TESTING AND MONITORING

OF

HIGH STRENGTH GEOSYNTHETICS

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ABSTRACT

The evaluation of the tensile properties of geosynthetics has been of paramount importance for the design for reinforcement applications of geotextiles. For the stabilization of very soft sediments in particular, criteria for fabric testing have been studied since this technique was first proposed by Haliburton, et.al. [1]. This paper reviews the test parameters that can influence the apparent tensile properties of a geosynthetic to demonstrate the rational behind the Wide Width Strip Method recently adopted as ASTM D-4595-86.

Along with the tensile properties of geotextiles, seam strength is of growing importance to engineers. The interaction of geotextile and seam as well as the potential for seam inconsistencies introduce a new set of parameters that influence seam testing. This paper identifies some of these parameters and presents the current effort within ASTM to standardize a geotextile seam strength test method.

Field measurements of the performance (strain) of geotextiles inplace can provide a better indication of the actual performance of the soil encapsulated fabric. Past methods used to monitor in-place strains within the fabrics are reviewed and problems related to the interpretation of strains in geotextiles under laboratory or field is difficult and can not be performed at this time without the need for subjective interpretations.

Introduction

The first use of geosynthetic reinforcement to support a low dike on soft sediments was in the construction of a long-term confined disposal site for dredged material for the U.S. Corps of Engineers at Pinto Pass, Alabama [1]. A key program in this first application was the evaluation of the properties of commercially available geotechnical fabrics [2]. Important properties of the geosynthetics were to include stress-strain behavior, ultimate strength in uniaxial tension, soil-geosynthetic frictional resistance, creep, and wet tensile strength. This paper does not review frictional or creep considerations. A minimum fabric strength of 17.5 kN/m (100 lb/in) at 10% elongation was used in this initial project. More recent projects require minimum fabric strengths of 385 kN/m (2200 lb/in) and a modulus at 5% strain of at least 5,000 kN/m (29,000 lb/in). Clearly the problems of testing such fabrics has escalated with increased performance requirements.

It is also important to remember that the test procedures described herein relate to geotextiles in isolation. In practice, these geotextiles will be encapsulated in soil and acted on by confining stresses normal to their plain. McGown, et al [3] has clearly shown that the stress-strain behavior of highly structured nonwovens and composite geotextiles is significantly altered by confinement. Woven geotextiles, however, did not exhibit such a change. Since high strength geotextiles are normally woven, the impact of testing in isolation should not be significant.

Parameters Influencing Tensile Testing

From the initial tests performed by Haliburton, it was apparent that the measured stress-strain behavior of a geotextile was significantly influenced by details of the testing procedures. Such test details include the method of gripping the fabric, rate-of-strain, sample size/aspect ratio, initial preload, and fabric conditioning. Beyond such mechanical details, the interpretation of the resulting load-extension curves are a subject of controversy. These details are reviewed herein and compared to procedures incorporated in the ASTM Wide-Width Test, D 4595-86 [4].

Method of Gripping the Fabric-- Conventional tensile testing procedures assume a positive gripping mechanism that not only provides a secure load transfer, but also defines the gage length of the specimen. Strains in the sample are then evaluated based on crosshead movement. Unfortunately, slippage of geotextiles is difficult to prevent without causing damage to the fibers. The most comprehensive study of gripping methods was performed by Myles [5] who identified the three main methods gripping geotextiles as mechanical wedge, encapsulation in epoxy or low melting point metal, and roller or capstan grips. These grips and their respective strain measuring points are shown on Figure 1. Grip arrangements have developed from the wedge mechanical strip, to the epoxy, and finally to the roller grip as fabric strengths and specimen sizes have increased. Myles notes that no single grip is adequate for all geotextiles and Table 1 provides his guidance for grip selection.

ASTM D4595 provides details of wedge type clamps but allows for modification of the grips for strong geotextiles subject to slippage. Criteria is provided for rejection of tests that fail at the jaws or slip from the jaws. Strains are measured in the center four inches of the sample using crosshead displacements if no slippage is evident or by mounting gages directly on the center portion of the specimen if slippage can not be prevented.

Rate-of-Strain For Extensions -- Early work by Sissons [6] indicates that many fabrics exhibit a slightly higher strength and lower extension as the rate-of-strain is increased. Myles [5] found that the influence of rate-of-strain was also a function of polymer, with polyesters being less sensitive to strains than polyolefins. Typical load-extension envelopes for differing rates of strains and shown on Figure 2. Additional work by Shrestha and Bell [7] on woven and nonwoven polyester and polypropylene fabrics found on significant effects by varing the rate-of-strain from 1.25 to 12%. All of these researchers recommend a rate-of-strain of 10% per minute. Accordingly, ASTM D-4595 requires a constant rate-of-strain of 10 ± 3% per minute.

