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Strength Evaluation of Geotextiles

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Introduction

Since around 1975, the use of Geotextiles and related materials in civil engineering construction has grown phenomenally the world over. In some cases they have replaced conventional materials such as steel and cement, and in some cases they are the only means by which construction is made possible. Though the functions commonly served by geotextiles are categorized as four, viz. separation, reinforcement, drainage and filteration, the applications seemed to be very wide ranging—from construction of roads over poor subsoils to reinforced railway embankments to bridge abutments. Now that geotextiles have begun to be manufactured in our country, there is a need to realise their potential in India (Venkatappa Rao, 1986, 1987) and also fill the gaps to make them viable for use in Indian situations by the civil engineer.

In the early 70's, the world's leading textile industrial giants like Du Pont, Hoechst, ICI, Phillips and others have taken a lead not only in tailor-making the polymeric textile material for civil engineering applications but also in identifying newer and newer applications to push their products into the civil engineering industry. To some extent initiatives have been taken in developing new test procedures to simulate civil engineering situations and also in identifying design procedures for more conventional applications of geotextiles like in pavement structure, reinforced walls and filters and drainage media. But now dozens of new companies manufacture a few hundred types of geotextiles. Also thousands of designers, contractors and owners are eager to take advantage of the better performance they provide as well as the cost savings. As has been stated by Carroll (1986), this requires educating the user, "*which product is best suited to meet the need ? What properties and values are required ? How are the properties measured ? How do you specify ? How do you install ?*" To a certain extent, answers to these questions may be sought from the recent publications by FHWA (1984) and Koerner (1986) which are excellent and

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the most recent on the subject. This paper primarily focuses attention on the more immediate problem of testing and evaluation of geotextiles in the Indian context, for reinforcement applications.

In reinforcement applications, two properties viz. strength and friction are the most important for the designer. But the evaluation of these properties is by no means a simple task due to the non-availability of unified test standards. For, geotextiles, being basically a textile material, most of the tests suggested by textile engineers, were originally developed from a view point of their evaluation as apparel. A geotechnical engineer desires testing to be carried out on larger specimens possibly under simulated field conditions i.e. at smaller speeds and in combination with the soil to be used, whereas textile engineer is interested in testing just smaller pieces at faster rate, primarily for quality control. So it becomes of utmost necessity to develop test procedures and apparatus, using which the properties relevant to civil engineering applications may be evaluated.

The Problem of Evaluation

The first recorded geotextile standard was the Corps of Engineers Civil work specification. Afterwards agencies of various countries such as ASTM, DOT, FHWA etc. of USA; Canadian Standards Board, Canada, BSI, Britain; RILEM of France; NNI, Holland and DIN, Germany, have tried to develop standards for evaluation of civil engineering properties.

Two types of tests were deemed necessary : index tests and performance tests. Index texts measure properties that do not relate directly to the performance of fabric but can be used in specifications to indicate the acceptability of a fabric for a given application. Performance tests measure behaviour of geotextile under simulated field conditions and results are often used for design. A number of tests, both index as well as performance, with varying specifications have been developed by various agencies. Some of these are discussed in subsequent sections.

After selection of a particular test, the number of specimens to be tested for each fabric in a test needs to be decided. There is no unanimity even regarding this aspect. After testing, the interpretation of result is also not clear. Task Force 25 set up by FHWA recommends "minimum certifiable property value criteria" while some other agency like Swedish Standards suggest to quote average value with coefficient of variation.

Task Force 25 has developed an acceptance/rejection criteria for geotextiles. It states "*If any of the samples tested fails to meet specification criteria, the shipment must be retested using an equal or greater number of samples and are not to include samples from those rolls that had previously failed. If all the samples from the retest pass the criteria, the shipment must be accepted. If however any of the samples from the retest fails to meet specification, the shipment can be rejected.*"

One more problem needs mention regarding specification. As technology of geotextile use is quite recent, there is no guideline available about range of values required for a particular use. Only recently Koerner and Hausmann (1987) have given some range of properties required for reinforcement purposes.

Establishment of an unified international standard has not been successful uptil now, as agencies from different countries may have different perspective even on technical issues. Further, the beneficiaries of international standards are multinational companies, whose business depends on foreign trade. But countries like USA where industries market only in the country itself, show very less interest for it (Carrol, 1986).

In India, the problem is more acute since there is no test apparatus available for assessment of geotextiles. In this paper, an attempt has been made to present a critical appraisal of the various test methods recommended by various standards and apparatus fabricated for conducting some tests. Based on the apparatus developed, strength properties of three Indianmade polypropylene woven fabrics are presented.

