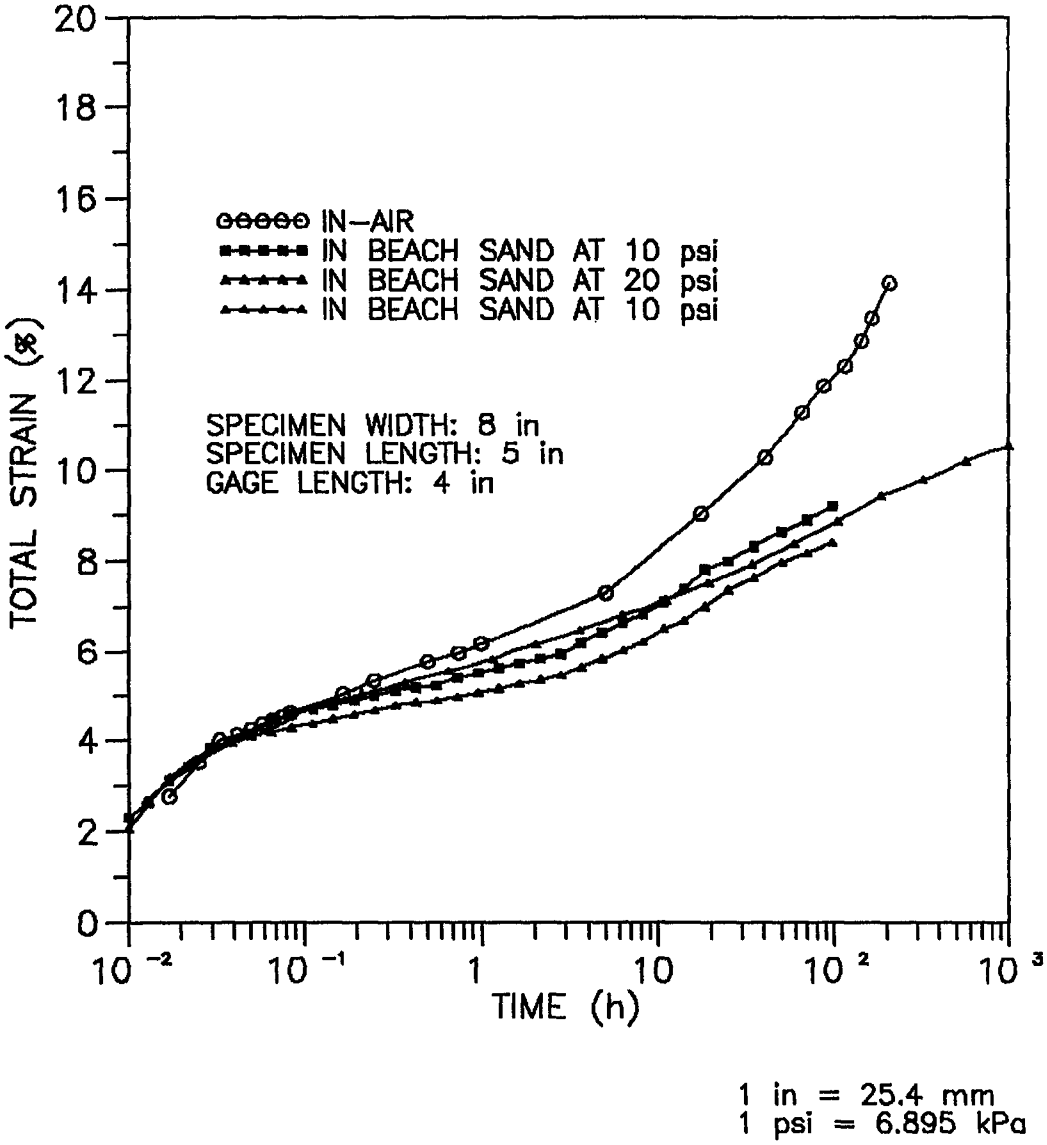