Specimen Size/Aspect Ratio -- The aspect ratio of a specimen is normally defined as the width of the specimen divided by the gage length. A comprehensive evaluation of the influence on specimen size and aspect ratio was reported by Shrestha and Bell [7]. Based on 383 tensile tests on 6 commercially available geotextiles, Shrestha and Bell made the following observations:

- The ultimate strength of a geotextile was not influenced by specimen size but the strain at failure was significantly influenced by both specimen width and aspect ratio.

- Load-strain relationships measured may vary with specimen width and gage length. Woven geotextiles are most influenced by aspect ratios greater than 4.0 and specimen gage lengths less than 50 mm (2 inches). Nonwoven geotextiles are most influenced by aspect ratios less than 2.0 and widths less than 100 mm (4 inches).

Based on these observations, Bell recommends a wide width strip tensile test using specimens 200 mm (8 inches) wide and 100 mm (4 inches) long. In a rather spectacular series of tests. Myles [5] performed wide width test on specimens to 1 meter in width. All specimens had effective aspect ratios less than 1.0. The influence of specimen width on ultimate strength is shown on Figure 3. The data indicates that a 200 mm (8 inch) wide test will overestimate the strength of a woven geotextile by 10% and underestimate the strength of a nonwoven geotextile by 20%. Based on this, Myles recommends a minimum specimen width of 200 mm (8 inches).

ASTM D4595 requires a 200 mm wide specimen unless limitations are experienced in clamping or test equipment capacity. In those cases, 100 mm (4 inch) wide specimens may be substituted.

Initial Preload -- A major problem in the tensile testing of geotextiles is a consistent definition of the origin point on the force - elongation curve. This point is difficult to define because of slack common in test specimens. Many fabrics, especially multi-ply geotextiles, require a certain amount of strain to remove internal slack or align fibers and develop resistance. A small pre-load is typically applied to the specimen to bed the fabric into the gripping mechanism and to produce a uniform tension throughout the specimen. Myles [5] recommends a preload for 200 mm (8 inch) samples of 0.1 kN (22 lbs) in general and up to 1% of the ultimate load for coarsely woven fabrics. Preloading is particularly important when using roller grips since these grips rely on drag forces generated by fabric tension to provide adequate resistance.

ASTM D4595 is currently being evaluated by a round robin series to establish precision and bias. Interim guidelines provide for a minimum preload of 44.5 N (10 lb) for materials having an ultimate strength less than 17.5 kN/m (100 lb/in). For stronger materials, a pretensioning force of 1.25% of the ultimate would be used. A maximum preload force of 222 N (50 lb) is specified however.

Evaluation of Modulus Geotextile specifications are increasingly specifying minimum modulus values as part of the selection criteria. Such modulus valves are typically (1) secant values based on a given strain or (2) offset modulus values. Problems in interpretation of modulus values include the previously discussed difficulty in defining the origin point of the load-curve and the nonlinear behavior of many fabrics.

Figure 4a shows the load-elongation curve for a geotextile exhibiting a linear behavior. At the commencement of the test the load will be zero unless a preload is used. As the test is begun, the fabric strains without loading until it reaches the daylight point. The offset modulus is obtained from the slope of the linear portion of the load-extension data. An offset strain is then defined by extending the linear portion of the data back to the zero load line. It is important to understand that the (unknown) strain from the indicated commencement of test to the daylight point is eliminated by preloading and that the amount of offset strain is influenced by the amount of preloading.

For geotextiles that do not have a linear range, the modulus is typically defined as a secant modulus at 5 or 10% strain. Figure 4b shows the construction of the secant modulus. Note that the origin is really the daylight point and is influenced by the level of preload, if any. For high strength geotextiles, however, the amount of preload allowed (50 lb for ASTM) is insignificant relative to the ultimate loads. The strain level defining the secant modulus should reflect the actual strains anticipated in the geotextile during service.

Considerations for Seam Testing

The performance of individual rolls of geosynthetics can be investigated by examining the tensile behavior of the material. Performance of an entire system of multiple rolls or panels in a reinforcement function must be addressed in terms of seam strength. For many applications using high strength geotextiles, sewn seams are utilized. Testing of seams takes on even greater importance in Construction Quality Assurance, since most seams are constructed in the field where conditions may make control of seam quality more difficult.

Seam performance is a function of the parent geotextile, type of seam, thread type, stitch count, tension and other parameters. Diaz [8] presents an overview on seam types and thread selection. For Geotechnical Engineers, ultimate seam strength is the most important performance parameter and fortunately, the easiest one to test. ASTM Committee D-35 is currently reviewing a draft test method for determining the tensile strength of sewn seams for geotextiles. It closely parallels The Wide Width Strip Tensile Test, ASTM D-4595, since a comparison between geotextile and seam strength is usually desired. The proposed method utilizes similar test equipment and griping mechanism as D-4595. A strain rate of 10% per minute is used.

Testing of seams differs from testing of geotextiles alone in that a transverse "structural member" (the seam) is included in the specimen. This may result in a relatively large scatter in breaking loads, especially for high strength geotextiles having seam strengths in excess of 52 kN/m (300 lb/in). Some general seam parameters that affect seam tensile test results are discussed briefly below. Each parameter is greatly influenced by both the parent geotextile and all aspects of the seam itself.

