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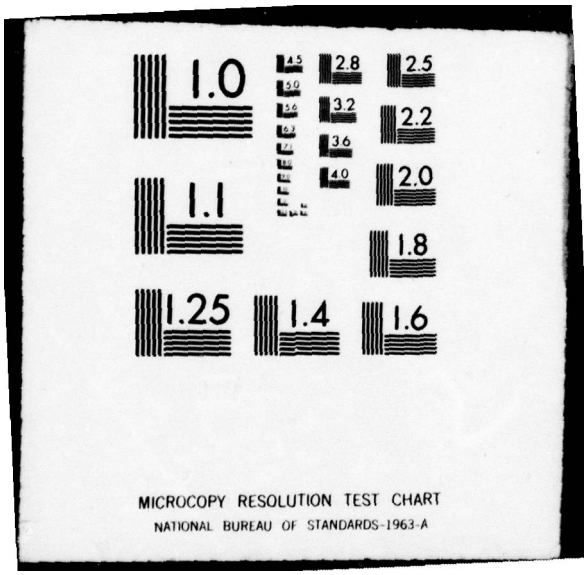
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TRUE LOAD-DEFORMATION RELATIONSHIPS FOR COATED AND UNCOATED FABRICS

by

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December 1978
Final Report

Prepared for Assistant Secretary of the Army (R&D)
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A baseline survey was prepared on the application of fabrics in civil engineering with an emphasis on the testing techniques by which physical and mechanical properties of fabrics and/or membranes are determined. It was found that several characteristics are required to fully evaluate a fabric's potential for use in civil engineering construction.

Standard test methods used with fabrics are not always adequate for this

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20. ABSTRACT (Continued)

evaluation, and new tests are being developed to evaluate fabrics under various specific conditions. These tests should be simple to perform, provide useful information, and be accepted as reasonable by both manufacturer and user. Both new test methods developed by other researchers and test methods presently being used for evaluating fabrics and/or membranes are discussed.

Several selected load versus elongation test methods were evaluated in the laboratory. For this evaluation, 10 fabric materials were selected. An attempt was made to select fabrics with a range of physical properties that would enable a better evaluation of the test methods. The Capstan linear variable differential transformer (LVDT) test, a unidirectional test method designed to accurately describe the load versus elongation relationships of both low- and high-strength fabrics and/or membranes, was devised. The results of the evaluation indicated that the Capstan test gives representative load versus elongation data for woven fabrics. The effects of slippage in the jaws on the elongation results were eliminated. This method could also be useful for obtaining load versus elongation properties of high-strength fabrics that cannot be tested by established test methods. When the nonwoven fabrics were tested using the Capstan method, distortion of the fabric caused a skewing of the clasps. This skewing resulted in a binding of the LVDT's, causing incorrect results. Major adjustments in equipment and procedure will be needed to eliminate the distortion problem. The 2-in. cut strip, an established unidirectional test method, was another method evaluated in the laboratory. It was found to be a useful test for woven fabrics with a breaking strength of less than 1000 lb per in. and where the true elongation of the fabric is not critical. The plane strain tensile testing device developed by Sissons at the University of Strathclyde, England, was also evaluated in the laboratory. This method allows restraint of the specimen at right angles to the direction of stressing. The plane strain test method is a workable multidirectional test method, but modification is necessary to restrict or eliminate the effects of the restraining device on the breaking strength of the material. The effect of the restraining device on the breaking strength is not as great with small loads as it is with large loads, and is less with nonwoven fabrics than it is with woven fabrics.

Further study of the evaluation of geotechnical fabrics and/or membranes is needed.

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PREFACE

The investigation reported herein was conducted under the Department of the Army Project No. 4A161101A91D, In-House Laboratory Independent Research (ILIR) Program, sponsored by the Assistant Secretary of the Army (R&D). This investigation was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) in the Geotechnical Laboratory (GL).

The investigation was performed during the period February 1977 to September 1978 under the general supervision of Messrs. J. P. Sale, Chief, and R. G. Ahlvin, Assistant Chief, GL, and the direct supervision of Messrs. W. L. McInnis, Chief, Materiel Development Division; S. G. Tucker, Chief, Membrane Branch; and Dr. M. M. Al-Hussaini, Engineer, Soil Mechanics Division. Mr. T. W. Vollor was the principal investigator and author of this report.

Commander and Director of the WES during the conduct of this study and the preparation of this report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	0.0254	metres
mils	0.0254	millimetres
ounces (mass) per square yard	33.90575	grams per square metre
pounds (force) per inch	175.1268	newtons per metre
pounds (force)	4.448222	newtons

TRUE LOAD-DEFORMATION RELATIONSHIPS FOR COATED AND UNCOATED FABRICS

PART I: INTRODUCTION

Background

1. A multitude of new fibers, fabric construction, and types of elastomers are available today. The uses of these materials have increased significantly, including uses in conjunction with soil structures. Woven and nonwoven fabrics are being investigated for use in field fortification for the Army, soil confinement for expedient bridge piers and abutments, stabilizing roads and railroads, filter blankets, reinforced earth walls, and many more applications. One of the most perplexing problems in the selection of membranes for specific uses is the development of adequate specifications to enable the purchase of the necessary products at a competitive price from a potential supplier. Quite often, methods of tests must be specified that are time consuming and valid only for comparison purposes. There is no specific information available that specifies methods of testing that will give the physical properties pertinent to the intended use of the membrane. Therefore, the selection of one membrane from similar available membranes must rely on personal judgment based on visual observation and prototype testing. Considerable information is furnished by suppliers listing typical properties of their materials, but these properties are not related to the uses of the material and cannot always be used to obtain an accurate comparison of materials. When high-strength fabrics and/or membranes are needed for a particular application, the problem of obtaining the useful physical properties of a fabric and/or membrane is magnified. Most test methods available are oriented toward wearing apparel or low-strength fabric applications rather than for heavy-woven industrial fabrics. Therefore, the available test methods designed for low-strength fabrics have been modified so that results with high-strength fabrics can be obtained. These modifications often make the

results less representative of the material and do not provide the proper information for making a judgment. Test methods and procedures are needed that can be used with both low- and high-strength fabrics and that will give the pertinent physical properties necessary for accurately assessing a fabric material.

2. Since both woven and nonwoven fabrics have a wide range of geotechnical uses, a brief discussion of each is presented in the following paragraphs.

a. The American Society for Testing and Materials (ASTM)[1] defines a woven fabric as "a planar structure comprising two or more sets of yarns interlaced in such a way that the elements pass each other essentially at right angles and one set of elements is parallel to the fabric axis." The yarns that run parallel to the fabric axis are called warp yarns and can be hundreds or thousands of yards long, depending upon the number of yards of warp originally wound on the loom beam.[2] The yarns that run perpendicular to the fabric axis are called filling yarns and are limited in length to the width of the loom doing the weaving. There are many types of fabric weaves available. The plain weave is the simplest and most common weave and the one from which all others are derived.[2]

b. The ASTM[1] defines a nonwoven fabric as "a textile structure produced by bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, or solvent means and combination thereof." Wool and other felts, paper, upholstery battings and waddings, in which fibers are not bonded together, are by general custom not considered to be nonwoven.[2] If the fibers are random, the nonwoven fabric normally becomes unidirectional with equal physical properties in all directions. However, the fibers can be oriented in the warp or machine direction of the sheet, making this direction the stronger.[2]

Both the woven and nonwoven fabrics can have resinous coatings applied to them. Selection of the coating resin is influenced by the physical and mechanical properties of coating and base fabric, together with the associated processing economies.[2]

Purpose

3. The purpose of this study was twofold: (a) evaluate the

usefulness of new test methods being developed by other researchers and old test methods commonly being used to assess the physical properties of fabrics and/or membranes for geotechnical uses; and (b) devise and evaluate a test method that more accurately describes the load versus elongation relationships of both low- and high-strength fabrics and/or membranes.

Scope

4. To achieve the objectives of this study, the literature was reviewed to identify the old test methods being used to evaluate fabrics and/or membranes and to identify new test methods being developed by other researchers. Some of these test methods are discussed in this report. The design of a new test method to give more accurate load versus elongation relationships in both high- and low-strength fabrics was undertaken by WES. This test method and other selected load versus elongation test methods were evaluated in the laboratory.

PART II: METHODS OF DETERMINING PHYSICAL PROPERTIES OF MEMBRANE FABRICS

5. Physical properties of fabrics and/or membranes are important in the selection of a material for a particular use. There are many test methods available to determine physical properties of fabrics and/or membranes. Many of the methods are designed to evaluate the same physical property yet the value obtained from each is entirely different. Therefore, it is important to be familiar with what tests are available and which of these would be most suitable in making a selection. Some of the areas of testing and methods used to determine physical properties in these areas are given below. The following discussion does not by any means include all the areas of testing, nor are the test methods presented representative of all the tests in a particular area.

Tensile and Elongation Tests

6. In general, there are two methods for determining the tensile strength and elongation of a membrane within its own plane: unidirectional and multidirectional.

Unidirectional test methods

7. The unidirectional class of test methods is used more frequently. Some of the more commonly used of these methods are discussed.

8. Grab test. The grab test recognized by ASTM D 1682[3] and Federal Test Method Standard (FTMS) No. 191, "Textile Test Methods," (Method 5100)[4] is a test using a minimum 4-in.-wide* by 6-in.-long sample. The center inch of the sample's width usually is gripped for the application of the load. The value of load obtained from the grab test is not only the strength of the 1-in.-wide area that is in the grips but also reflects supporting strength of the interconnected yarns around the 1-in.-wide area. The supporting strength may be of considerable

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* A table for converting U. S. customary units of measurement to metric (SI) units is given on page 4.

importance, depending on the expected application of load and also the type of fabric being tested. The grab test is limited to fabrics with strengths under 1000 lb per in. The elongation obtained using this test is not a true elongation but an apparent elongation. The initial gage length is not necessarily the length of fabric that was elongated. Depending on the fabric, there is pullout of fabric from between the clamps that will add to the original gage length.

9. Modified grab test. The modified grab test is a modification of the test discussed above. It is recognized in ASTM D 1682-64.[3] A 1-in.-wide area is gripped; however, lateral slits sever all yarns bordering the 1-in. area. Strength of the specimen is tested through weakening the fabric and causing it to break at the slits. This method offers little or no advantage over the grab test, except it will fail fabrics that cannot be failed with the grab method. The modified grab test introduces a tearing action at the slits as the sample elongates. The more elongation a fabric has, the more tearing action that is introduced. The results are of dubious value and prevent one from using the modified grab test to compare fabrics with different elongation properties.

10. Ravel strip test. The ravel strip test is recognized by ASTM D 1682-64[3] and FTMS No. 191, Method 5104.[4] The ravel strip test is one in which the specified width of sample is obtained by raveling away yarns from either side of the area of fabric to be tested. The method is used to determine the breaking load of a specific width of fabric. The advantage of the method is that the same number of yarns can be broken in each specimen, thus lowering the possibility of scattered results. The elongation results are apparent elongations for the same reason stated in the grab method. The method is only applicable to fabrics that can be raveled. The wider the test specimen, the more accurate the results. However, the wider the test specimen, the greater the total breaking load and the more difficult it is to hold the test specimen in the clamps.

11. Cut strip test. The cut strip test is recognized by ASTM D 1682-64[3] and FTMS No. 191, Method 5102.[4] The cut strip method is used

for testing the nonwoven fabrics, coated fabrics, and other fabrics not suited for the ravel strip test method. Due to the nature of the fabrics being tested with the cut strip, the number of broken yarns may vary. The cut strip test may cause a larger scatter of results than the scatter obtained with the ravel strip method. The elongation results are apparent elongations for the same reason stated in the grab test method. The wider the test specimen, the more accurate the results. However, the wider the test specimen, the greater the total breaking load and the more difficult it is to hold the specimen in the clamps.

Multidirectional test methods

12. The multidirectional class of test methods for determining load versus elongation properties of fabrics has not been commonly used. Neither ASTM nor FTMS No. 191 has a multidirectional test available. The load versus elongation of fabrics, especially nonwoven fabrics, is radically different when tested according to a unidirectional or a multidirectional test method. Therefore, the physical properties of fabrics determined by subjecting them to multidirectional loads are important in the selection of fabrics for use in soil structures or any application where the membrane is stressed in more than one direction. There are many new multidirectional test methods being developed, and two of these are described as follows.

13. Plane strain tensile test. At the University of Strathclyde, England, C. R. Sissons[5] developed a plane strain tensile testing device that allows restraint of the specimen at right angles to the direction of stressing. Restraint is accomplished by means of 10 lightweight wooden brackets in which steel pins are set. Details of bracket construction are given in Figure 1. The brackets comprise two wooden laths hinged together at one end. The test fabric is placed symmetrically over the pins in the bottom brackets, and pressed into place. The top brackets, with holes to take the pinpoints, are then swung across and clamped in position. Each end of the fabric is placed in jaws that clamp the full width of fabric. The gage length between clamps is 20 cm. An extension rate of 10 percent per minute is used. The major advantage of this test is the provision for restraining the specimen in the

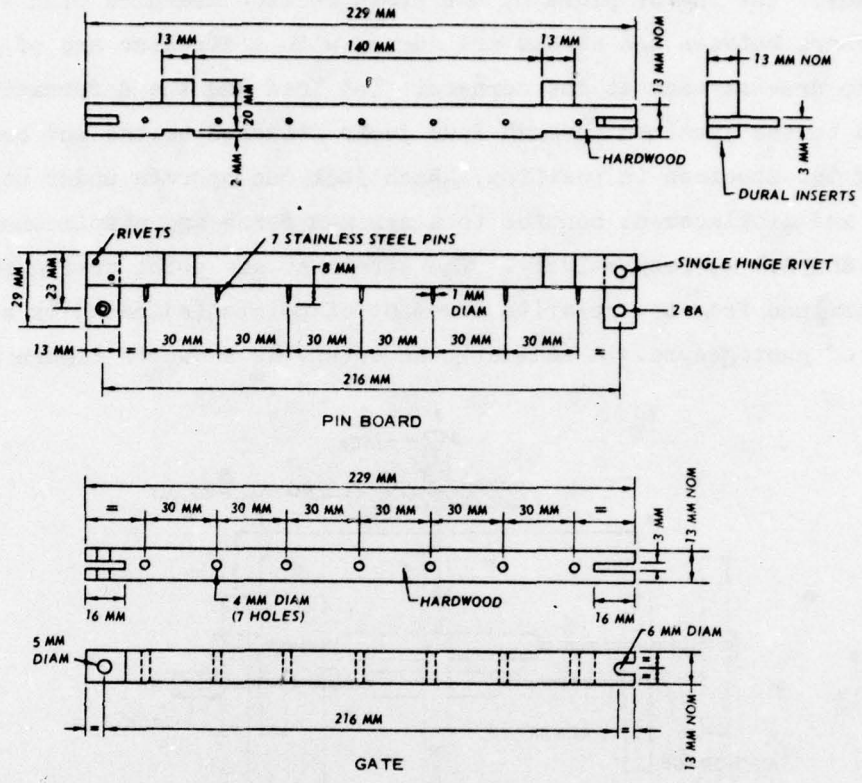


Figure 1. Detail of brackets used in plane strain test

direction perpendicular to loading, thus creating conditions that can be approximated by plane strain. However, with present procedures, the stress that results from the restraints is not measured, thus the stress-strain and strength are obtained in a manner similar to that used for unidirectional tensile tests. There is a localized loading on the fabric at the points where the needles enter the fabric, which is not typical of field conditions. Although the plane strain method is not perfect, it is a very promising test because of its simplicity and it requires no special skills to conduct.