General Test Conditions

From a geotechnical view point, four groups of tests can be visualised (Murray and McGown, 1982).

(*i*) *Soil Testing*—The engineering properties of the soil to be used should be determined to identify the desirable properties of the geotextile. This should also include chemical tests to ensure that components liable to attack geotextiles, are not present in significant amount.

(*ii*) *In-Isolation Test*—The geotextile sample for testing may be unconfined or confined say between rigid platens. Most of the in-isolation tests proposed have very little relevance for design purpose.

(*iii*) *In-Soil Tests—These tests are carried out* with the geotextile confined in soil, preferably using the same soil to be used later in construction. The use of a standard soil may be of value for obtaining relative performance data as well as for quality control purposes. The extent of confinement and environmental conditions may be fixed on the basis of field condition.

(*iv*) *Prototype Trials*—Large scale laboratory tests or field trials may be used to measure the overall performance of soil-geotextile systems and the resulting data can be used directly in design, provided that the environmental conditions of the trial conform to those at site. Alternatively, it may be possible to assess the performance of the soil and geotextile components of the system separately for design purpose.

Murray and McGown (1982) suggest in-isolation tests and in-soil test with the standard soil, to be collectively referred as 'Index Tests, which may be used for comparative purposes and as a means of fabric selection. According to Bell (1982), most of the tests originating from the textile community could be classified as 'Index Tests', that did not give a number that could be directly used in a design equations.

FHWA—Geotextile Engineering Manual (1984) states that if index test results are to be used as design parameters, high factors of safety shall be used. For critical applications or when severe conditions exist, soil-fabric interaction evaluation through laboratory model studies or in field trial studies should always be performed.

The two important characteristics to be evaluated for use of geotextiles as reinforcement say in reinforced walls are strength and modulus and geotextile-soil friction. In this paper attention is focussed on the former aspect, a companion paper (Venkatappa Rao and Pandey 1988) deals with the latter aspect. Strength can be evaluated either directly or indirectly, as described below.

Direct Evaluation of Strength

Four tests have been commonly used for direct evaluation namely narrow strip tensile test, grab tensile test, wide strip tensile test and plain strain test.

As per Shrestha and Bell (1982), width of strip has no significant effect on strength for woven fabrics. Despite this, wide strip tensile test is being increasingly recommended for evaluation of tensile strength and modulus to be used for design purpose while grab tensile strength is widely used by manufacturers as a quality control tool. Plain strain test is most suitable for non-woven fabrics which undergo excessive necking. The narrow strip test can be used to get environmental resistance of fabrics as the size of the specimen required is small.

Indirect Evaluation

The strength can also be judged by various other tests which give the resistance of fabric.

(*a*) *Burst resistance* : It is the resistance of fabric to withstand localised pressure. With geotextile placed over weak soil subgrade, underlyingan aggregate base course, moving loads may burst fabric as illustrated in Fig. 1. Three tests are in common use :

—Mullen's burst test

—Ball burst test

—CBR push through test

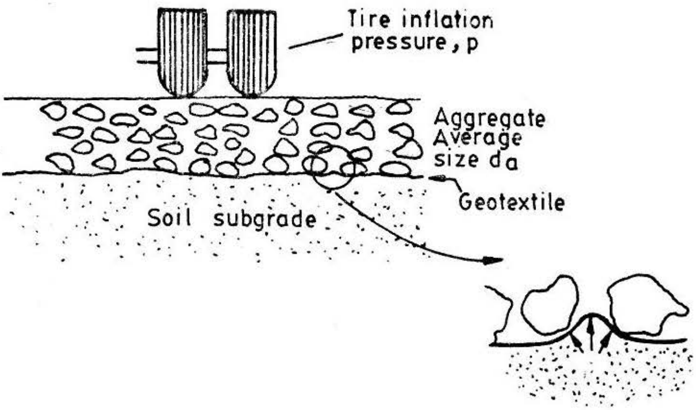


FIGURE 1 Field Situation for Burst Resistance Test.

Mullen's burst test can be used for soft fabrics only (fabric of small strength) and Ball burst test and CBR push through test can be used for high strength fabrics. In CBR push through test, a plunger of standard dimension is pushed through a tightly held fabric of standard size at a specified rate. The failure load gives push through load and this load, when divided by cross sectional area of plunger, gives CBR push through resistance. A Ball is used instead of plunger in Ball burst test while a rubber membrane is used in Mullen's burst test.