Condition of laboratory sample-- The most common source of significant variability in seam strength data is variability of laboratory samples. Seams may be sewn in the field, in the laboratory or at a fabrication point away from the installation site. Even the most closely controlled process may generate seam data that exhibits greater variability than the geotextile alone. Quality and consistency of the seam are measured in each test. It is of critical importance that the laboratory sample be selected carefully to ensure that it is a truly representative sample of the entire seam. This may not be satisfied by sampling only the seam ends. Once the laboratory sample is removed, the testing technician must closely examine the sample and report any damage or any other inconsistencies. Selection of each specimen should be made carefully, with the location of the specimen, the stitch count, etc. recorded.

Once the specimen is tested to rupture, the mode of failure is recorded and compared to previous test specimens. Essentially two types of failures occur: a thread (seam) break, or a rupture of the geotextile outside or adjacent to the seam area. In general, seams made in a consistent manner from the same geotextile and tested under the same conditions should exhibit the same type of failure. Changes in seam or geotextile quality may easily be indicated by changes in the failure mode of the specimen, especially when accompanied by significant changes in tensile strength.

<u>Width of the Specimen --</u> In many instances, it is difficult to obtain a sufficient number of laboratory samples of proper size to carry out the most effective testing program. This is especially true of field seams, which cannot effectively be patched or repaired once a sample is removed. In an effort to preserve an efficient number of test specimens, narrow-width (that is, less than 8 inches wide) specimens may be considered. The authors have performed a series of tests on specimens ranging from 1 to 8 inches in width removed from large seam samples. The test data are for a woven multi-layer polyester geotextile seamed using a double stitch prayer seam. All specimen breaks occurred within the geotextile itself adjacent to the inner stitch. The normalized strength per unit width was plotted against specimen width, and is presented on Figure 5. The apparent seam strength decreases with increasing specimens width to a width of 6 inches. The test data from the 8 inch test series was used as the benchmark for all data. The results indicate that the 8 inch specimen width currently recommended is justified. The behavior of the geotextile is quite similar to the behavior reported by Myles [5] presented on Figure 3.

It may be concluded that narrow specimens less than 6 inches in width should only be used for index or comparison testing unless a thorough correlation testing program is carried out to compare results to 8 inch wide specimens.

Note the scatter shown on Figure 5. Variability of strength data is partially due to the multiple laboratory samples examined, as well as built-in variability inherent in testing. The behavior illustrated may not be indicative of behavior of other geotextiles, seam types or failure modes, but does indicate a pattern that has been previously observed for other types of geotextiles and seams.

For design or specification conformance testing, a specimen width of 8 inches is recommended for laboratory testing. For testing seams in the field, narrow-width testing may be acceptable if correlated to laboratory wide width testing. The authors have constructed a portable field tensile testing device that can test seams without removing samples. Preliminary results indicate that approximately 20 to 25 wide width laboratory tests and about 50 to 60 insitu narrow width tests are required to achieve a good correlation for high strength woven geotextiles [9]. This concept has obvious advantages over conventional techniques, and is being further studied.

Conditioning of specimens-- For several of the high strength reinforcement applications currently being constructed, the geotextile will be placed under water or will eventually be saturated. The performance of wet versus dry seam specimens should be examined. Because of a complicated interaction between the geotextile and seam, behavior of wet specimens may be considerably different from dry specimens. The current proposed ASTM seam tensile test procedure recommends that a series of at least ten wet specimens be tested in a comparison program. ASTM D-4595 recommends a conditioning (saturating) period of 24 hours prior to testing wet specimens. Although this time delay may prove to be inconvenient for some projects, wet testing of seam specimens is recommended in cases where a significant difference wet and dry behavior is exhibited.

Specimen Preparation and Testing--

Specimen preparation, especially for woven geotextiles, is important to ensure accurate test results. For wovens, it is critical that the edges of specimens be identified by following yarns, not just cutting edges perpendicular to the seam. This ensures that the end yarns are parallel, which results in more accurate test results. When heat cutting specimens, overcutting and removal or unravelling of end yarns to the proper specimen width is suggested. Testing indicates that for some geotextiles, heat cut edges may actually reduce apparent seam strength due to damage to adjacent yarns cause by heating. This results in an effective specimen width less than the width reported. Overcutting of the specimen by a total of 0.5 inch and then removal of end yarns to a final with of 8.0 inch has proven successful.

Unravelling of the seam during testing can occur. This results in significantly lower seam strengths. Knotting of the thread or melting or heat cutting the edge of the specimen blockout tabs should eliminate this problem. Any unravelling or excessive transverse strain or "neckdown" should be reported. Wider blockouts may be required.

The potential problem associated with gripping and proper placement of geotextile specimens into the test jaws are also experienced when testing seam specimens. Improper placement and alignment of the specimens can result in significant underestimation of seam strength. These problems may be magnified due to the presence of the transverse seam. Tear-type failures often occur, which originate at the outer edges of the seam.