14. Biaxial tensile test. This test was developed at the Civil Engineering Department of Delft University. The test, as described by Viergever and de Feijter,[6] consists of two mutually perpendicular grips. Each grip is made of two end beams held by two reaction rods. A cross-shaped specimen with four 0.15-m-wide project straps is clamped to the

end beams. The inside plane of the cross section measures 0.15 × 0.15 m, and corners between the straps are curved with a circular arc of radius 0.2 m to prevent tear at the corners. The load and the deformation are applied to the specimen through four jacks attached to the end beams holding the specimen in position. Each jack can operate under both stress and displacement control to a maximum force and displacement of 150 kN and 0.1 m, respectively. The strain at any point during the test is determined from the relative movement of points indicated by a sequence of photographs. A schematic of setups is shown in Figure 2.

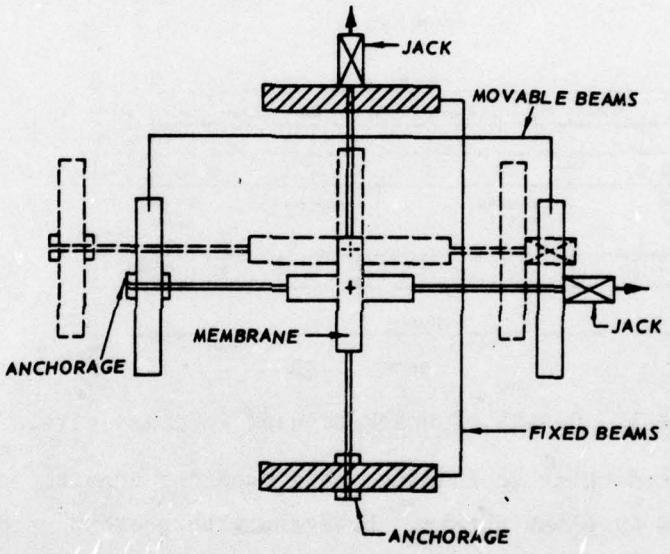


Figure 2. Biaxial tensile test

15. A number of uniaxial and biaxial tensile tests were conducted by Viergever and de Feijter[6] on plastic and other building material. The results indicated that the tensile strength under biaxial conditions is less than uniaxial tensile strength on the order of 10 percent.

Creep and relaxation test

16. Among the important physical properties of fabric is the increase in the length under constant but prolonged loading. Very little information is available about the time-dependent extension, or creep behavior, of yarn and fabric being used in civil engineering applications.

17. The creep test is very simple and requires little equipment. The testing equipment consists of a fixed frame for holding one end of the strip of fabric while a load of known magnitude is affixed to the other end. The deformation is recorded throughout the test.

18. Tests by Finnigan[8] on yarns and fabric subjected to a constant load have shown that the strain or creep at any time can be expressed as

$$\varepsilon_t = \varepsilon_o + Cf(t)$$

where

ε_t = the strain at any time

ε_o = initial elongation

C = constant called creep coefficient

t = time

It was also shown that $f(t)$ is a decreasing logarithmic function of time.

19. Tests by Finnigan[8] on polyester and polymide fabrics showed that 25 percent of the creep measured after 1000 hr was recorded within the first hour. Thus, data from a short-period test can realistically be extrapolated. Finnigan's tests demonstrated that applying twist to the specimen increased the rate of creep, whereas applying heat decreased the rate. Water had no influence on the results. A similar study on polyester and polymide by Van Leeuwen[7] showed that the creep strength was only about 60 to 80 percent of the standard uniaxial tensile strength, and that the creep of polyester was less than that of polymide.

Pressure Cell and Penetration Tests

20. In many field problems, the deformation occurs not only within the plane of the membrane, but also in a direction perpendicular or normal to the plane. Deformations perpendicular to the membrane plane may occur as a result of irregular subsoil or by severe differential

settlement or other reasons. In order to simulate this field condition in the laboratory, several devices have been proposed.

Pressure cell device

21. A pressure cell device for providing information about the deformation and penetration resistance caused by sharp stones has been described by Van Leeuwen.[7] The apparatus, as shown in Figure 3, consists of a round membrane specimen clamped between two hemispherical

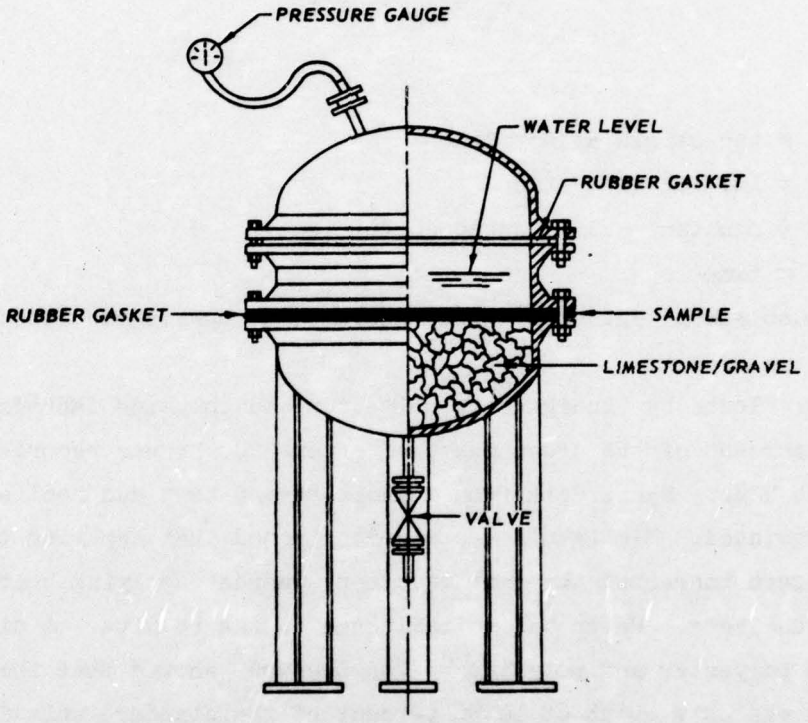


Figure 3. Pressure cell for testing materials

steel vessels with 60-cm inside diameter. The two hemispheres are connected through a circular ring by several bolts. The lower vessel is filled with a granular material such as sand, gravel, or crushed stone and covered with the membrane specimen that is sealed at the edges by a rubber gasket. Water pressure is applied at the top of the specimen, deforming it around the upper surface of the granular material. By measuring the volume change of the water at any applied pressure, it is possible to obtain information with regard to

stress-strain behavior and resistance to penetration by granular soils. Another pressure cell used to measure burst pressure is the conventional burst test, FTMS No. 191, method 5122. This method is used to blow the fabric into a hemispherical shape. Bursting occurs when further deformation of the fabric is not possible. The failure pressure gives a measure of the pressure necessary to cause rupture of the fabric in the field.

Cone penetration test

22. The energy absorption of the membrane is determined in the cone penetration test until leakage occurs as a result of cone penetration. The cone represents a falling stone. This test, as described by Viergever and de Feijter,[6] consists of a circular membrane 0.2 m in diameter mounted on a drum and clamped at the edges (Figure 4). The

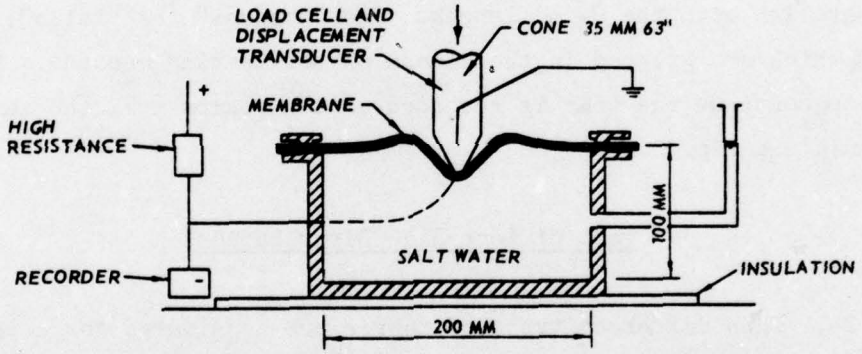


Figure 4. Principle of cone penetration test

drum is filled with water under atmospheric pressure. A cone of standard size is forced at the center of the membrane at a constant loading rate of 50 kN per sec up to a maximum force of 20 kN. A record of both force and deformation is obtained during the test. The material can be tested either by placing it on the drum without tension or by using specimens pretensioned to 60 kN per m^2 in one direction while preventing deformation in the perpendicular direction.

Tear Strength Test

23. Tear strength tests are designed to measure the amount of

force required to start or continue a tear in a fabric after the fabric has been damaged, for instance, by a sharp stone. In general, the loading on a fabric installed in the field takes place very slowly. Thus, the high velocity of the laboratory tear test has very little significance for design purposes. To simulate the in situ case, Sissons[5] described a tear test utilizing a 15-cm-square specimen and a pointed hook which serves dual purpose of causing the initial cut and providing the means to propagate the tear in a manner similar to that caused by a sharp stone. To simulate hand tearing or abuse of the fabric during installation, the tongue tear is a representative test. The tongue tear is in both ASTM D 2261[9] and FTMS No. 191, Method 5134. A 3- by 8-in. rectangular sample is cut from the fabric in the desired direction to be tested. In the center of the 3-in. direction, a 3-1/2-in. slit is made parallel with the 8-in. length. Two "tongues" (or "tails") are formed which are gripped in the clamps of the testing machine. The force to continue the tear is recorded as the clamps pull the sample to simulate a rip.

Test of Pore Size Distribution

24. When different types of fabric are considered for a particular engineering use, it is necessary to apply tests that give valid and comparable results for the pore size of different types of material. The pore size measured is usually the effective pore size for passage of material rather than the actual dimension.

25. A test procedure for determining the average pore size was developed by Ruddock[10] and can be described as follows. The fabric sample is stretched slightly taut over a wire sieve of coarse mesh 200 mm in diameter, and 30 g of a coarse grade ballotini (dry spherical glass balls) is placed on it. The sieve is vibrated in a sieve shaker for 10 minutes, and the amount of ballotini that passes through the fabric is then weighed. The procedure is repeated several times with finer grades of ballotini on the same sample. At least four grades of ballotini should be tried on each sample. If reproducible results can

be obtained for an individual fabric, then the curve of percentage of pores finer can be used as a measure of the pore size distribution or as an index for comparison between fabrics.

Summary

26. Three basic modes of strength testing may be considered. In the first mode, the membrane is subjected to tensile stress within its own plane. In the second mode, the membrane is subjected to forces normal to its plane. In the third mode, the load is applied directly at a spot with tearing action. In addition to strength tests there are mechanical properties, such as pore size, which must be considered. It follows, therefore, that several tests are required to fully evaluate a fabric's potential for use in civil engineering construction. These tests should be simple to perform, provide useful information about situations, and be accepted as valid by both manufacturer and user.

PART III: TEST MATERIALS AND TEST METHODS

Test Materials

27. Selection of test materials was based on type and construction of fabrics, strength and elongation properties, and availability of the fabric. An attempt was made to select fabrics with a range of physical properties that would enable a better evaluation of test methods. In order to obtain the range of physical properties desired, available information and manufacturers' specifications were used (Table 1). Some of the fabrics had no stated strength properties available. The two general types of fabrics selected for testing, woven and nonwoven, are described in the following paragraphs.

Woven fabrics

28. Reeves Bros. Inc. Style No. DE6635B. This material is a neoprene-coated, single-ply, Kevlar 29 fabric. The Kevlar 29 fabric weighs 7.0±0.5 oz per sq yd and is woven in a rip-stop weave with a double yarn every sixth yarn or every 1/4 in. and a yarn count of 24 by 24. The total weight of the material is 31±0.5 oz per sq yd. This material was chosen because the Kevlar fabrics have high strength with low elongation.

29. Reeves Bros. Inc. Style No. DE6636A. This material is a neoprene-coated, single-ply nylon 66 fabric. The nylon fabric weighs 5.5±0.5 oz per sq yd and is woven in a rip-stop weave with a double yarn every fifth yarn or every 1/4 in. and a yarn count of 20 by 20. The total weight of the material is 27±0.5 oz per sq yd. This material was chosen because the nylon fabric is similar to the Kevlar fabric described above but exhibits different strength and elongation properties.

30. Reeves Bros. Inc. Style No. DE15680. This material is a urethane-coated, single-ply, 1000-denier polyester fabric. The fabric weighs 5.5±0.5 oz per sq yd and is a plain weave with a yarn count of 22 by 22. The total weight of the material is 13.4±0.5 oz per sq yd. This material was chosen because it is a polyester fabric similar in weight to the nylon fabric discussed above. Also, this material has a

urethane coating, rather than a neoprene coating.

31. Sackurity. This material is a vinyl-coated, single-ply, 1000-denier polyester fabric. The fabric is a plain weave with a yarn count of 13 by 9. The total weight of the material is 12.6±0.3 oz per sq yd. This material was selected because of its unique construction. The fabric was coated using a vinyl foaming process that coated the yarns of the fabric without stopping up the openings between the yarn.

32. Laurel Erosion Control Cloth (LECC) Type I. LECC Type I is woven from a polypropylene monofilament yarn. It is a plain weave weighing 6.5±0.2 oz per sq yd with a yarn count of 30 by 18. This material was chosen because of the polypropylene monofilament yarn and because it is an uncoated fabric in a plain weave.