(*b*) *Puncture Resistance* : Sharp stones, tree stumps, roots, miscellaneous debris and so on, on the ground beneath the geotextile present problem for puncturing through the fabric after loads are imposed above it, as shown in Fig. 2. This can be evaluated using a special test probe specified by ASTM.

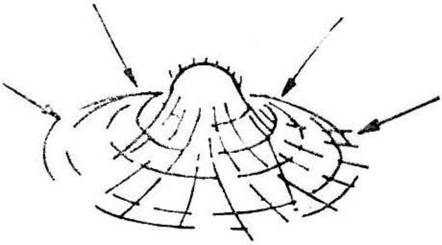


FIGURE 2 Field Situation for Puncture Resistance Test.

(*c*) *Penetration Resistance* : When sharp edged stones etc. are dropped on a laid fabric, there are chances of fabric getting penetrated. The cone drop test simulates such a condition. In Cone drop test, a cone of standard weight is dropped from a specified height on a tightly held fabric of standard dimension. The size of the hole formed is measured with the help of cylindrical dummies, and the size of hole gives an idea about the strength of fabric, bigger the hole, weaker is the fabric.

Burst resistance, puncture resistance and penetration resistance give an idea about the overall fabric strength. Some other less commonly used tests are fatigue strength test, tear strength test, creep resistance, etc. which are often used at the stage of preliminary evaluation.

Apparatus Developed : Test equipments to conduct narrow strip tensile test, wide strip tensile test, CBR push through test and cone drop test were fabricated to test geotextiles. The specificatinos chosen for these are detailed below.

Narrow Strip Test : After a review of specifications given by ASTM D 1682 and BS (as given in Rankilor, 1981), arrangement was made to conduct tests on 25 mm wide strips. Specifications used are as follows :

Width of specimen = 25 mm
Gauge length = 75 mm
Overall size of specimen = 150 mm long × 25 mm wide
Jaw size = 38 mm long × 25 mm wide
Deformation rate = 200 mm/min.

Wide Strip Test : Various specification specify various widths upto 8″ (200 mm). But on trial basis, jaws to test 80 mm wide specimens were fabricated, with the following specifications :

Width of specimen = 80 mm
Gauge length = 76 mm
Overall length of specimen = 125 mm
Jaw size = 80 mm wide
Strain rate = 50 mm/min.

CBR Push Throught Test : After review of the specifications of ASTM, the following specifications were used.

Inner diameter of specimen = 150 mm
Diameter of Plunger = 50 mm
Deformation rate = 50 mm/min.

The above three tests are conducted on a 10 to—capacity INSTRON—1194 universal testing machine with facility for deformation rate upto 500 mm/min.

Cone Drop Test : A specified cone of standard weight is dropped by a standard height on the fabric held lightly between two sizes. The size of the hole caused gives an idea about the fabric strength. Specifications, recommended by ICI, used for the test are as follows :

Inner diameter of specimen	= 150 mm
Total weight of cone-guide rod assembly	= 1 kg
Included angle of cone	= 45°
Height of fall	= 500 mm

Fabrics Tested

Three Indian Polypropylene woven fabrics of specifications given in Table 1 were tested using the apparatus developed. The fabrics are manufactured by the Bombay Dyeing and Manufacturing Co. and marketed by AIMIL, New Delhi.

TABLE 1

Specifications of Geotextiles

Sample No.	colour	Mass per unit area (g/m^2)	Thickness at pressure of 20 g/cm^2 (mm)	No. of threads per inch		Weave pattern	Pore size* in microns	
				Warp direction	Weft direction		Mean	Maximum
499	Black	270 (277*)	0.70	26	38	One up one down	25	69
500	Off white	200 (207*)	0.56	22	32	One up one down	102	230
501	Off white	306 (307*)	0.76	18	24	One up one down	174	243

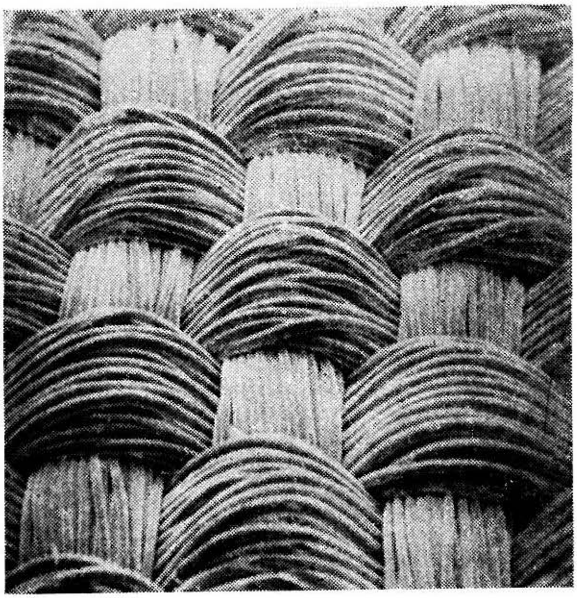
*Values supplied by the manufacturers.