The current ASTM draft proposes that a 1 inch seam "blockout' be utilized to reduce tear-type failures. A sketch of the suggested specimen shape is presented in Figure 6A. An alternative shape to the current ASTM specimen is presented in Figure 6B. The tapered blockout shown in Figure 6b has been extemely successful in almost completely eliminating tear-type failures. The authors have performed over 400 tensile tests on high strength seam specimens using the tapered blockout and have observed only 3 tear-type failures. Observations during testing show that the tapered blockout, which is heat cut, does not contribute to the tensile strength of the specimen. It can be concluded that for either the tapered blockout or the square blockout shown in Figure 6A, an effective specimen width of 8 inches should be used for calculation of seam strength.

Monitoring Field Performance

The field performance of high strength geotextiles is monitored by insitu measurements of strains that develop in the geotextile in service. Strain monitoring techniques include the use of strain gauges bonded to the surface of the fabric and "clip on" gauges that bridge between two attachment points on the fabric. Unfortunately, all of these techniques can produce errors due to their presence on the fabric and to time variant electrical properties.

Surface Mounted Strain Gauge

-- The surface mounted resistance strain gage measures the strain in the fabric by monitoring the change in resistance of the foil gauge elements as they are strained. The important consideration here is that the gage must accurately follow the strains in the fabric. The bonding element must provide this union over the full range of strains anticipated in the field. Enka N.V. of Holland has reported good results using Micro Measurements gauges 40CBY that have a 4 inch gage length. The bonding adhesive is however not known for this installation and the gage manufacturer will not make recommendations for this application.

Resistance gauges suffer from three principle sources of error. The first relates to the influence of time and strain levels on the bonding. Even large strain tolerant resistance gauges are intended for strains less than 1%. Additionally the bonding element itself is typically an epoxy that is subject to its own time dependent property changes. The installation procedures should be adequately validated in the laboratory over strain levels and time periods anticipated in the field. The second source of error relates to waterproofing of the installation. The changes in resistance are measured in micro-ohms and even vapor diffusing through a coating can mimick strain. The third source of error relates to the cross-sensitivity of these gauges to bending stresses. Folding of the gauges can create significant "apparent strains". Once installed, there is no way of differentiating artificial strain readings from actual strain measurements without laboratory investigations of "apparent strains".

The major problem associated with strain gauges, however, is the limited gage length possible. These devices are limited to measuring strain at essentially a point. If significant strain gradient exist within the cross section of the fabric, the data may be difficult to interpret.

"<u>Clip On Gauges</u>" -- This type of gage measures the relative movement between two points on the fabric by means of a mechanical bridge. The bridge may consist simply of a rod that is attached to an electrical displacement transfer such as potentiometer or an LVDT. The gage length can be quickly modified by simply using a longer rod.

LVDT's and potentiometers can be purchased in a water-tight form and offer very good long term stability. Both systems have a very low force required for movement of the transducer mechanism. They are, however, relatively bulky and easily damaged by construction activity.

An alternate from of "clip on" gage developed by Myles is shown on Figure 7. This bridge uses literally a metal bridge that is strain gauged and calibrated for movement of the two attaching plates. The plates can be mechanically or adhesively attached to the geotextile. As with the other clip on gauges, the gage length of the transducer can be easily modified. The bonding of the strain gauges to the metal bridge is much easier than bonding these gauges to a fabric. The problem of moisture penetration of the gauges still remains. Additionally, the metal bridge must be covered to enable the bridge to freely move and to prevent damage from soil placement. The impact of these inclusions on the strains in the adjacent fabric is not known.

<u>General Field Monitoring Considerations</u> -- The first consideration in establishing a field monitoring program is to properly establish what one is trying to measure and where gauges should be placed to maximize the value of information obtained. This placement schedule should consider the potential for the loss of as much as 50% of the gauges during construction of the facility. Much of this loss is due to poor routing of cables from the transducers to the monitoring station. Cable routing, anchorage points, minimum slack, etc. must be carefully evaluated.

Summary

High strength geotextiles are becoming an increasingly important tool for engineers in design for reinforcement applications. Geotextile and seam strength testing has come to the forefront, especially for high strength geotextiles. Testing and recording of data are subject to variability introduced by a series of specimen preparation and testing parameters. These parameters include obtaining representative samples and specimens, specimen width and aspect ratio, gripping of specimens, rate of extension, preloading and selection of moduli.

For geotextile testing, the current Wide Width Strip Tensile Test, ASTM D4595, addresses many of these parameters and suggests a test method that yields reasonable design data given the constraints on testing capabilities currently available. The recommended test parameters seem justified, although they must be reevaluated for any special design or construction conditions encountered. ASTM D4595 presently forms an excellent test guideline that will serve as the baseline for additional reference testing and future refinement.