33. LECC Type II. LECC Type II is woven from a polypropylene monofilament yarn. It is a rip-stop weave weighing 6.5±0.2 oz per sq yd with five yarns woven every 7/8 in. in the warp and two yarns every 7/8 in. in the fill. The yarn count is 39 by 39. This material was chosen because of its weave and for comparison with LECC Type I.

Nonwoven fabrics

34. Typar 3401. Typar is a nonwoven fabric manufactured from continuous filaments of a spun-bonded polypropylene. The fabric is 15 mils thick and weighs 4 oz per sq yd. This material was chosen because it is a nonwoven fabric and because of the spun-bonded polypropylene construction.

35. Polyfelt TS400. Polyfelt TS400 is a nonwoven, continuous filament, needle-punched polypropylene fabric. The fabric is 177 mils thick and weighs 9.9 oz per sq yd. This material was chosen because of the polypropylene fiber and it is a needle-punched fabric.

36. Bidim C-34. Bidim C-34 is a nonwoven, continuous filament, polyester fiber needled to provide mechanical interlocking. The fabric is 90 mils thick and weighs 9.6 oz per sq yd. This material was chosen because it is a nonwoven polyester fabric.

37. Mirafi 140. Mirafi 140 is a nonwoven fabric constructed from two types of continuous filament fibers. One is entirely polypropylene, whereas the other is a polypropylene core encased in a nylon

sheath. The fabric has a thickness of 30 mils and weighs 4 oz per sq yd. This fabric was chosen because of its construction and the types of fiber used.

Test Methods

38. Many physical properties of fabrics must be considered in the selection of a material for a particular use. However, prime consideration is usually given to strength properties. As discussed in paragraph 20, there are three basic modes of strength tests: loads within plane of fabric, loads perpendicular to plane of fabric, and loads at a spot on the fabric. Due to the time and money constraints on this study, and an emphasis on load versus elongation test methods, only tests for properties when the force was within the plane of the fabric were selected for evaluation. Three tests of this type were evaluated and are described as follows.

2-in.-wide cut strip

39. The 2-in.-wide cut strip is used in a standard test method of the American Society for Testing and Materials ASTM D 1682.[3] It is a unidirectional test used to evaluate the load versus elongation of fabrics. The procedures of the ASTM test method were followed using a constant-rate-of-traverse tensile testing machine. In brief, three 2-in.-wide by 6-in.-long test samples were cut from the warp and fill directions using a die. The test samples were conditioned according to ASTM D 1682,[3] paragraph 8. The Instron model 1116, 50,000-lb testing machine was used to apply the load. The testing machine had a load scale selection that met the requirements of ASTM D 1682. A constant rate of traverse of 12±1/2 in./min was used. Instron G-61-3D pneumatic-hydraulic clamps were used to hold the test specimens with a variable force at the grip face in pounds. A 3-in. gage length was used with all test specimens. The front and rear jaw faces measured 1 in. in the direction of pull and 2 in. perpendicular to the pull. The load versus extension results were recorded on the testing machine's strip chart recorder.

Capstan linear variable
differential transformer (LVDT) test

40. The Capstan LVDT test is a unidirectional test method developed by WES in an effort to obtain a more nearly true load versus elongation relationship. The test samples followed the same conditioning as stated for the 2-in. cut strip method. The test samples were 2 in. wide by 26 in. long. The middle 12 in. of the test sample was cut using a die and the 7 in. on each end was cut using a template and knife. Instron model G-61-11F webbing Capstan grips (Photo 1) were used to hold the test sample on each end. Approximately 10 in. of fabric on each end of the sample was used in the Capstan grips leaving 6 in. out of the middle of the test specimen to be stressed. An extension-measuring device to obtain extension of the test sample during loading (Photo 2) was placed within the 6-in. length being stressed. The extension-measuring device used two spring-loaded clasps (Photo 2), which maintained a constant gripping force on the fabric during loading. A ±250-mil miniature LVDT was mounted on either side of the clasps (Photo 2) to measure the extension on both sides of the test sample. The extension recorded was the average of the two LVDT measurements. Gage length spacers (Photo 2) were used to position the clasp on the test sample so that an accurate gage length could be obtained. One-, two-, and three-inch gage lengths were used depending on the extension expected. The more extension expected, the smaller the gage length used. A 5000-lb load cell was used to measure the load and an X-Y recorder was used to record the extension versus load of the test sample. The Instron model 1116, 50,000-lb testing machine was used to apply a load to the test sample. A setup of the test is shown in Photo 3.

Plane strain tensile test

41. The plane strain tensile testing device was developed at the University of Strathclyde, England, by Sissons.[5] The integral part of this multidirectional test is that the fabric is restrained at right angles to the direction of load. This restraining force is achieved by means of lightweight wooden brackets with steel pins. WES, using Sissons' device, developed its own procedures for testing which are as

follows. A wooden form was constructed with three sides fixed and one side adjustable (Photo 4). The bottom halves of the wooden brackets, containing the pins, were placed in the form and held in place by sliding the adjustable side forward (Photo 5). The test sample, 20 cm wide by 30 cm long, was placed on the brackets (Photo 6). The other halves of the brackets were placed lightly on top of the fabric with care being taken to line up the pins with the receiving holes (Photo 7). A stiff wooden block was placed on the top (Photo 8) forcing the brackets down and causing the pins to penetrate the fabric and enter the receiving holes. Photo 9 shows the placement of metal dowels used to hold the brackets in position for removal from the form. After the test device was removed from the form, spring clips were placed over each of the brackets to hold them together (Photo 10) and the metal dowels could be removed from the brackets (Photo 11). The sample was then ready to be placed in the testing machine. Instron G-61-3D pneumatic-hydraulic clamps were used with specially constructed jaw faces (Photo 12). The jaw faces measured 25.5 cm perpendicular to the direction of load and 5 cm parallel to the direction of load. Bolt holes were placed on 23-cm centers so that added pressure could be put on the jaw ends. Photo 13 shows a sample placed in the jaws and ready to be loaded. A constant-rate-of-traverse speed of 12-1/2 in./min was used so that the results of this test could be compared with the results of the 2-in.-wide cut strip test method. The load versus extension results were recorded on a built-in strip chart recorder of the testing machine.

PART IV: RESULTS AND EVALUATION OF TEST METHODS

Results and Evaluation

42. Three test methods for stress-strain properties were selected for evaluation. The results and evaluation of these methods are presented in the following paragraphs.

2-in.-wide cut strip

43. The average results obtained using the 2-in.-wide cut strip test method are shown in Table 2. All the fabrics in the test program were tested using this method. The neoprene-coated Kevlar (DE6635B) fabric slipped in the jaws on the first attempt to break the fabric. Efforts were made to pin the fabric; however, slippage still occurred. The pins at the top of the jaws were forced down on the jaw edges, which cut the fabric. As a result, the fabric was weakened, and failure occurred at this point. The jaw size was modified to 2- by 2-in. front and rear faces. Pinning was still required to eliminate the excessive slippage. Using this setup, breaking strengths in the warp and fill directions were within 1 and 3 percent of the original values. Elongations of warp and fill were within 7.4 and 0.8 percent of original values. No problems were encountered clamping and holding any of the other fabrics. The elongation results of the cut strip were more scattered than the breaking strength results. The greater scatter of the elongation results was caused by the fabric pulled from between the jaws, causing a change in gage length. This pullout cannot be accurately measured so that the gage length can be corrected. Examination of the breaking strengths of the nonwoven fabrics showed a much lower value for breaking strength than expected. When comparing the breaking strength data of the nonwoven fabrics from Table 1 to that shown in Table 2, one can see that the cut strip test gives a much lower value of breaking strength than that value reported by the manufacturers shown in Table 1. During testing of the nonwoven fabrics, there was a large contraction of the test specimen perpendicular to the direction of load application. This caused a stress contraction at the narrowest

point thus causing a low total load failure. Therefore, the cut strip test method does not give a representative value of strength for the nonwoven fabrics tested. Thus, from the results of these tests, the cut strip test is a useful unidirectional test for woven fabrics whose breaking strength is less than 1000 lb per in. and where the true elongation of the fabric is not critical.

Capstan LVDT Test

44. Nonwoven fabrics. The results of the Capstan test method are shown in Table 2. The results obtained when testing the nonwoven fabrics were not consistent. The elongations of the nonwoven fabrics were larger than the ±250-mil miniature LVDT could measure. The ±250-mil LVDT will measure a deflection in one direction of 0.5 in. Using a 1-in. gage length would mean that a 50 percent elongation could be measured, although a 36 percent elongation was the maximum obtained during testing. Adjustments could have been made to the equipment, enabling the measurement of larger elongations. However, the distortion of the nonwoven fabrics when loaded was causing the LVDT to bind, thus giving erratic results even in the 0-36 percent range. Therefore, due to the distortion and large elongations characteristic of the nonwoven fabrics, no results were recorded using the Capstan test method.

45. Woven fabrics. As can be seen in Table 2, better results were obtained with the woven fabrics using the Capstan test method. The results from the woven fabrics indicated that an acceptable scatter of test values could be expected. No major problems were encountered with setting up the testing apparatus. A discussion of the results on each of the woven fabrics is as follows.

a. LECC Type I. Preliminary tests indicated that a 1-in. gage length should be used. Results of the test indicated little scatter and no obvious discrepancies in the warp and fill directions. Typical warp load versus elongation curves* from the Capstan test method and the cut strip test method are plotted in Plate 1. The curves display that the larger the load, the greater the differences in elongation of the two test methods. The

* The percent elongation for all curves was obtained by dividing the increase in fabric length by the original length multiplied by 100.

elongation at break using the Capstan test is 37.4 percent less than the elongation at the same load of the cut strip test. This large difference in elongation of the two test methods indicates that the slippage in the jaws of the cut strip method has a large effect on the elongation results. Typical fill load versus elongation curves resulting from the two test methods are plotted in Plate 2. Both fill load versus elongation curves follow essentially the same path up to approximately 1.5 percent elongation. At that point, the two curves show that the Capstan method has less elongation at the same load than the cut strip method shows. As the load increased, the difference in elongation became greater until at a breaking load of 280 lb, the elongation of the Capstan method was approximately 16.9 percent less than the elongation at the same load on the cut strip method. The tests indicate that there is a substantial difference between true elongation and the apparent elongation obtained from the cut strip method.

b. LECC Type II. Preliminary tests indicated that a 1-in. gage length was required. The Capstan test method gave good results in the warp direction when tests were conducted on the LECC Type II fabric. Typical warp load versus elongation curves for both the Capstan and cut strip methods are shown in Plate 3. The curves in Plate 3 are in close proximity to each other for approximately the first 6 percent of elongation. At that point, the Capstan curve separates from the cut strip curve. At a load of 190 lb per in., the elongation on the Capstan curve is 14 percent less than the elongation at same load on the cut strip curve. Due to problems with distortion of the fabric when loading in the fill direction, no meaningful results were obtained using the Capstan test method.

c. Sackurity. Preliminary tests indicated that a 1-in. gage length would be easier to work with on this fabric. The Capstan test method gave good results in both the warp and fill directions when testing the sackurity fabric, and little distortion of the fabric was noted. A typical warp curve obtained using the Capstan test method and one using the cut strip test method are shown in Plate 4. The curves of the two test methods are in close proximity to each other up to 4 or 5 percent elongation. After that, the elongation rate of increase of the Capstan test is less than that of the cut strip method. At failure, the elongation of the Capstan test was 33.5 percent less than that obtained with the cut strip test. A typical fill load versus elongation curve of the two methods is shown in Plate 5. The two curves can be considered the same until approximately 10 percent elongation and from that point start to separate. At failure, the elongation

for the Capstan test was 30 percent less than the elongation for the cut strip test.

d. DE15680. Preliminary tests indicated that a 1-in. gage length should be used. However, after testing the urethane-coated polyester fabric, it was obvious from the results that a larger gage length could have been used. The Capstan test method gave what appears to be good results in both the warp and the fill directions. Very little distortion of the fabric was observed during loading. Typical warp curves of the Capstan test method and the cut strip test method are shown in Plate 6. The two curves approximate each other up to about 4 or 5 percent elongation. The difference in elongation starts increasing at that point until at break the elongation of the Capstan test method is 66 percent less than the elongation of the cut strip test method. Typical fill curves of the Capstan test method and the cut strip test method are shown in Plate 7. More distortion was noted in the fabric during loading in the fill direction than in the warp direction. The average breaking strength using the Capstan test method was 72 lb per in. less than the breaking strength obtained using the cut strip method. The elongation at break in the fill direction was less than that obtained in the warp direction. The load versus deformation curves obtained when testing the urethane polyester fabric had some sharp breaks, which indicated that the LVDT's were binding due to the distortion of the fabric.

e. DE6636A. Preliminary tests indicated that a 1-in. gage length should be used. After testing was completed on the neoprene-coated nylon fabric, it was determined that a larger gage length could have been used. The Capstan test method gave what appears to be good results in the warp direction; however, because of distortion of the fabric when loading in the fill direction, the results were not considered accurate. Typical warp curves of the Capstan test method and the cut strip test method are shown in Plate 8. The breaking strengths of each of the three samples tested according to the Capstan test method were within 3 percent of the mean of the three results. The two curves are similar up to approximately 4 or 5 percent elongation, at which time the difference in elongation starts increasing until at break the elongation of the Capstan test method is 64.3 percent less than the elongation of the cut strip test method. The results obtained in the fill direction using the Capstan test method were not so good. Distortion of the fabric, which caused skewing of the LVDT's, was noted on all fill tests.