Structure of Fabrics

Scanning electron micrographs of the three fabrics are presented in Figs. 3 (*a*) to (*c*).

Specimen Preparation

When the fabric is cut with scissors, the fibres in end portions come out,



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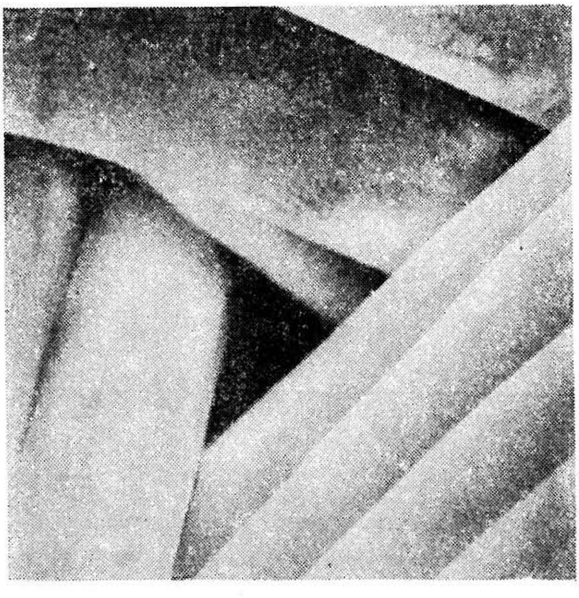

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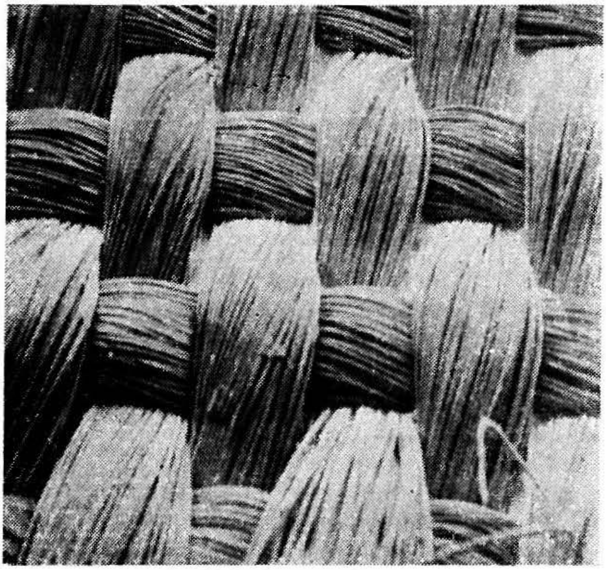
FIGURE 3(*a*) Scanning Electron Micrographs for Fabric 499.



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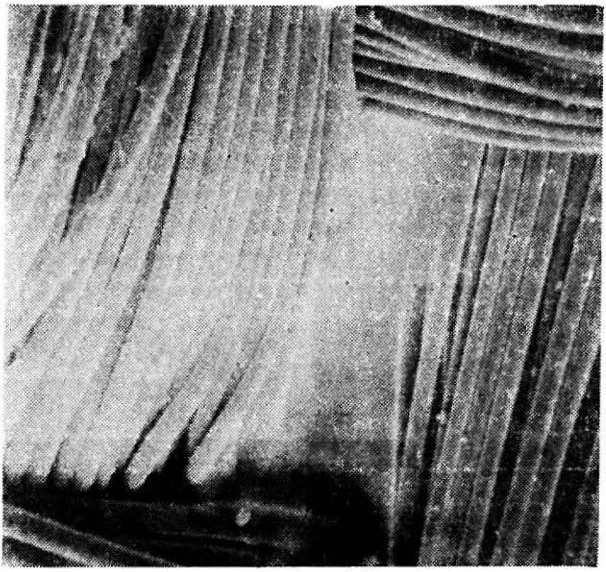