Tensile testing of seams may represent a more complicated problem. The interaction between the geotextile and seam may not always be predictable, and variability in test data must be anticipated, especially for high strength seams. Variability in field seams introduces an additional tier of test parameters that can influence test results. Extra care in selection of samples, and even additional sampling, may be required. Certainly more study of high strength seams and a greater data base is needed.

ASTM is currently evaluating a seam strength test method which parallels ASTM D4595. The current approach seems justified, although comparison testing is needed to answer many questions regarding test variability.

The most effective method to evaluate the accuracy of current test methods is to monitor field performance. Strain monitoring is currently done only on a small scale. Several techniques including surface mounted or clip-on gauges are available. ASTM D35 is currently developing a Standard Practice on insitu monitoring which identifies some monitoring techniques and methods of data acquisition and interpretation. Even with such a document, the engineer must identify the parameters to be measured and design the most effective monitoring program. Such efforts are hampered by a lack of funding and planning. A real effort is needed by the Geosynthetics community (users and producers) to convince owners to include performance monitoring in project design, construction and maintenance budgets.

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(9) Bove, J. and Richardson, G. "Field Seam Testing of Geotextiles in Reinforcement Applications." Symposium on Geosynthetics for Soil Improvement ASCE Nashville May, 1987. (Accepted for Review.)

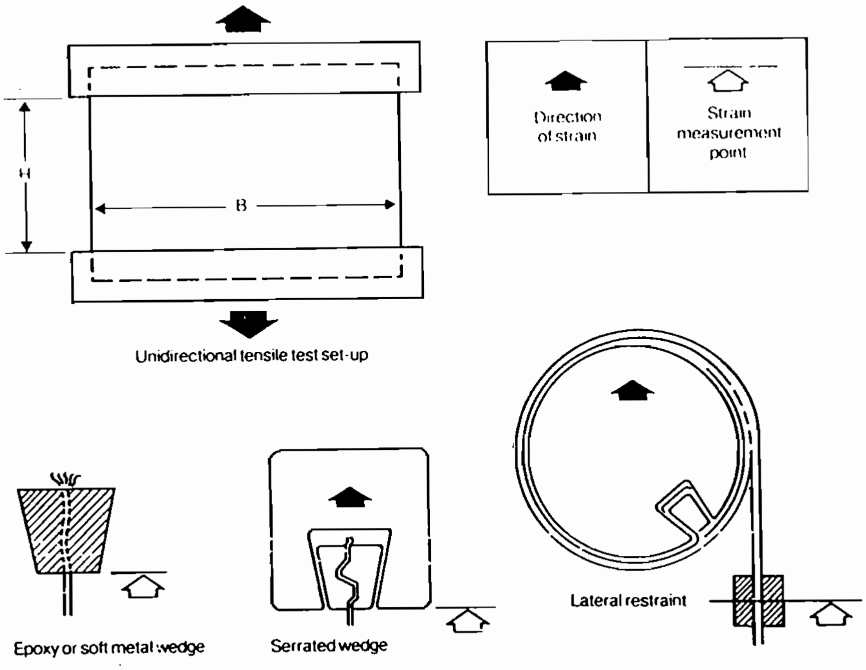
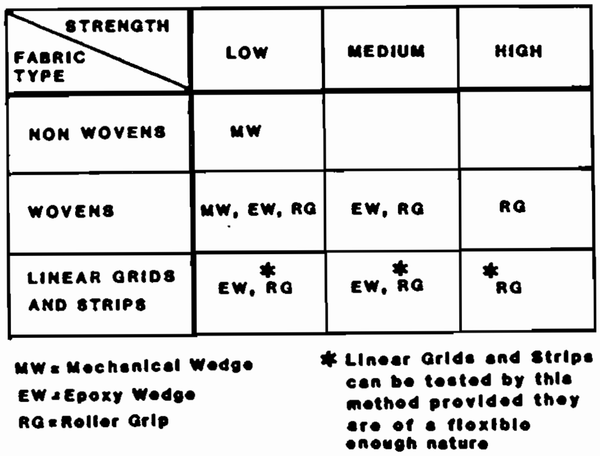


FIGURE 1 GEOTEXTILE CLAMPING SYSTEMS, AFTER MYLES [5]



STRENGTH / FABRIC TYPE	LOW	MEDIUM	HIGH
NON WOVENS	MW		
WOVENS	MW, EW, RG	EW, RG	RG
LINEAR GRIDS AND STRIPS	* EW, RG	* EW, RG	* RG

MW = Mechanical Wedge
EW = Epoxy Wedge
RG = Roller Grip

* Linear Grids and Strips can be tested by this method provided they are of a flexible enough nature

TABLE 1 - RECOMMENDED CLAMPING SYSTEMS FOR DIFFERENT GEOTEXTILE TYPES AND STRENGTHS, AFTER MYLES [5]