Typical load versus elongation curves of the Capstan and the cut strip are shown in Plate 9 for comparison. The Capstan curve shows an area of no deflection from load of 165 lb per in. to failure, or 253 lb per in., which indicates a binding of the LVDT. As can be seen in Table 2, the elongation in the fill direction was less than the elongation in the warp direction. This does not agree with the results obtained with the cut strip method, which showed a larger elongation in the fill than in the warp direction. Since it would be expected that the elongation in the fill direction would be larger than in the warp direction and because of the indicated binding of the LVDT's, the results obtained on the fill sample by the Capstan method are considered dubious.

f. DE6635B. Preliminary tests indicated that a 3-in. gage length could be used with the Capstan test method. The results obtained using the 3-in. gage length appeared to be good in the warp and fill directions. The breaking loads of the Capstan test method for the warp and fill directions were low when compared to the cut strip method. The reason for this apparent discrepancy is believed to be that the two tests used material from two different production runs of fabric. Difficulties holding the material in the jaws were encountered when using the cut strip method. The original material was depleted in an effort to obtain meaningful results, and a different run of the material had to be used to obtain results. Due to time and money restraints, the Capstan test method could not be rerun using the same run of material used in the cut strip method. Typical warp curves of the Capstan test method and the cut strip test method are shown in Plate 10. The breaking strengths of each of the three samples tested according to the Capstan test method were within 5 percent of the mean of the three results. The two curves do not follow each other initially as did the curves obtained with some of the other fabrics, but appear to show a difference in elongation from the beginning. This difference continued to increase until failure on the Capstan curve. Elongation of the Capstan curve was 71 percent less than the elongation at the same load on the cut strip curve. Typical curves for the Capstan and cut strip showing load versus elongation in the fill direction are shown in Plate 11. The curves obtained with the fill direction were smooth and appeared to be reasonable. The breaking strengths of each of the three samples tested according to the Capstan test method were within 11 percent of each other and the elongations at break were within 6 percent of each other.

Plane strain tensile test

46. The results of the plane strain test method are shown in Table 2. No results were obtained using the neoprene-coated Kevlar (DE6635B) fabric and the urethane-coated polyester (DE15680) fabric. The load required to break an 8-in. width of these fabrics was too large for the jaws used to hold the samples. Efforts to pin the fabrics in the jaws did not eliminate the slippage. Three fabrics, the neoprene-coated nylon (DE6636A), the LECC Type I, and the LECC Type II, also slipped out of the jaws when loaded but attempts to pin these fabrics did prevent slippage in the jaws. When the results obtained from the plane strain test and the results from the cut strip test are compared, the woven fabrics show less strength in both warp and fill directions for the plane strain test. Of the woven fabrics, the neoprene-coated nylon showed the greatest difference with 77 and 71 percent less strength in warp and fill directions, respectively. Difficulty was encountered in forcing the needles through the neoprene-coated nylon fabric, indicating that the pins were breaking or weakening the fibers in the yarns. During the testing of the neoprene-coated nylon samples, failures occurred at a very low load, and all failures seemed to involve a tearing action along a line of needles. The tearing action of the failure indicated an unevenness in the load distribution caused by the pins in the wooden brackets. Tearing action was observed with the other woven fabrics to a lesser degree. Damage to the nonwoven fabrics was not noted during the placement of the wooden brackets. The pins slipped through the nonwoven fabrics with very little force required. As shown in Table 2, the breaking strength obtained using the plane strain method of testing was higher than that obtained using the cut strip test. Table 2 also shows that the elongation of both the woven and nonwoven fabrics was less using the plane strain test. The decrease in elongation is attributed to the pins restricting the fabric from necking down. With a decrease in elongation, a higher breaking load is expected in order to have the same rupture energy. The rupture energy is the numerical value of the area under the load versus elongation curve. This would explain the increase in breaking strength of the nonwoven fabrics

obtained when using the plane strain test. The increase in breaking strength should have been evident when testing the woven fabrics. However, as explained earlier, the pins weakened the woven fabrics, causing a low breaking load to occur. The decrease in strength caused by the pins also occurred in the nonwoven fabrics but was not as evident. The plane strain test method is a workable test method, but modification is necessary to restrict or eliminate the effect of the pins on the breaking strength. The effects of the pins are low at initial loading, but this effect should be defined by a more comprehensive study.

Concluding Remarks

47. The results of the Capstan test indicate that the test can give representative load versus elongation data in woven fabrics. If the difference in the apparent elongation obtained from the cut strip test and the more nearly true elongations obtained from the Capstan test is as large as the test data indicate, then the Capstan test method would be extremely helpful where the load versus elongation properties of a fabric are important. The method also could be useful for obtaining load versus elongation properties of high-strength fabrics that cannot be tested by established test methods. When the nonwoven fabrics were tested using the Capstan method, distortion of the fabric caused a skewing of the clasps. This skewing resulted in a binding of the LVDT, causing incorrect results. Major adjustments in equipment and procedure will be needed to eliminate the distortion problem and permit nonwoven fabrics to be tested. The plane strain test method is a workable test method but must be modified to restrict or eliminate the effects of the pins on the breaking strength of the material being tested. The effect of the pins on the breaking strength is not as great with small loads as it is with large loads, and is less with nonwoven fabrics than it is with woven fabrics.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

48. Several characteristics of fabrics are required to fully evaluate a fabric's potential for use in civil engineering construction. Standard test methods used with fabrics are not always adequate for this evaluation, and new tests are being developed to evaluate fabrics under various specific conditions. These tests should be simple to perform, provide useful information about specific circumstances, and be accepted as reasonable by both manufacturer and user.

49. The standard or accepted test, cut strip, is a useful unidirectional strength test for woven fabrics whose breaking strength is less than 1000 lb per in. and where the true elongation of the fabric is not critical. The elongation at break obtained using the cut strip method is not accurate because of the slippage of the fabric in the jaws during testing. The amount of this error in elongation is dependent upon the loads involved when testing and the stretching properties of the material being tested. The results of this test on nonwoven fabrics do not appear to give a true representation of the fabric character. The results of the Capstan test indicate that it can give accurate load versus elongation data in woven fabrics. Major modifications would be required to attempt to test nonwoven fabrics with this test method. Since slippage in the jaws is not a problem with the Capstan grips, the method also could be useful for obtaining load versus elongation properties of high-strength fabrics that cannot be tested by established test methods. The plane strain test method using wooden brackets is a workable test method but needs modification to restrict or eliminate the effect of the pins on the breaking strength.

Recommendations

50. Based on the results of this study, the following recommendations are made:

a. Develop a multidirectional test method for determining strength versus elongation of a fabric.

b. Further study the Capstan versus the cut strip test, the grab test, and other conventional methods to more fully evaluate the accuracy of elongation measurements.

REFERENCES

1. American Society for Testing and Materials, "Standard Definitions of Terms Relating to Textile Materials," Designation: D 123-75, 1975 Annual Book of ASTM Standards, Part 32, 1975, Philadelphia, Pa.

2. Kaswell, E. R., Wellington Sears Handbook of Industrial Textiles, 1st ed., West Point Manufacturing Company, Inc., West Point, Ga., 1963.

3. American Society for Testing and Materials, "Standard Methods of Test for Breaking Load and Elongation of Textile Fabrics," Designation: D 1682-64, 1964 Annual Book of ASTM Standards, Part 24, 1964, Philadelphia, Pa.

4. U. S. General Services Administration, "Textile Test Methods," Federal Test Method Standard No. 191, Dec 1968, Washington, D. C.

5. Sissons, C. R., "Strength Testing of Fabrics for Use in Civil Engineering," International Conference on the Use of Fabrics in Geotechnics, Paris, France, Vol II, 1977, pp 287-292.

6. Viergever, M. A. and de Feijter, J. W., "Biaxial Tensile Strength and Resistance to Cone Penetration of Membrane," International Conference on the Use of Fabrics in Geotechnics, Paris, France, Vol II, 1977, pp 311-315.

7. Van Leeuwen, J. H., "New Method of Determining the Stress-Strain Behavior of Woven and Nonwoven Fabrics in the Laboratory and in Practice," International Conference on the Use of Fabrics in Geotechnics, Paris, France, Vol II, 1977, pp 299-304.

8. Finnigan, J. A., "The Creep Behavior of High Tenacity Yarns and Fabrics Used in Civil Engineering Application," International Conference on the Use of Fabrics in Geotechnics, Paris, France, Vol II, 1977, pp 305-307.

9. American Society for Testing and Materials, "Standard Test Method for Tearing Strength of Woven Fabrics by the Tongue (Single Rip) Method (Constant-Rate-of-Extension Tensile Testing Machine)," Designation: D 2261-71 (reapproved), 1976 Annual Book of ASTM Standards, Part 32, 1976, Philadelphia, Pa.

10. Ruddock, E. C., "Tests on Woven and Non-Woven Fabrics for Pore Size and Damage by Aggregate," International Conference on the Use of Fabrics in Geotechnics, Paris, France, Vol II, 1977, pp 317-321.

Table 1

Physical Properties Available for Fabric Selection

Fabric Name	Physical Properties							
	Weight oz/sq yd	Thickness mils	Breaking Strength lb/in.		Elongation at Break percent		Tearing Strength lb	
			Warp	Fill	Warp	Fill	Warp	Fill
Woven Fabrics								
DE6635B	31.0±0.5	29	1063	942	12	15	141	140
DE6636A	27.0±0.5	27	385	224	20	25	75	69
DE15680	13.4±0.5	20	--	--	--	--	--	--
Sackurity	12.6±0.3	22	350	200	--	--	--	--
LECC Type I	6.5±0.2	14	--	--	--	--	--	--
LECC Type II	6.5±0.2	17	--	--	--	--	--	--
Nonwoven Fabrics								
Typar 3401	4.0	15	130	--	6.2	--	70	--
Polyfelt TS400	9.9	177	309	--	110	--	64	--
Bidim C-34	9.6	90	255	--	70	--	125	--
Mirafi 140	4.0	30	110	--	110	--	--	--

Table 2

Load and Elongation Test Evaluation Results

Fabric Name	2-in. Cut Strip				Plane Strain with Wooden Brackets				Capstan LVDT Test			
	Breaking Strength lb/in.		Elongation at Break percent		Breaking Strength lb/in.		Elongation at Break percent		Breaking Strength lb/in.		Elongation at Break percent	
	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
Woven Fabrics												
Sackurity	223	132	23	28	196	107	19	25	233	128	16	21
LECC Type I	298	154	23	30	244	139	18	25	274	134	13	22
LECC Type II	208	160	29	25	170	180	24	22	172	140	20	13
DE15680	387	290	19	23	--	--	--	--	381	218	11	10
DE6636A	385	267	24	26	85	75	15	19	383	244	15	9
DE6635B	1130	1138	15	18	--	--	--	--	985	732	4	3
Nonwoven Fabrics												
Mirafi 140	35	34	67	78	44	42	57	63	--	--	--	--
Polyfelt TS400	126	68	98	128	133	78	94	126	--	--	--	--
Bidim C-34	108	96	52	57	117	130	42	43	--	--	--	--
Typar 3401	45	34	39	35	51	35	39	34	--	--	--	--