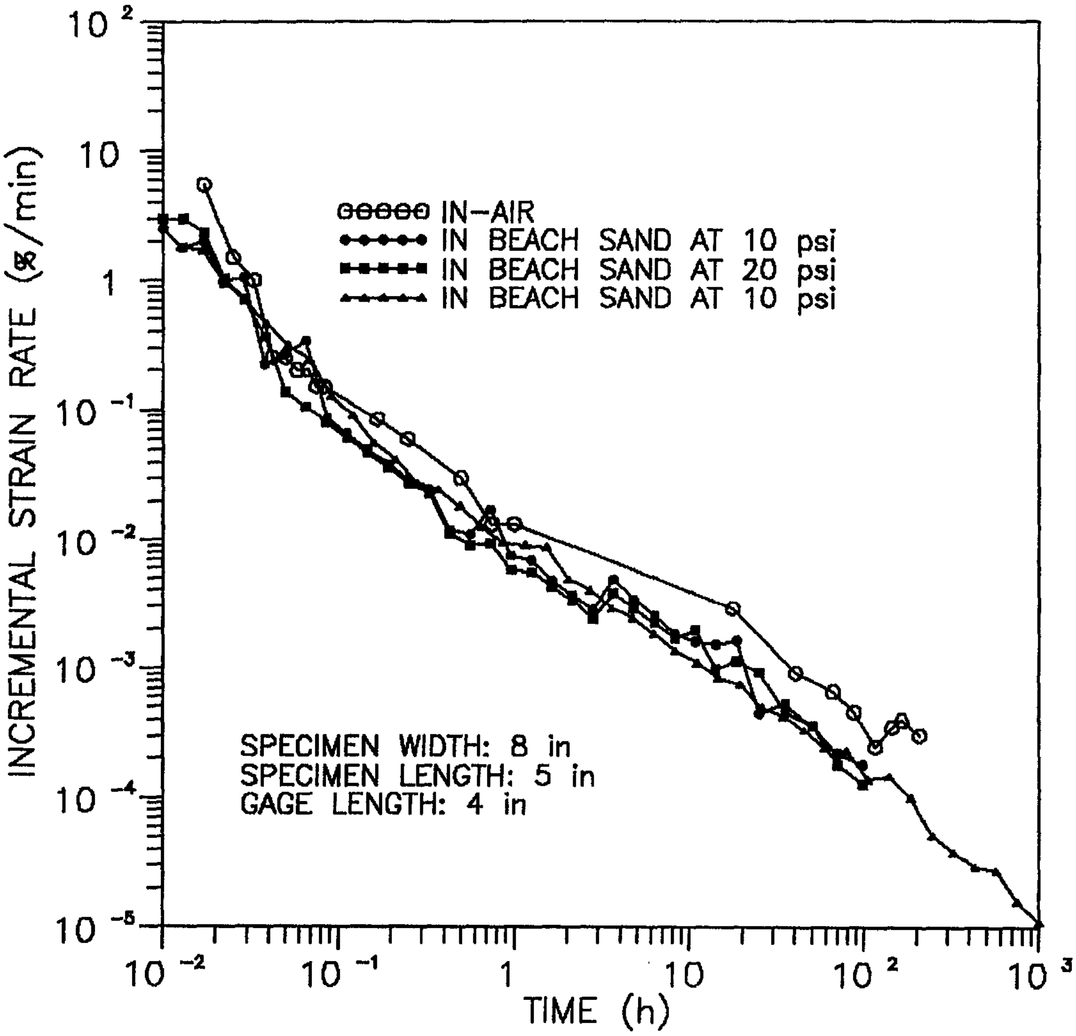