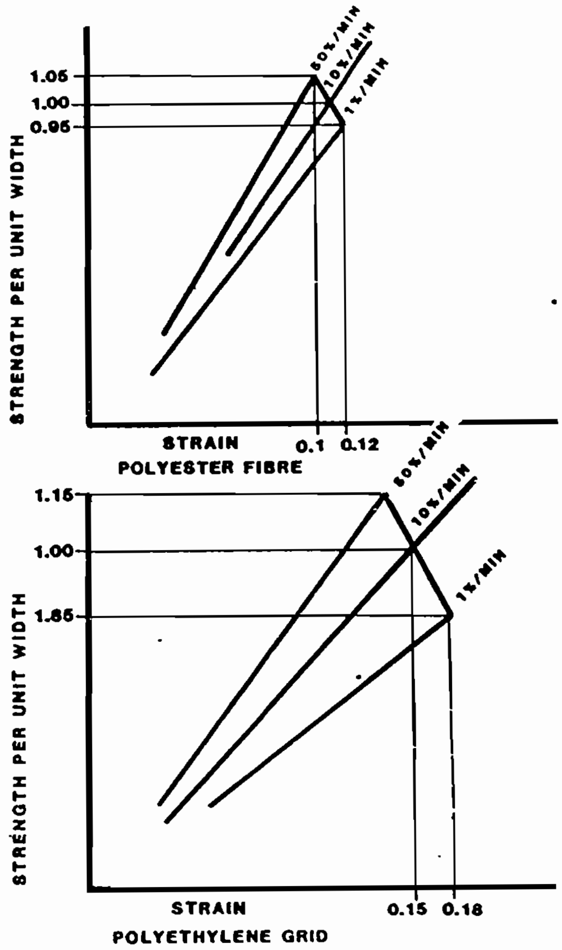


FIGURE 2 - LOAD/EXTENSION ENVELOPES FOR DIFFERING RATES OF STRAIN, AFTER MYLES [5]

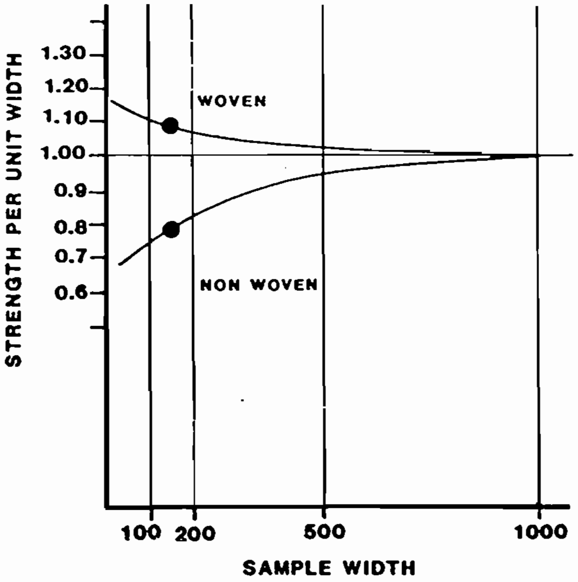
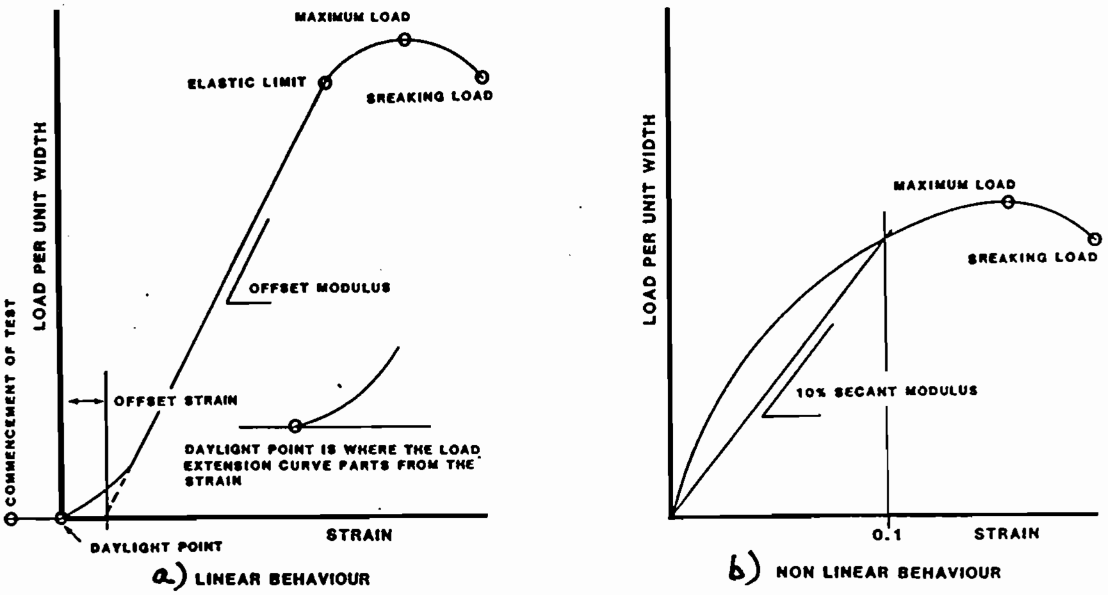