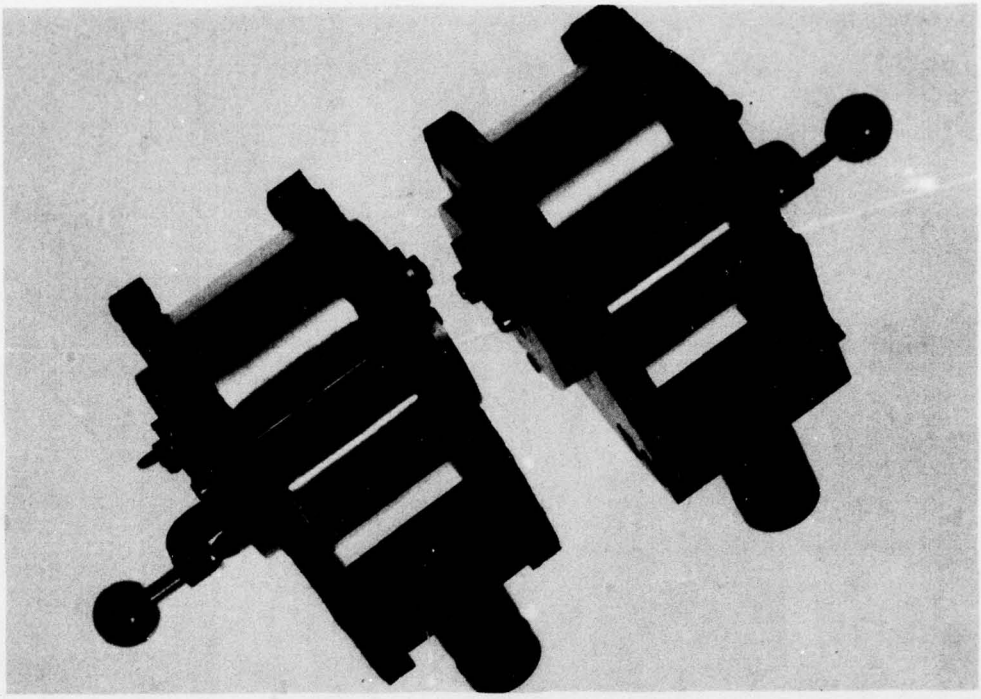


Photo 1. Instron model G-61-11F webbing Capstan grips

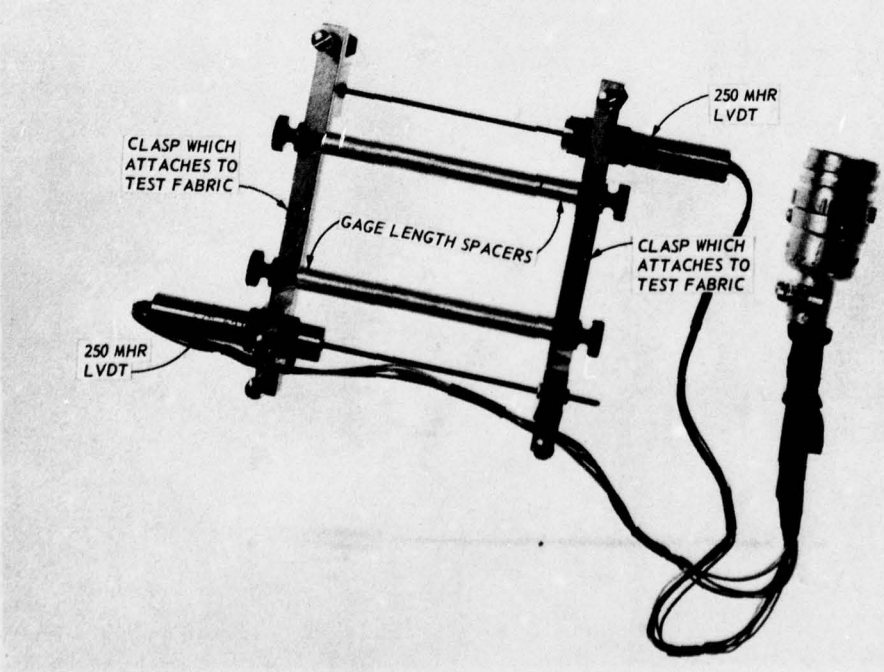


Photo 2. Extension-measuring device for Capstan test

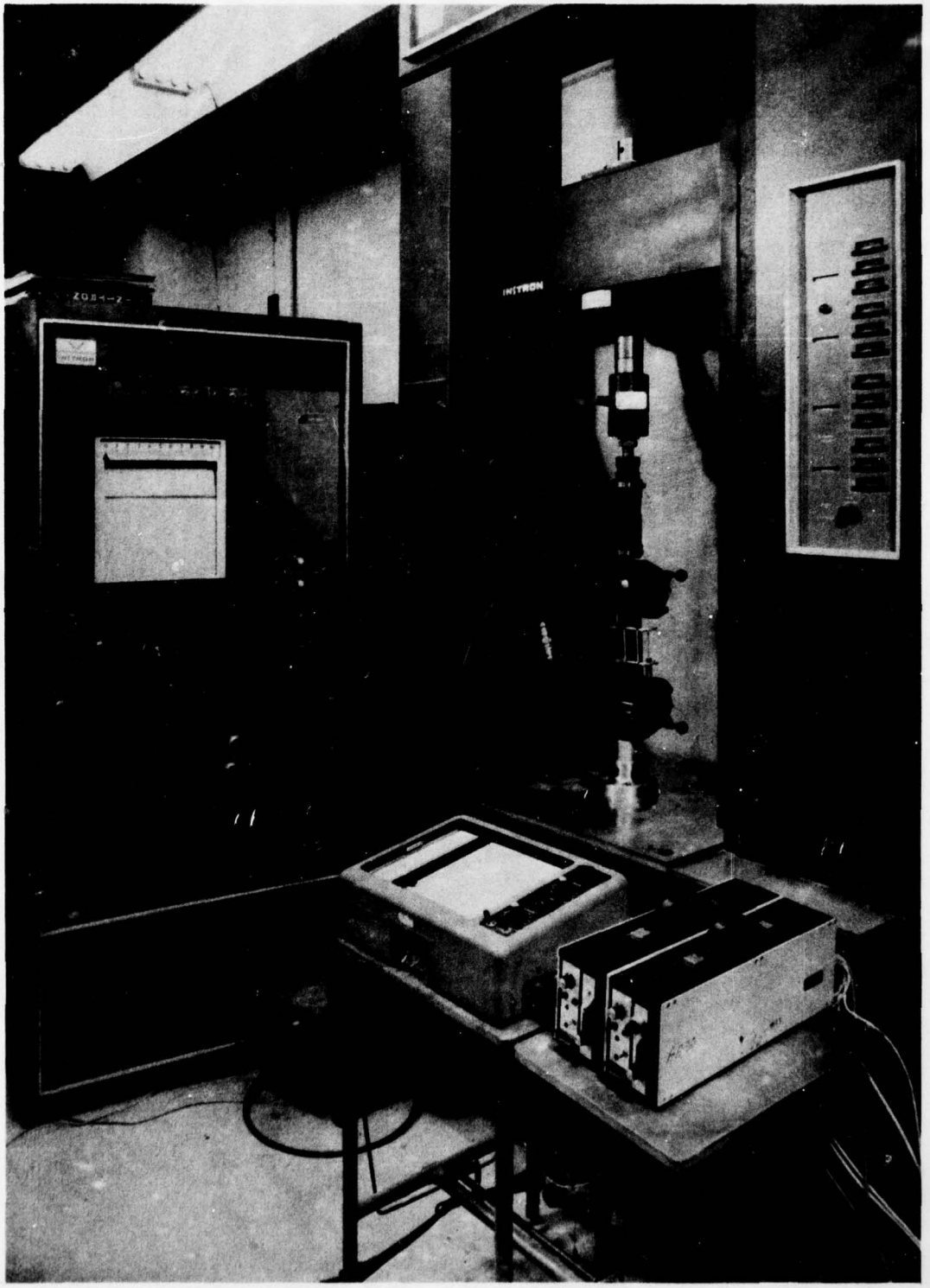


Photo 3. Capstan test setup

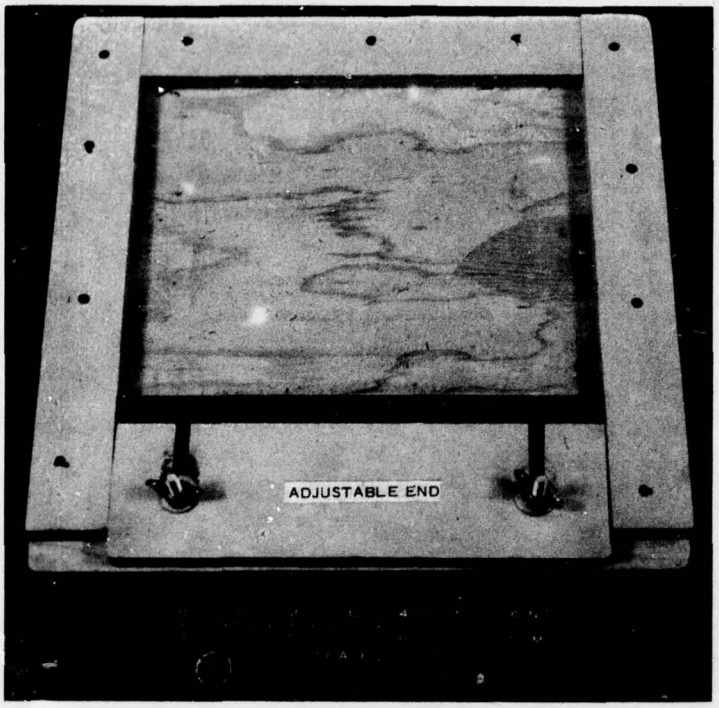


Photo 4. Wooden form for plane strain testing device

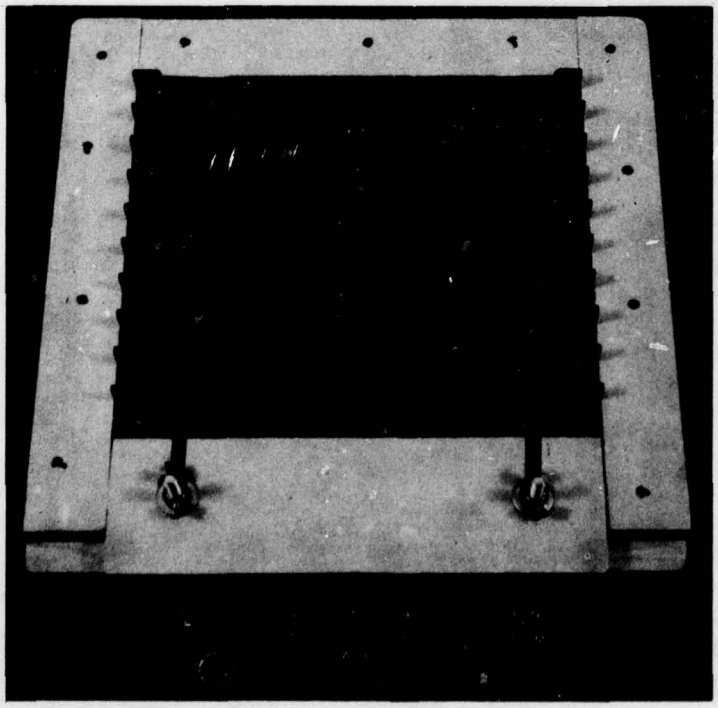


Photo 5. Wooden form with bottom brackets in place

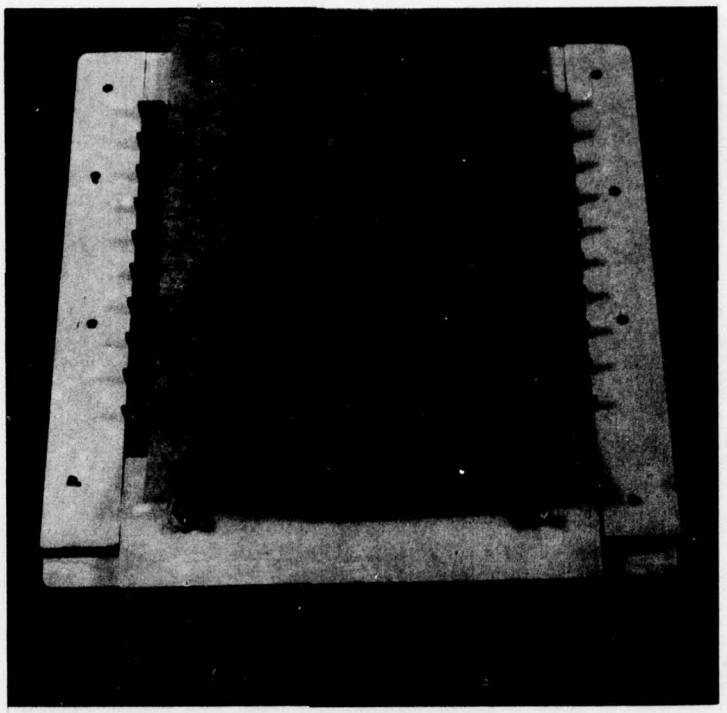


Photo 6. Placement of fabric on brackets

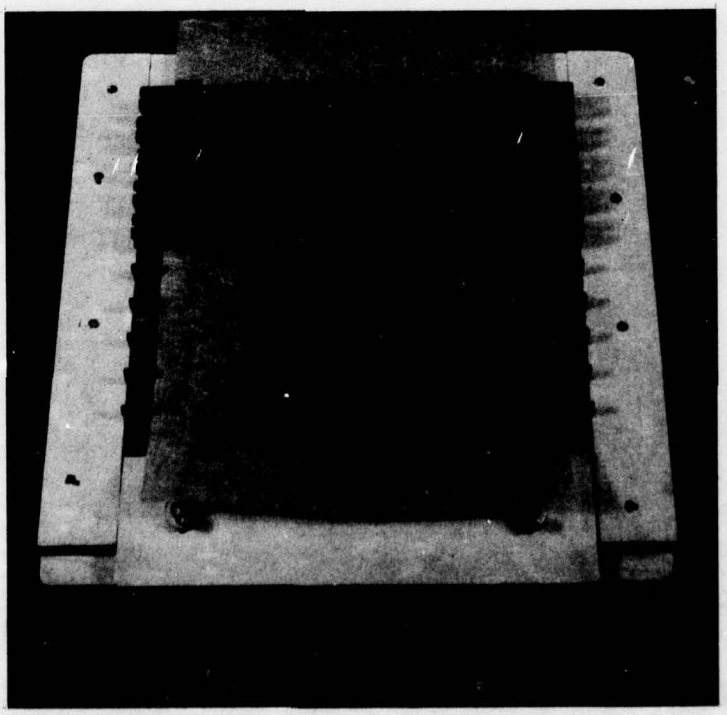


Photo 7. Placement of top brackets