Figure 4. **Typical total strain versus log of time response for a geosynthetic material during confined creep testing.**



1 in = 25.4 mm
1 psi = 6.895 kPa

Figure 5. **Typical log of incremental strain rate versus log of time response for a geosynthetic material during confined creep testing.**

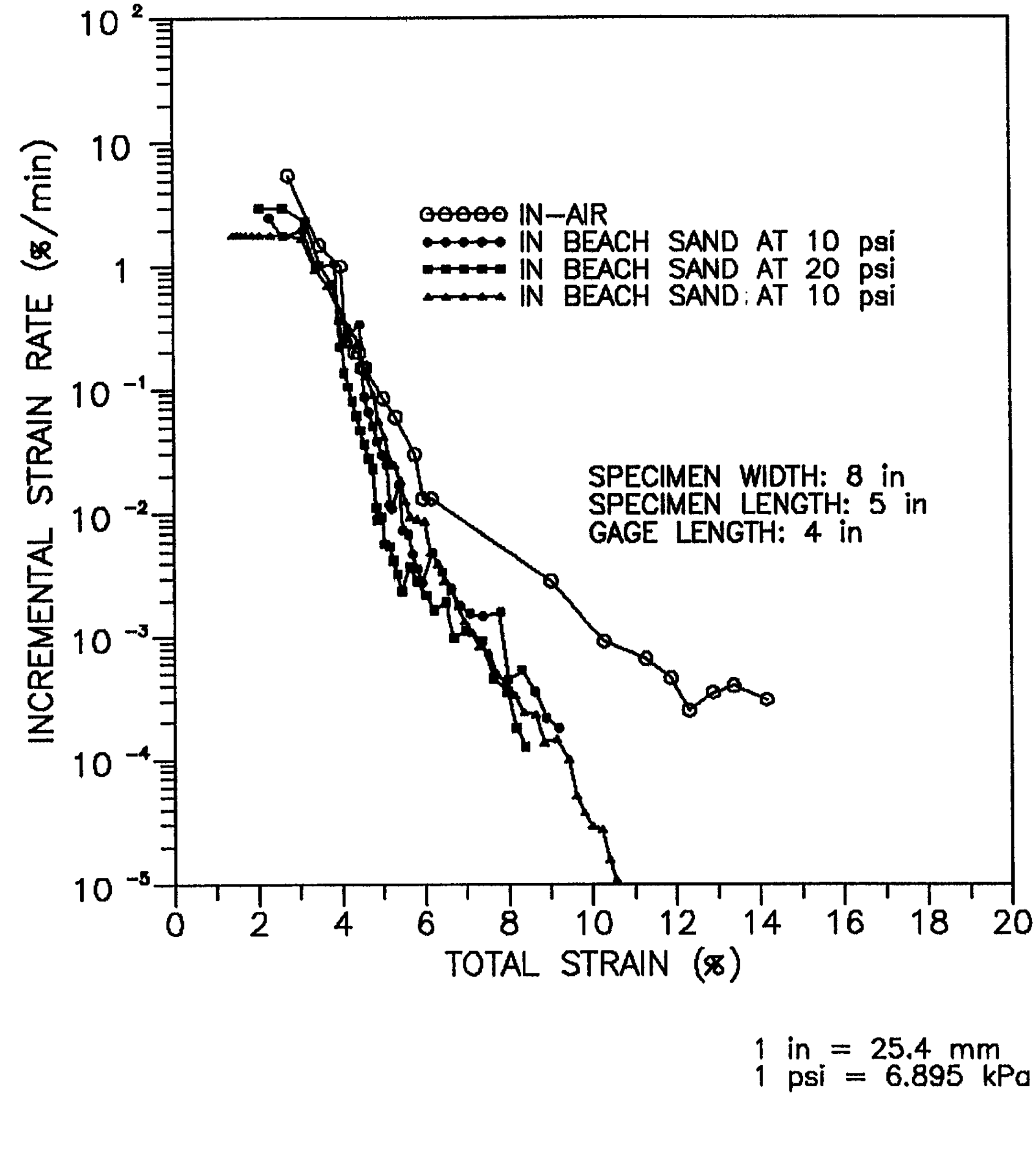


Figure 6. **Typical log of incremental strain rate versus total strain response for a geosynthetic material during confined creep testing.**

13. Report

13.1 *Confined Extension Tests:* The report should include the following information:

13.1.1 Description of test apparatus.

13.1.2 Test conditions, including which test procedure was used.

13.1.3 Any departures from standard procedure.

13.1.4 Notation that the specimens were tested as directed in this test method. Description of the material tested, including all pertinent information required for complete identification of the specimen.

13.1.5 Dimensions of the test specimen.

13.1.6 Identification of and description of soil, including soil classification, water content, unit weight, grain size, and other identifying information if available.

13.1.7 All basic data including normal stresses, tensile strength, initial tensile modulus, offset tensile modulus, and/or secant tensile modulus, strain at rupture, and, if requested, include a force versus strain curve for each test.

13.1.8 Description of the geosynthetic specimen conditions before and after testing.

13.2 *Confined Creep Tests:* The report should include the following information:

13.2.1 Description of test apparatus.

13.2.2 Test conditions, including which test procedure was used.

13.2.3 Any departures from standard procedure.

13.2.4 Notation that the specimens were tested as directed in this test method. Description of the material tested, including all pertinent information required for complete identification of the specimen.