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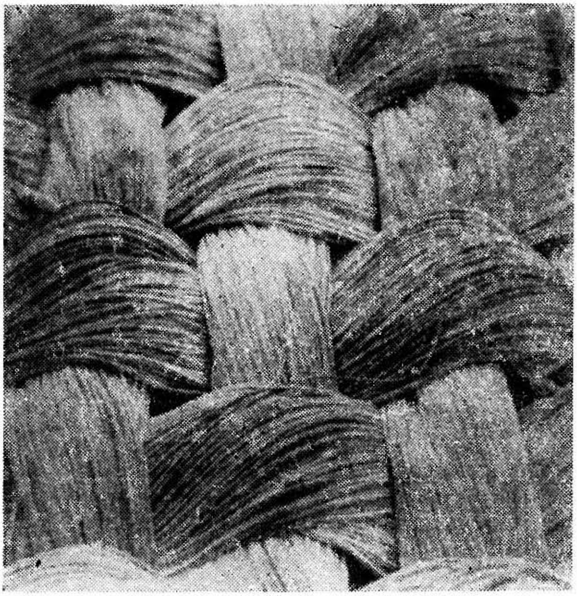
FIGURE (*b*) Scanning Electron Micrographs for Fabric 500.



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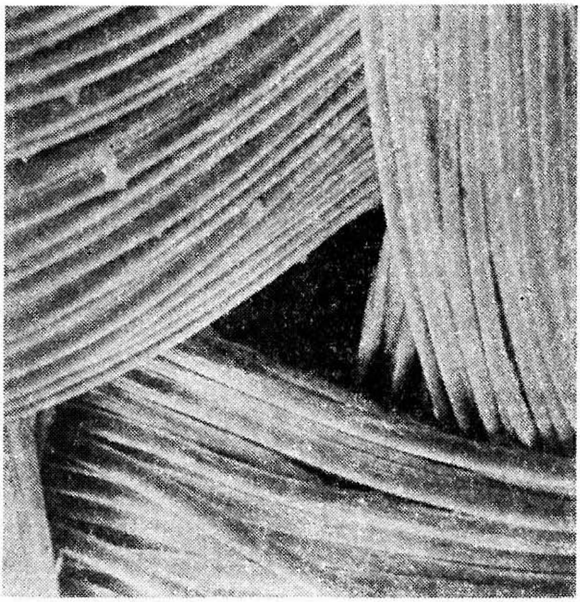

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FIGURE (*c*) **Scanning Electron Micrographs for Fabric 501.**

causing a reduction in the effective specimen size. Tests on such specimens may not give proper results. Also if cutting is not done properly, single thread may not be running for the full length. To avoid this, Rankilor (1981) recommends the use of a special cutting device. As such devices are not usually available in a soil laboratory, the following procedure was adopted.

A specimen slightly larger than actually required is cut and the end fibres are removed gradually till the required size is arrived at. It is also necessary to ensure that all threads run the full length of specimen.

A heavy sharp edge is kept on the end thread in given direction and the excess portion is removed by a sharp edged hot knife in a single stroke. The cutting in a single stroke prevents the edge thickening. This process is repeated on all the four edges so as to obtain a specimen of correct size.

Number of Specimens Tested

Usually 4 to 5 specimens were tested for each test.

Test Results

The results obtained for each of the abole tests are presented in the below:

Narrow Strip Tensile Test

Typical load deformation curves obtained in this test for fabric 499 are shown in Figs. 4 and 5 for warp and weft directions respectively. Warp direction is the machine direction while weft direction is the cross machine direction. Similar curves were obtained for the other two fabrics. As is the common practice in geotextiles, the tensile load is presented as kg/m and not as stress.

As it is inconvenient to present exhaustive data, some organisations (e.g. Swedish Standards) suggest presentation of the average values along with coefficient of variation. Hence the average values were calculated using values which are not very far from the average. Also using the load deformation curves, the secant tensile modulus were calculated and then averaged out. Table 2 presents such values for all the three fabrics.

From Table 2 it is clear that fabric 501 is the strongest fabric and 500 is the weakest. The tensile modulus for fabric 501 in warp and west directions is maximum. This fabric showed the least deformation in warp direction among the three fabrics tested. Out of the 3 fabrics tested, 501 is the best as it has got the highest strength and high tensile modulus.