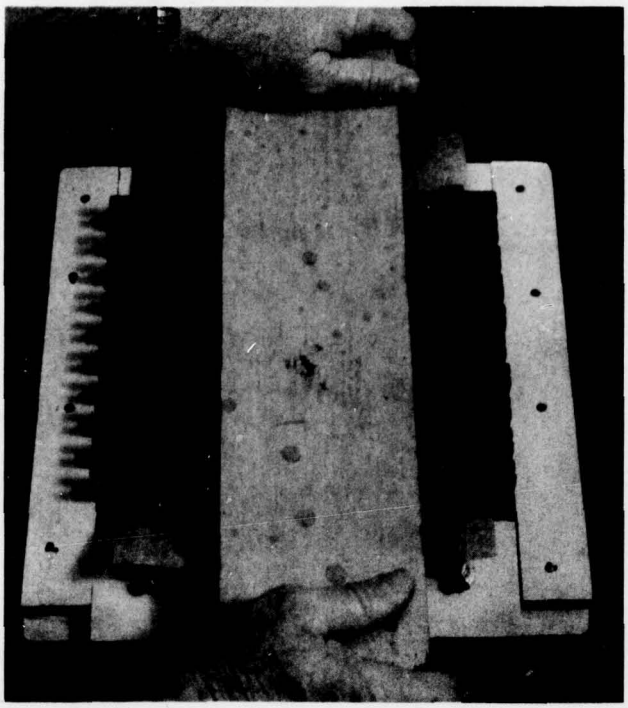


Photo 8. Setting of pins in fabric

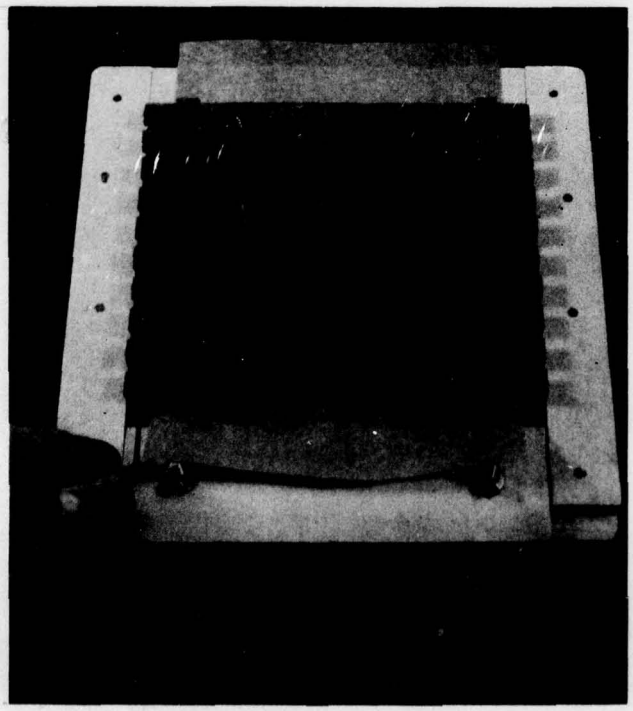


Photo 9. Placement of metal dowels

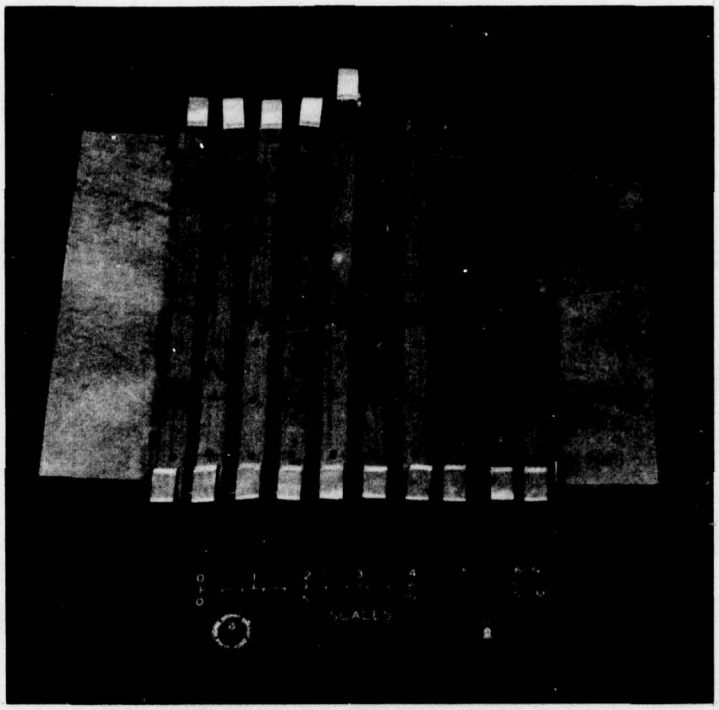


Photo 10. Placement of metal spring clips

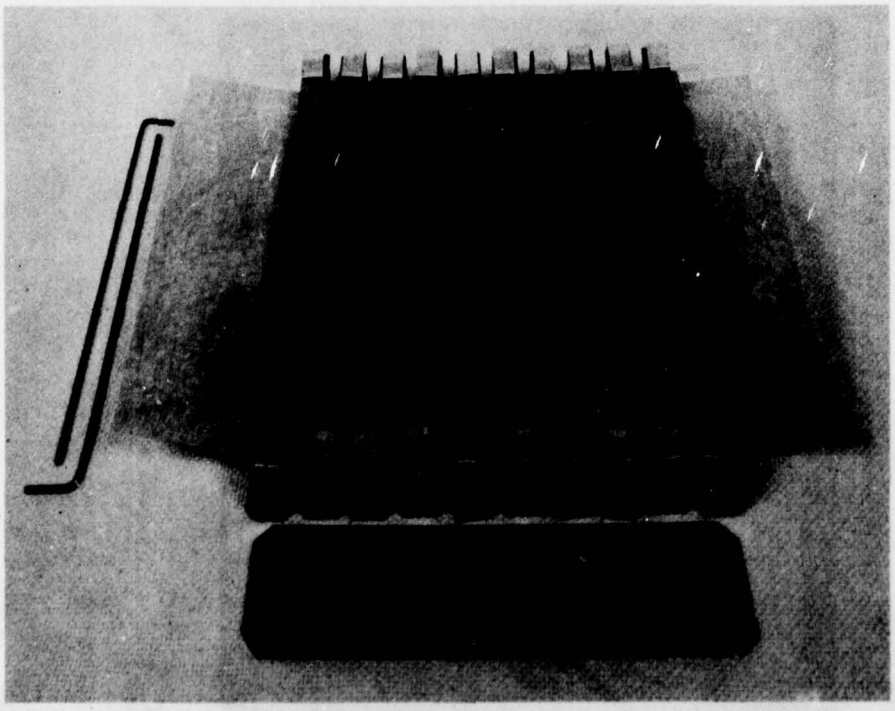


Photo 11. Plane strain testing device with metal dowels removed

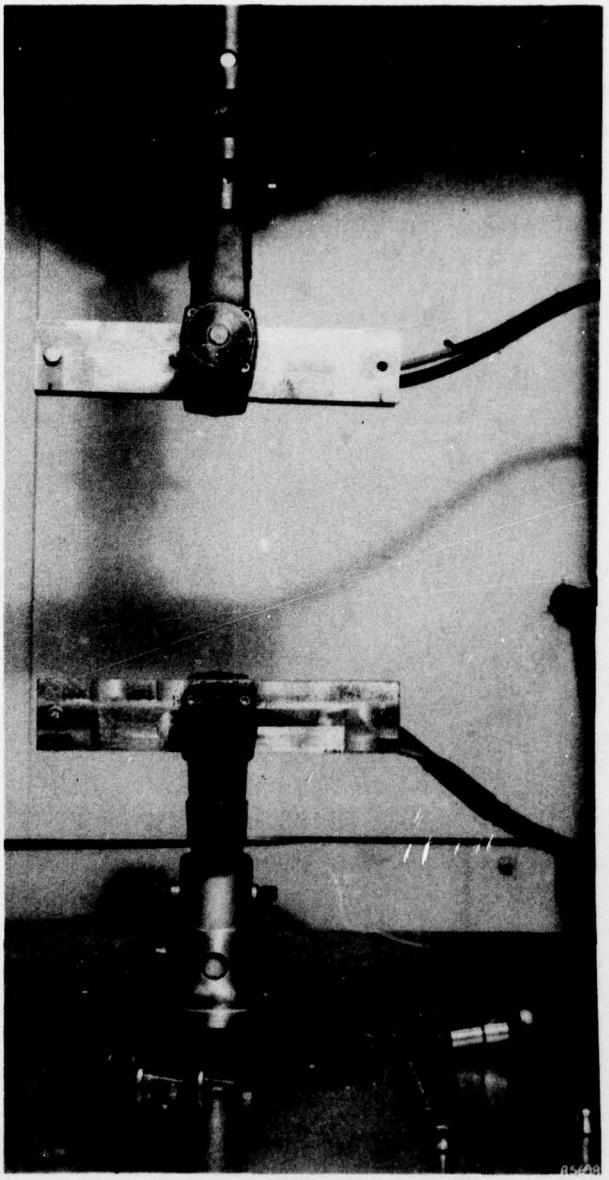


Photo 12. Instron G-61-3D pneumatic-hydraulic clamps

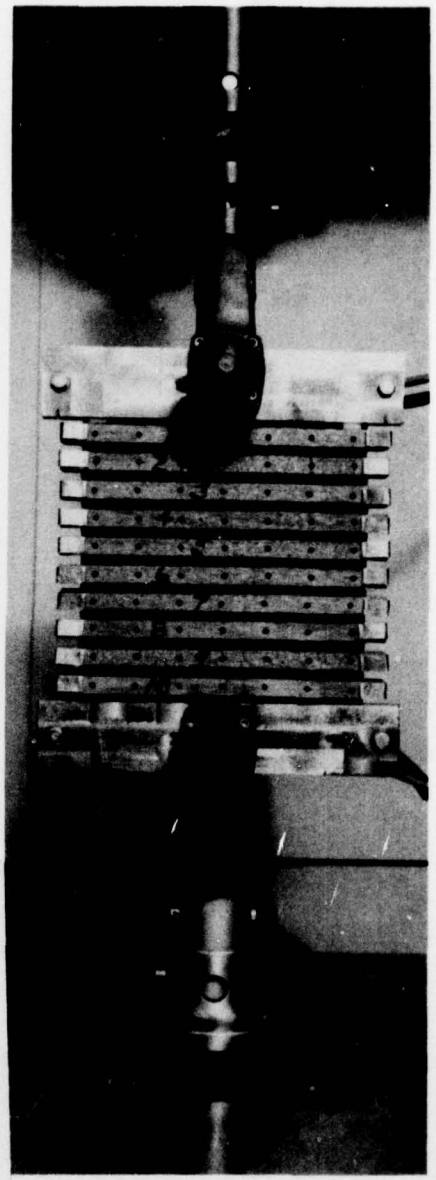
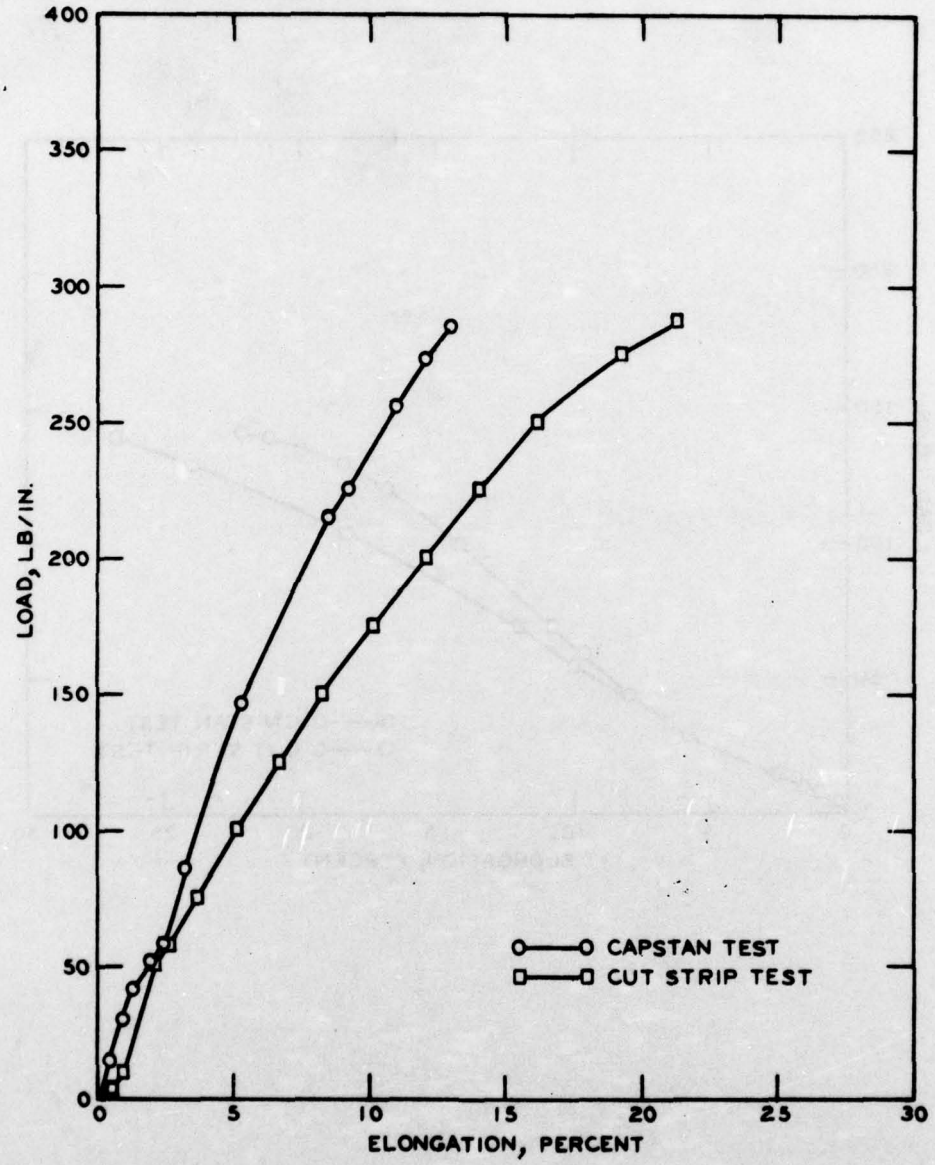


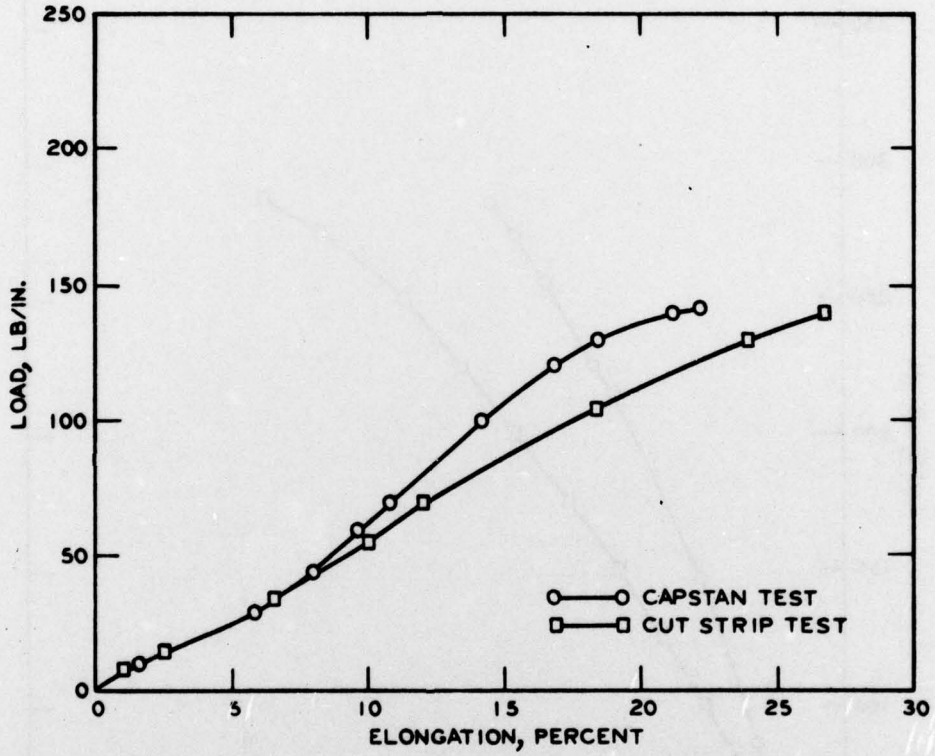
Photo 13. Sample placed in jaws and ready for load application