FIGURE 3 - INFLUENCE OF GEOTEXTILE SPECIMEN WIDTH ON TENSILE STRENGTH, AFTER MYLES [5]



a) LINEAR BEHAVIOUR

b) NON LINEAR BEHAVIOUR

FIGURE 4 - LOAD/STRAIN CURVE FOR GEOTEXTILES EXHIBITING
a) LINEAR BEHAVIOR
b) NON-LINEAR BEHAVIOR, AFTER MYLES [5]

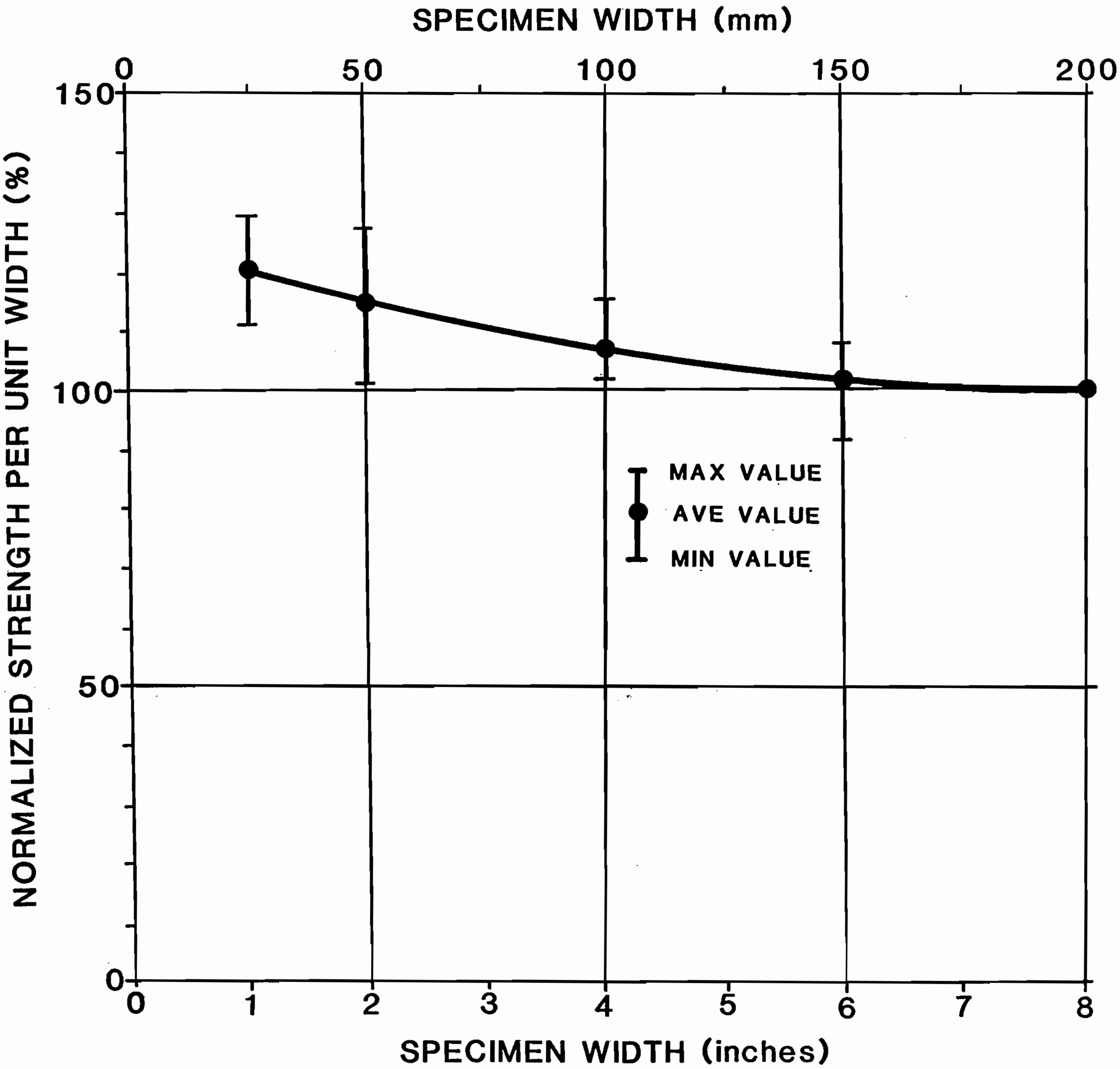


FIGURE 5 - INFLUENCE OF SEAM SPECIMEN WIDTH ON TENSILE STRENGTH