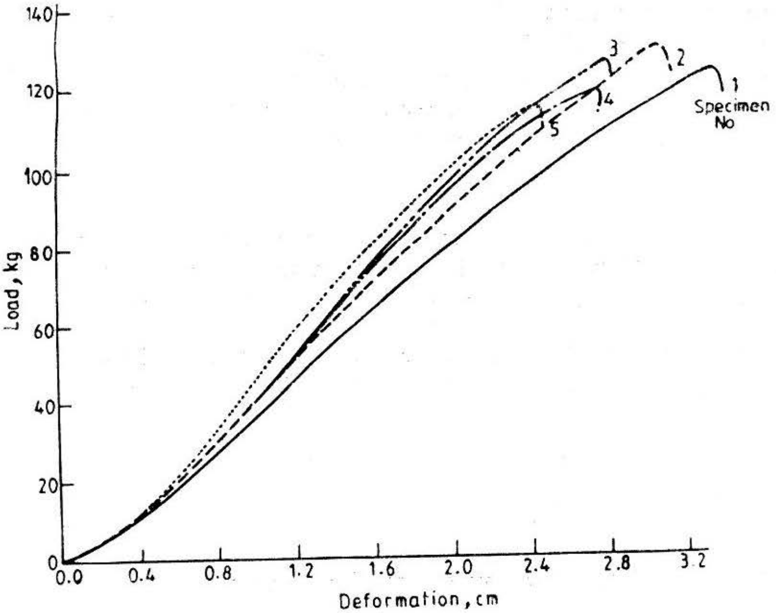

FIGURE 4 Load-Deformation Curves for Fabric 499 (warp direction) by Narrow Strip Tensile Test Apparatus

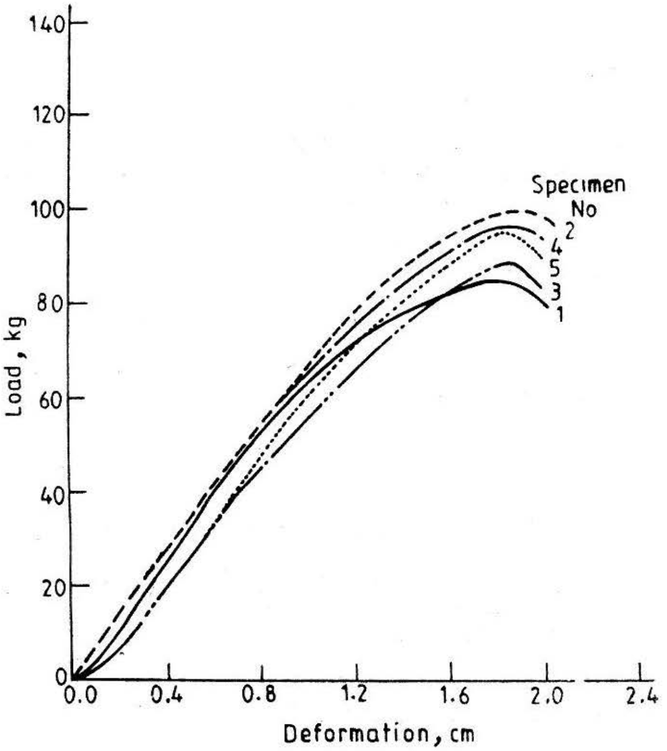

FIGURE 5 Load-Deformation Curves for Fabric 499 (weft direction) by Narrow Strip

TABLE 2

Summary Results of Narrow Strip Tensile Tests

Fabric type	Direction	Average tensile strength (kg/m)	Coeff. of variation (%)	Avg. 10% secant modulus (kg/m)	Coeff. of variation (%)
499	Warp	4950	4.36	11,000	3.20
	Weft	3720	5.73	20,000	2.80
500	Warp	4640	1.26	14,530	3.90
	Weft	3380	1.94	16,200	3.20
501	Warp	6380	2.0	15,400	7.40
	Weft	5540	3.6	22,400	0.00

Wide Strip Tensile Test

Figures 6 and 7 present the load deformation curves for the fabric 500 in warp and weft directions respectively. Similar curves were obtained for the other two fabrics. Table 3 gives the results obtained on three fabrics.