EROSION CONTROL CLOTH TYPE I

TYPICAL WARP CURVES

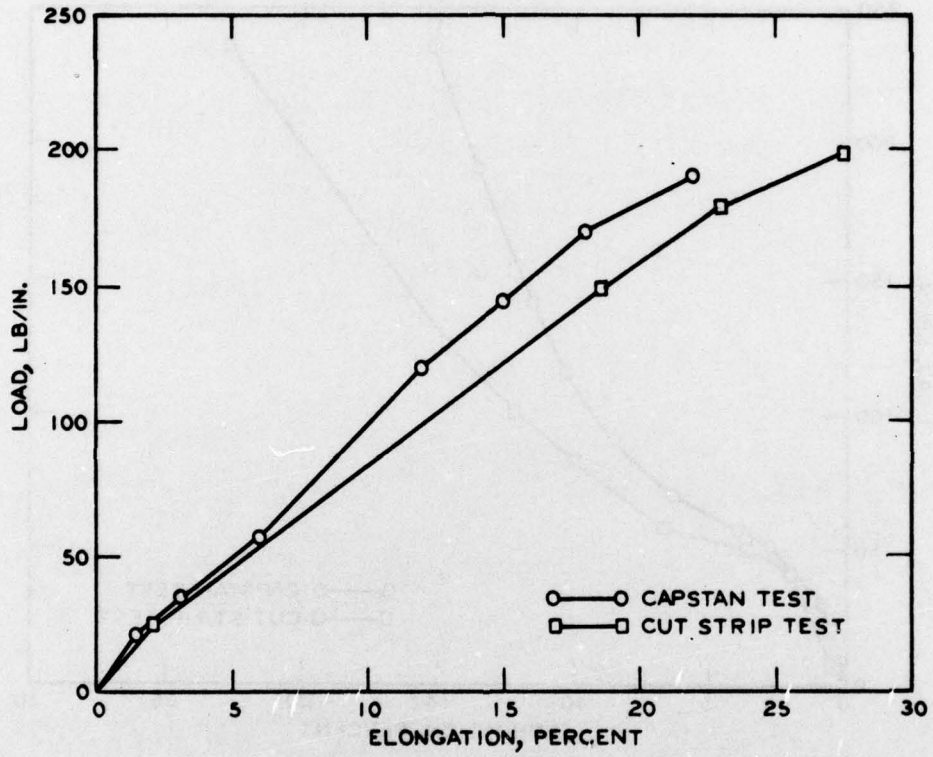
PLATE I



EROSION CONTROL CLOTH TYPE I

TYPICAL FILL CURVES

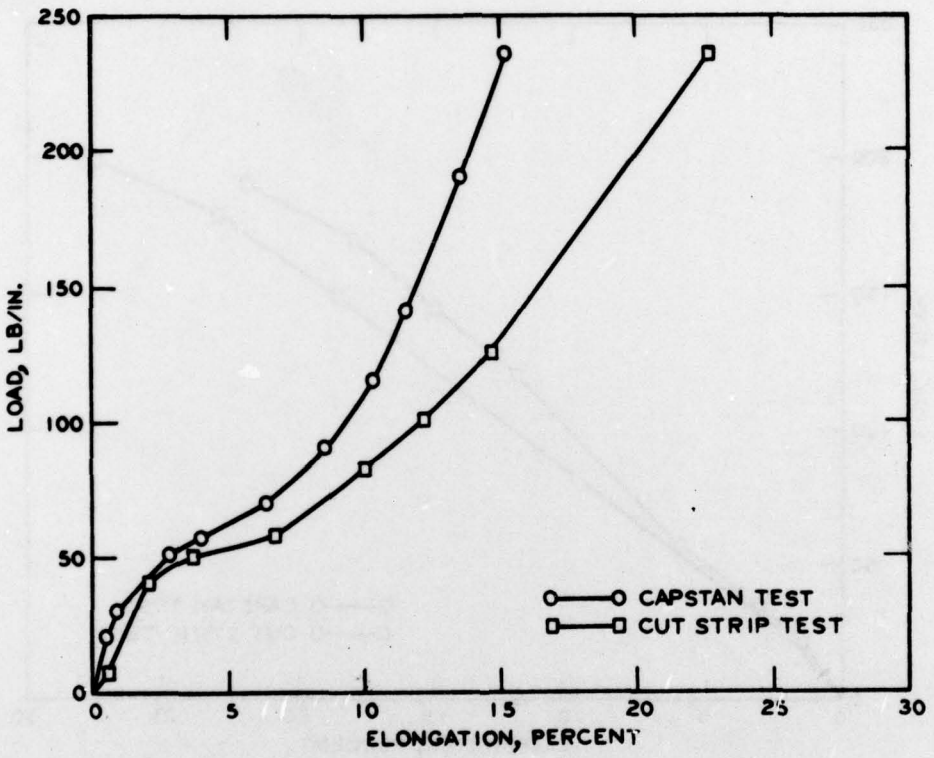
PLATE 2



EROSION CONTROL CLOTH TYPE 2

TYPICAL WARP CURVES

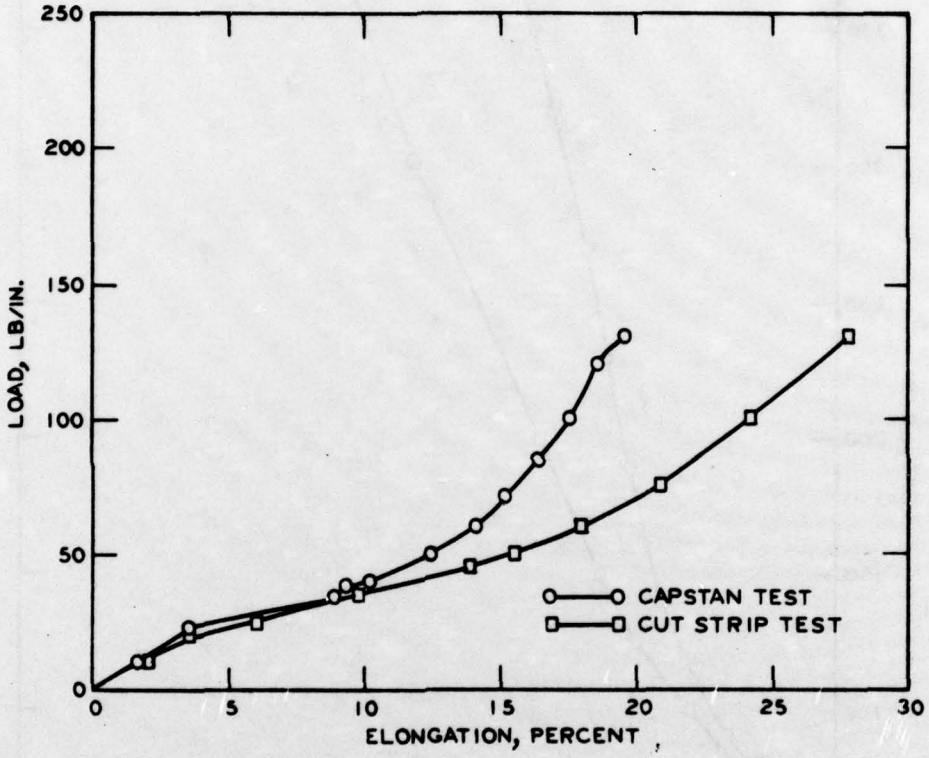
PLATE 3



SACKURITY BAG

TYPICAL WARP CURVES

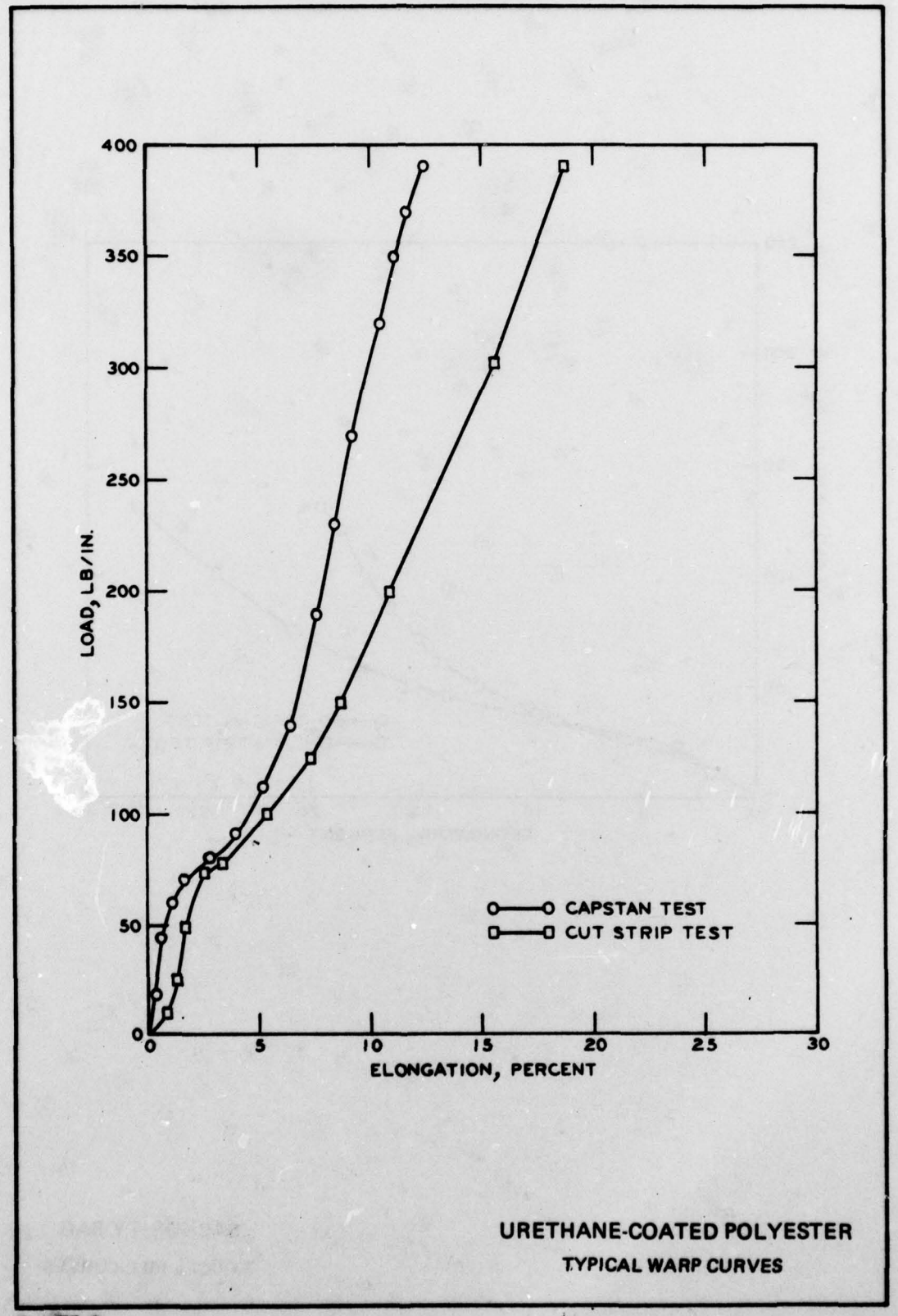
PLATE 4



SACKURITY BAG

TYPICAL FILL CURVES

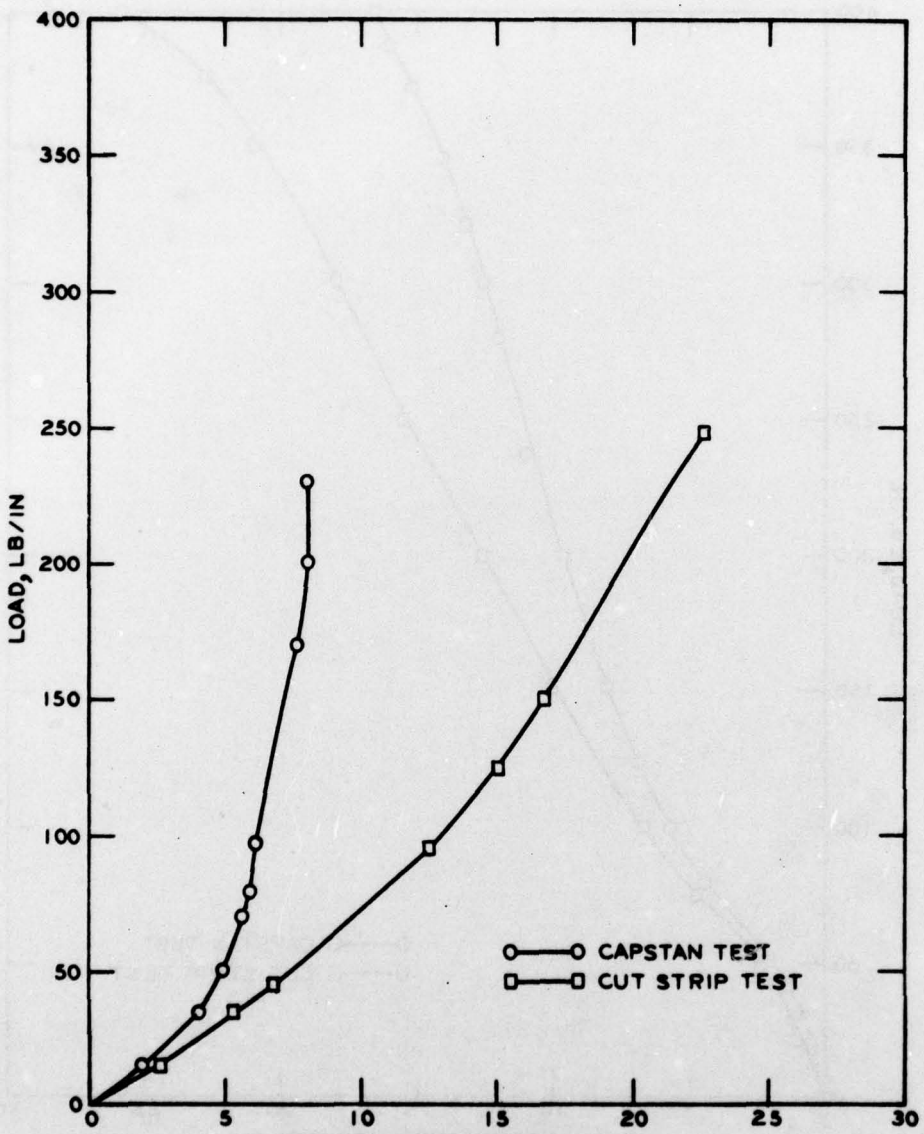
PLATE 5



URETHANE-COATED POLYESTER

TYPICAL WARP CURVES

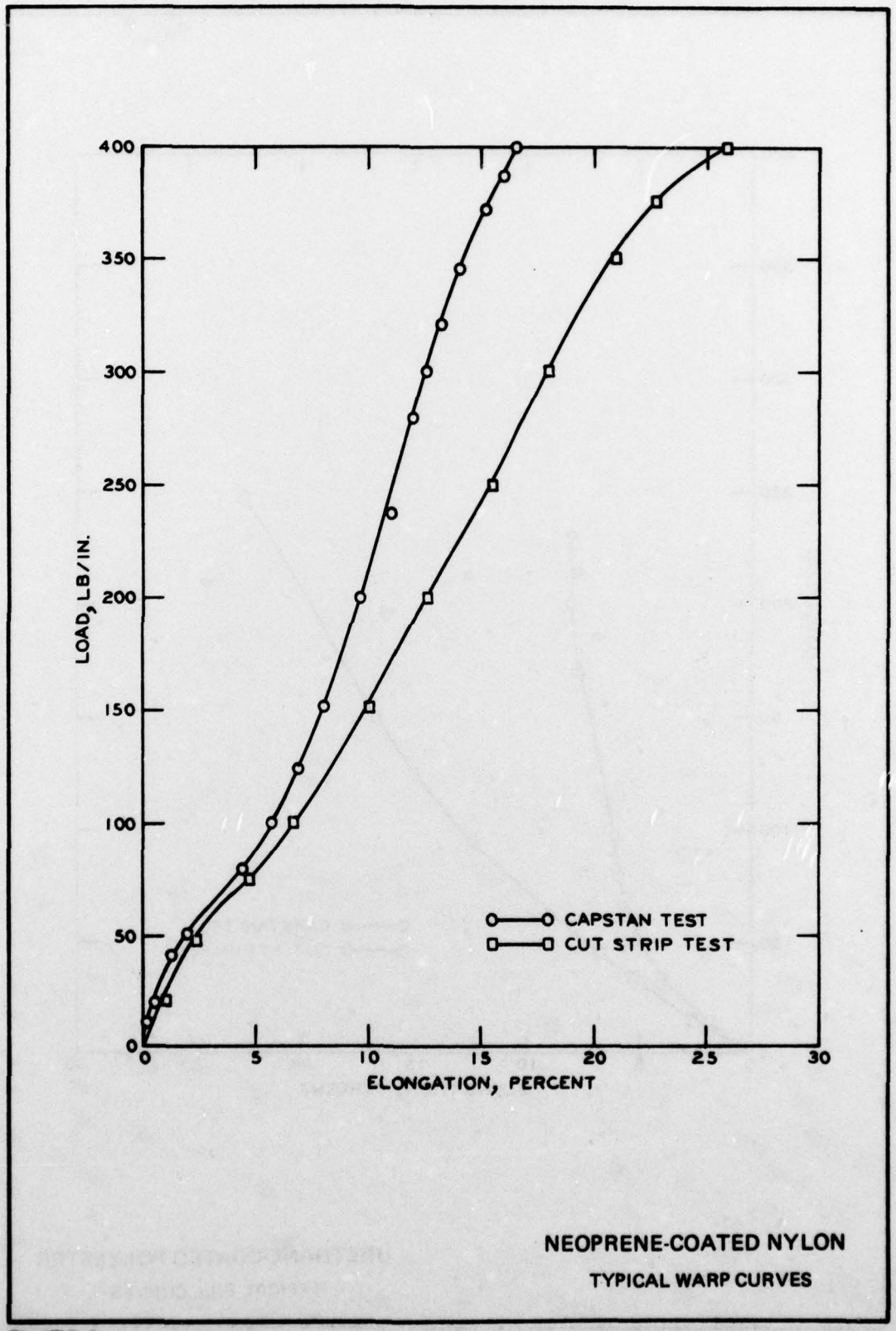
PLATE 6



URETHANE-COATED POLYESTER

TYPICAL FILL CURVES

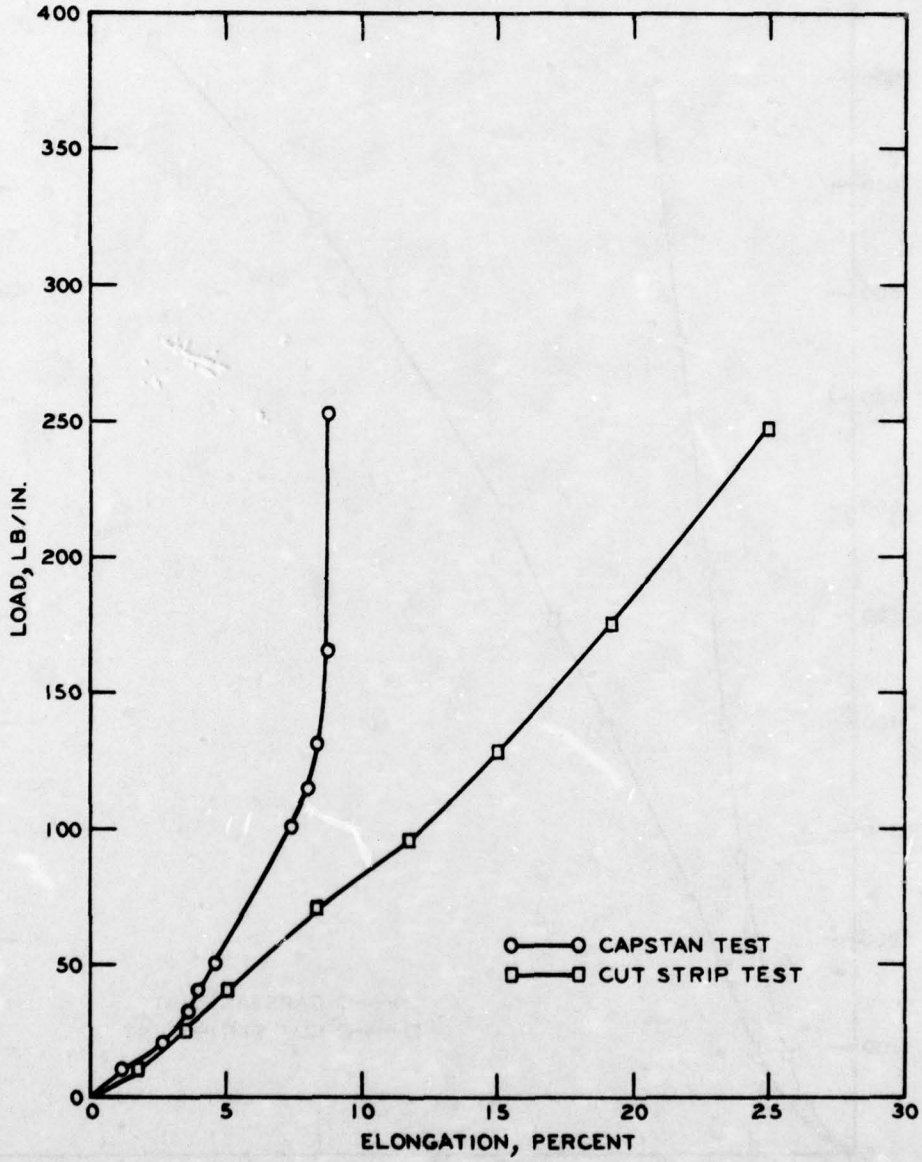
PLATE 7



NEOPRENE-COATED NYLON

TYPICAL WARP CURVES

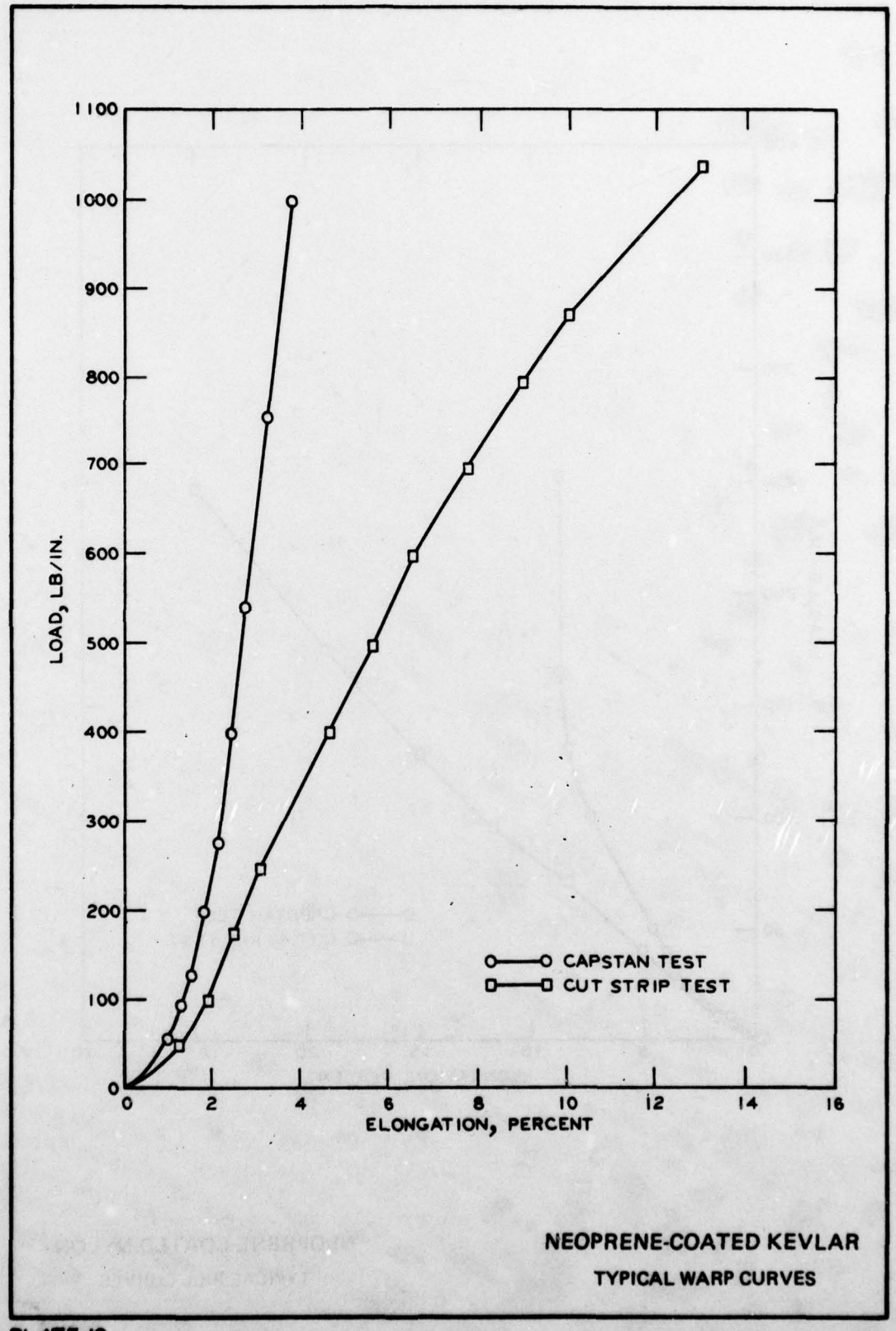
PLATE 8



NEOPRENE-COATED NYLON