13.2.5 Dimensions of the test specimen.

13.2.6 Identification of and description of soil, including soil classification, water content, unit weight, grain size, and other identifying information if available.

13.2.7 Dates of the confined creep tests.

13.2.8 For each test, plot of total strain in percent versus log of time in hours, log of incremental strain rate in percent/min versus log of time in hours, and log of incremental strain rate in percent/min versus total strain in percent under a given normal stress and creep load per unit width and as a percent of ultimate load as determined in appropriate ASTM test methods.

13.2.9 Description of the geosynthetic specimen conditions before and after testing.

14. Precision and Bias

14.1 Precision - The precision of the procedure in this test protocol is being established.

14.2 Bias - This test has no bias because the confined extension and creep behavior of geosynthetics are defined in terms of this test method.

15. Key Words

15.1 Geogrid; geosynthetics; geotextile; confined extension; confined creep; performance test.

APPENDIXES
(Nonmandatory Information)

X1. EXTENSOMETERS

X1.1 Three types of extensometers have been used successfully in testing geosynthetics.

X1.1.1 Direct reading extensometers are mounted directly on the geosynthetic. These extensometers typically consist of linear variable-differential transformers (LVDTs) units that read strain directly as the material extends. These units place an additional force (weight) on the material undergoing testing and may result in alteration of the force versus strain results. The user should determine that this additional force is or is not significant for the material being tested. This type of extensometer cannot typically be used during confined testing.

X1.1.2 Semi-remote reading extensometers use clamps that are mounted directly on the geosynthetic. Wires, pulley systems, or other physical devices connect the clamps to LVDT units. This type of extensometer are appropriate for confined testing, but provisions must be provided to protect the wires, etc., from influences due to confinement.

X1.1.3 Remote extensometers use clamps or markers that are mounted directly on the geosynthetic and sensing units that are mounted independently both of the geosynthetic and the clamps or markers. These sensing units use electromagnetic radiation, such as light, to sense the distance between the markers. These type extensometers may be inappropriate due to confinement.

X1.2 Users must bear in mind that clamps, markers, or other physical attachments can damage materials undergoing testing. This damage can cause premature failure in geosynthetics. It is of paramount importance to design and use clamps, markers, or other attachments in a manner that will not alter the test results by damaging the material undergoing testing.

X2. INITIAL GEOSYNTHETIC TENSILE MODULUS

X2.1 In a typical force versus strain curve (figure X2.1), there is usually a toe region *AC* that represents take up of slack, alignment, or seating of the specimen. For some geosynthetics, this portion can represent a significant part of the strain characteristic of the specimen. This region is considered when determining the initial geosynthetic modulus.

X2.1.1 The initial geosynthetic tensile modulus can be determined by dividing the force at any point along the straight-line projection of the force versus strain curve (i.e., line *AG* or its extension) by the strain at the same point (measured from point *A*, defined as zero strain).

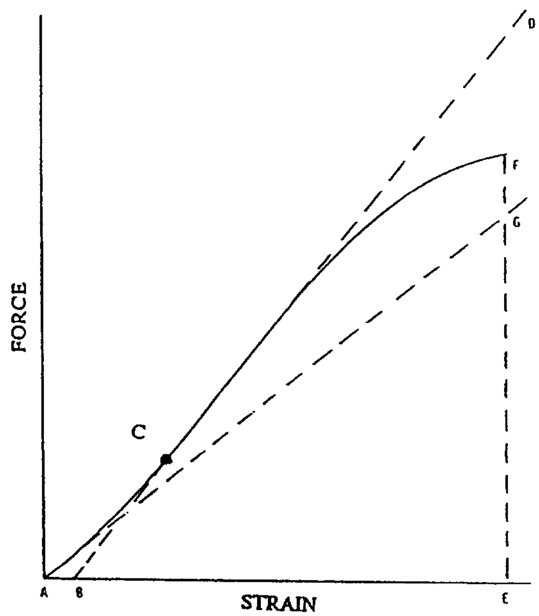


Figure X2.1. Material with Hookean region.