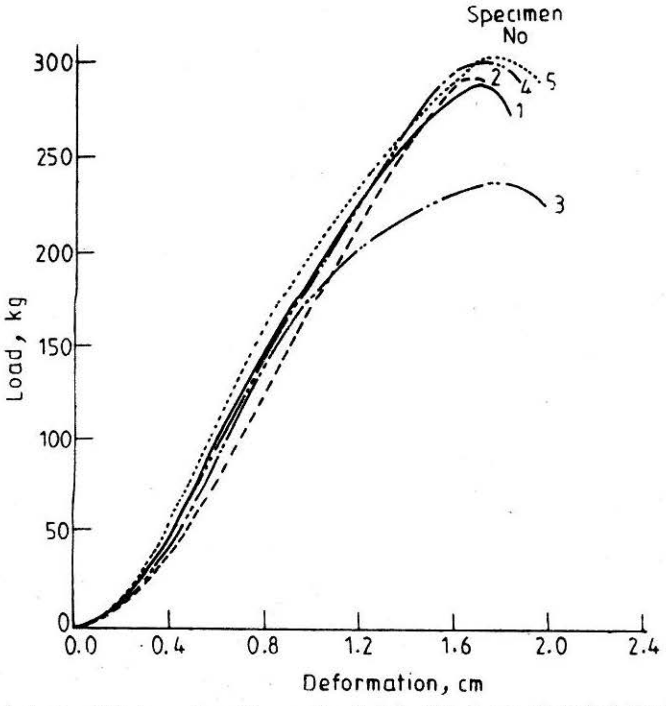

FIGURE 6 Load-Deformation Curves for Fabric 500 (warp direction) by Wide Strip Tensile Test Apparatus

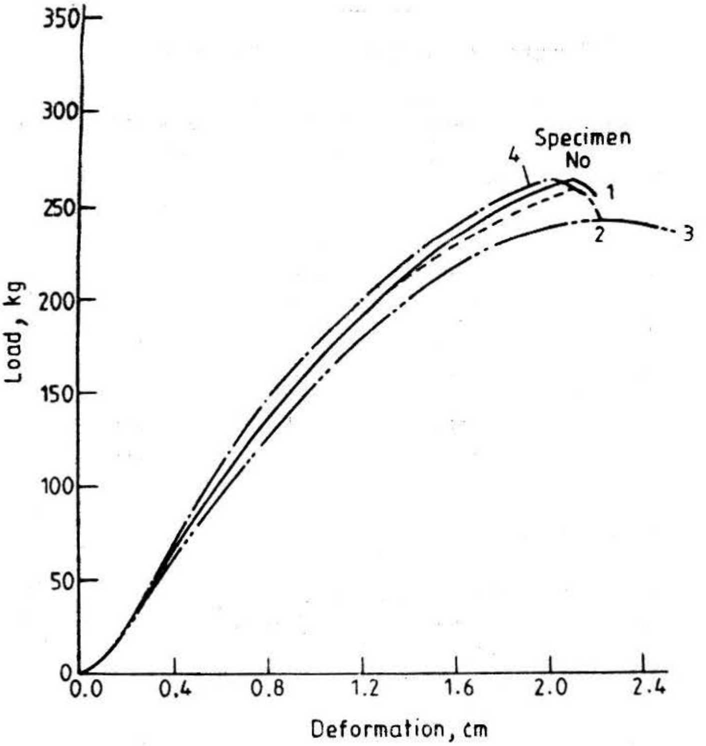

FIGURE 7 **Load-deformation Curves for fabric 500 (weft direction) by Wide Strip Tensile Test Apparatus**

The average values and coefficient of variation based on the above data are tabulated in Table 4.

Table 4 indicates that the fabric 501 is the strongest in wide strip tensile test also as has been observed for narrow strip strength. Fabric 500 is the weakest. The modulus of fabric 501 in warp direction is maximum while that for 500 is the minimum amongst the fabrics.

CBR Push Through Test

Typical load-deformation plots for fabric 501 are presented in Fig. 8. Similar curves were obtained for the other two fabrics. Table 5 gives the average value of push through resistance and coefficient of variation for all the three fabrics.

The push through resistance for fabric 501 is maximum while that for 500 is minimum. Fabric 499 has got an intermediate value. As the difference in the value of the resistance between 499 and 500 is not much and the coefficient of variation is greater for 499, it may also be possible that values for both fabric may be almost same. The fabric 499 has the

TABLE 3

Wide Strip Tensile Test Results

Fabric	Sl. No.	Warp direction				Weft direction			
		Peak load (kg)	Deformation at peak load (cm)	Elongation (%)	10% Secant modulus (kg/m)	Peak load (kg)	Deformation at peak load (cm)	Elongation (%)	10% Secant modulus (kg/m)
499	1	310	2.0	26.7	20,310	260	2.0	26.7	7,810
	2	295	2.1	28.0	18,440	310	2.55	34.0	8,440
	3	300	2.4	32.0	18,440	250	2.0	26.7	9,500
	4	280	2.1	28.0	17,000	265	2.0	26.7	9,500
500	1	290	1.7	22.7	14,380	265	2.1	28.0	15,940
	2	290	1.6	21.3	16,880	260	2.1	28.0	15,940
	3	300	1.8	24.0	17,250	245	2.2	29.3	13,750
	4	300	1.7	22.7	18,750	265	2.0	26.7	17,190
501	1	430	2.0	26.7	21,250	340	2.2	29.3	11,630
	2	440	2.4	32.0	23,750	375	2.0	26.7	17,500
	3	445	2.1	28.0	23,750	385	2.2	29.3	11,630
	4	445	2.1	28.0	23,750	320	2.3	26.7	10,000