TYPICAL FILL CURVES

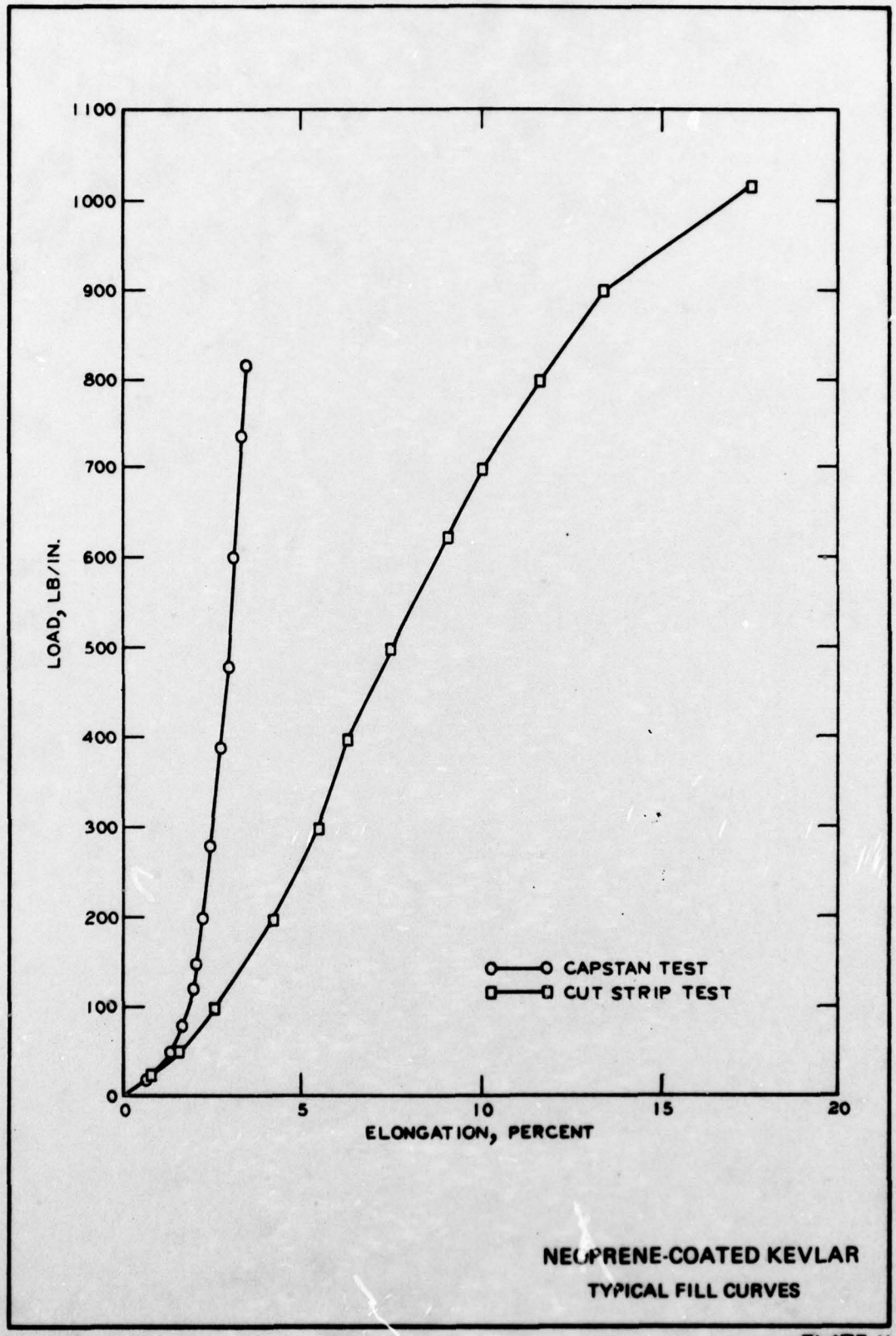
PLATE 9



NEOPRENE-COATED KEVLAR

TYPICAL WARP CURVES

PLATE 10



NEOPRENE-COATED KEVLAR

TYPICAL FILL CURVES

PLATE 11

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Vollor, Timothy W
True load-deformation relationships for coated and uncoated fabrics / by Timothy W. Vollor. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
32, [10] p., 11 leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; S-78-17)
Prepared for Assistant Secretary of the Army (R&D), Department of the Army, Washington, D. C., under Project No. 4A161101A91D.
References: p. 32.

1. Fabrics. 2. Membranes. I. United States. Assistant Secretary of the Army (Research and Development). II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; S-78-17.
TA7.W34m no.S-78-17