X3. OFFSET GEOSYNTHETIC TENSILE MODULUS

X3.1 In the case of a geosynthetic exhibiting a region of Hookean (linear) behavior (figure X2.1) after the nonlinear initial region, a continuation of the linear region of the curve is constructed through the zero-force axis. This intersection point *B* is the zero strain point from which strain is measured.

X3.1.1 The offset geosynthetic tensile modulus can be determined by dividing the force at any point along the line *BD* (or its extension) by the strain at the same point (measured from point *B*, defined as zero strain). The point where line *BD* first touches the force versus strain curve is the tangent point (i.e., point *C*).

X3.2 In the case of a geosynthetic that does not exhibit any linear region (figure X3.1), a line is constructed tangent to the point on the force versus strain curve exhibiting the maximum slope (i.e., point H'). This is extended to intersect the zero force axis at point B'. This intersection point B' is the zero strain point from which strain is measured.

X3.2.1 The offset geosynthetic tensile modulus can be determined by dividing the force at any point along line $B'K'$ (or its extension) by the strain at the same point (measured from point B', defined as zero strain).

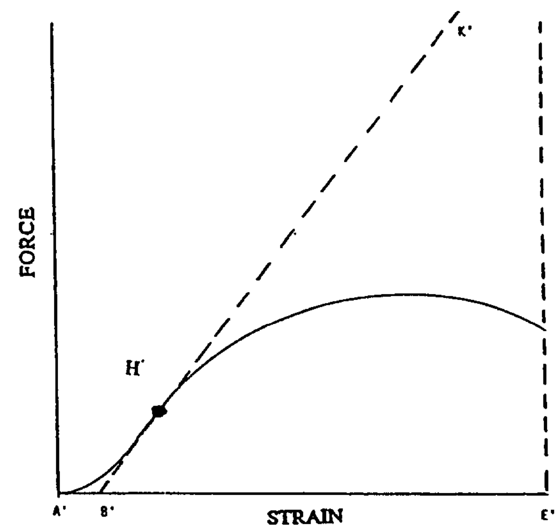


Figure X3.1. Material with no Hookean region.

X4. SECANT GEOSYNTHETIC TENSILE MODULUS

X4.1 In a typical force versus strain curve (figure X4.1), a straight line is constructed through the zero force axis, usually at zero strain point A'' and a second point usually at 10 percent strain, point M''. Point A'' is the zero strain point from which strain is measured.

X4.1.1 The secant geosynthetic tensile modulus at the selected strain level can be determined by dividing the force at any point along the line $A''M''$ (or its extension) by the strain at the same point (measured from point A'', defined as zero strain).

X4.1.2 Figure X4.1 also presents a straight line constructed through any two specified points where a secant modulus is to be calculated, point Q'' and point R'', other than zero and 10 percent strain. In this case, the line is extended through the zero force axis at point B''. This intersection is the zero strain point from which strain is measured. The secant geosynthetic tensile modulus can be determined by dividing the force at any point along line $Q''R''$ (or its extension) by the strain at the same point (measured from point B'', defined as zero strain). If this latter method is used, for example to account for zero-force offset due to removal of slack, etc., in the geosynthetic, the specified means for defining point Q'' and R'' should be identified in the testing report.

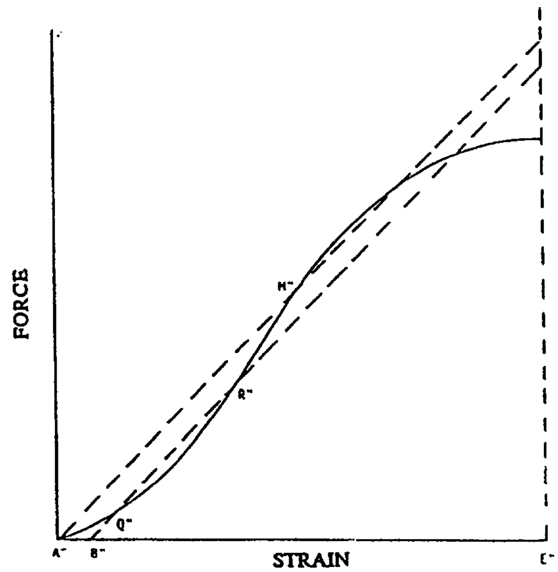


Figure X4.1. Construction line for secant modulus.

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