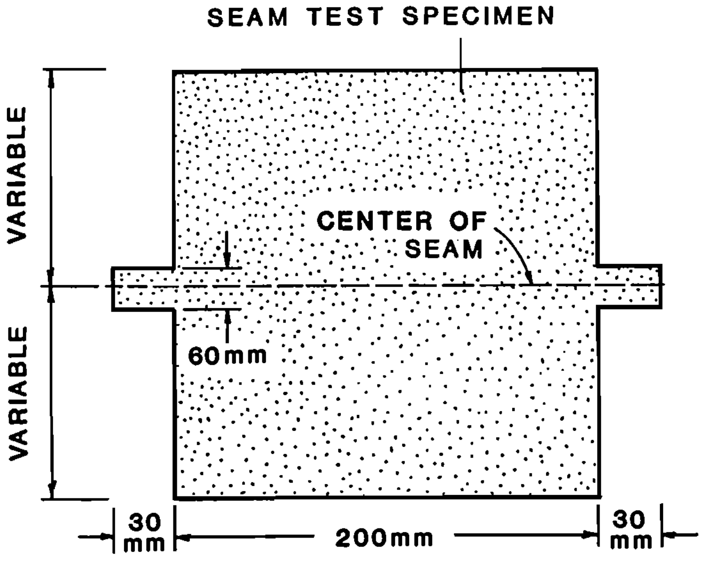


FIGURE 6a - CURRENTLY PROPOSED ASTM SEAM SPECIMEN CONFIGURATION

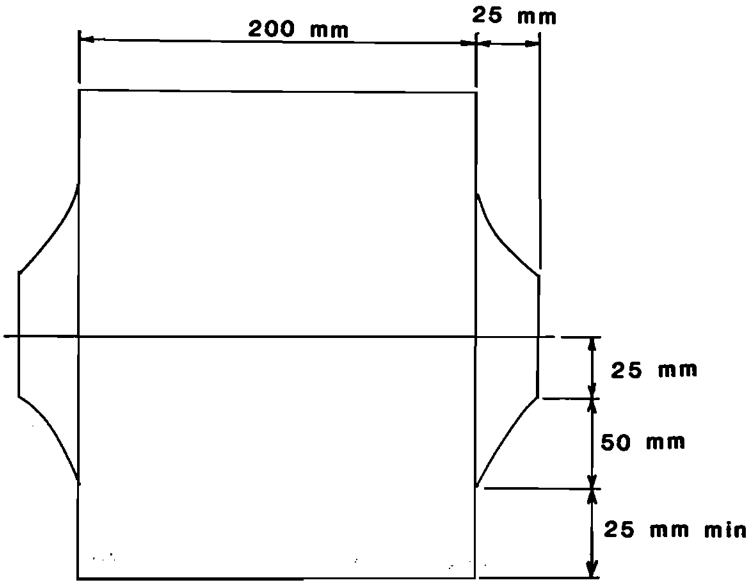


FIGURE 6b - ALTERNATIVE TAPERED BLOCKOUT SEAM SPECIMEN CONFIGURATION

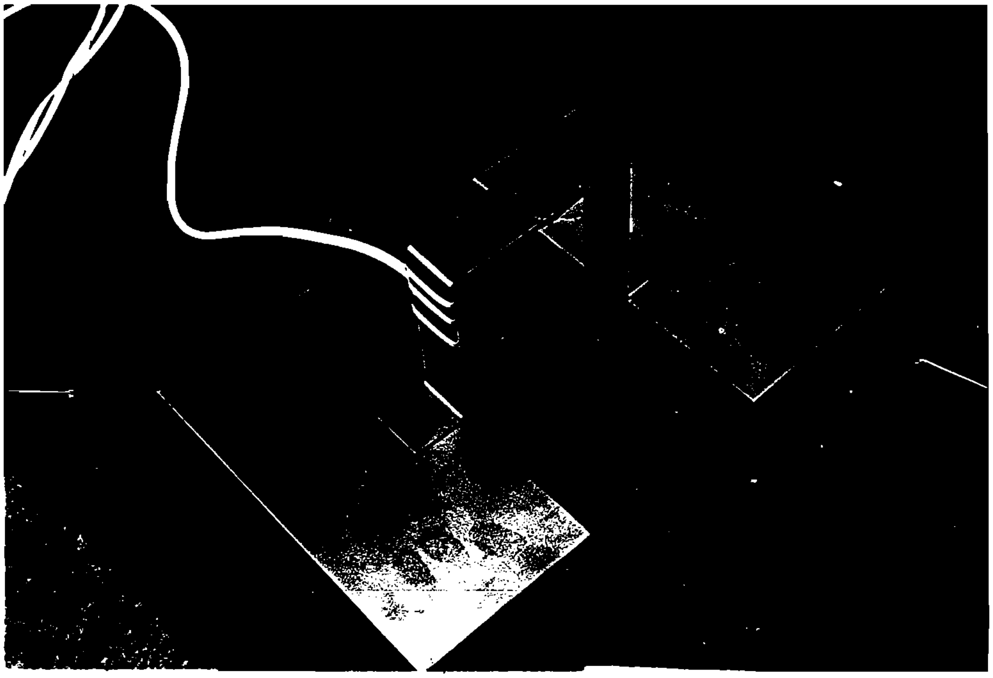


FIGURE 7 - "CLIP-ON METAL BRIDGE STRAIN GAUGE, COURTESY OF BERNARD MYLES