TABLE 4

Summary Results of Wide Strip Tensile Tests

Fabric type	Direction	Average tensile strength (kg/m)	Coeff. of variation (%)	Av. 10% secant modulus (kg/m)	Coeff. of variation (%)
499	Warp	3700	3.65	17,960	3.8
	Weft	3390	8.48	9,150	5.5
500	Warp	3690	1.70	17,625	4.6
	Weft	3230	3.17	16,350	3.6
501	Warp	5500	1.39	23,750	0.0
	Weft	4380	5.30	11,080	6.9

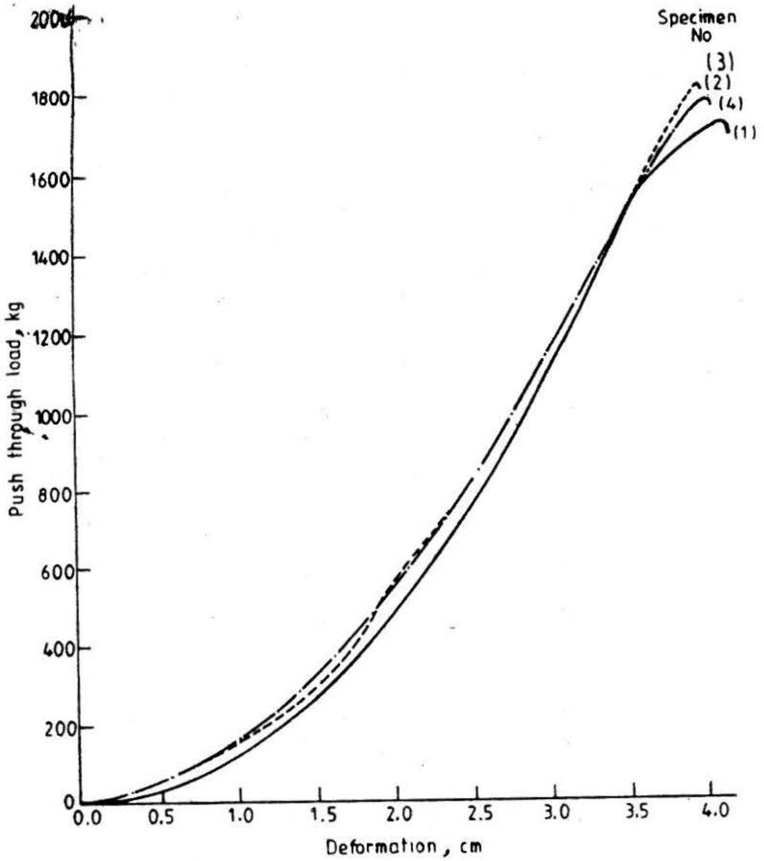

FIGURE 8 Push Through Load-Deformation Curves for fabric 501 Using CBR Push Through Test Apparatus

TABLE 5

Results of CBR Push Through Test

Fabric type	Average push through strength (kg/cm^2)	Coefficient of variation (%)
499	67.75	6.77
500	67.10	3.05
501	92.50	3.17

greatest capacity to undergo deformation before failure, so it can be used where large deformations are expected.

One Drop Test

The results obtained in this test are given as average values along with the coefficient of variation, in Table 6.

TABLE 6

Results of Cone Drop Test

Fabric type	Average diameter (cm)	Coefficient of variation (%)
499	1.21	0.00
500	1.41	1.08
501	0.53	9.95

As the diameter of the hole caused by cone in fabric 501 is least, this fabric is the strongest. Similarly fabric 500 can be said to be the weakest. There is a considerable variation in the size of the hole caused in the fabric 501 for different trials. This may be due to some inaccuracy in measurement of hole diameters as the size involved is very small.

Correlation of Test Results

The narrow strip strength is plotted against wide strip strength in Fig.9. The variation is linear. It shows that values obtained by narrow strip test are more than that obtained from wide strip test. However more data is required to confirm these observations.

Narrow strip strength and CBR push through resistance and narrow strip strength and cone drop test result are plotted on Figs.10 and 11 respectively. There indicates that higher the strength, higher will be the push through resistance and smaller the diameter of holes caused as expected.

Morritz and Murray (1982) observed that the breaking load in a tensile test at a certain width can be converted to another width by a multiplication factor and that the conversion between CBR and tensile tests is only possible to a limited extent dere to the different stress distributions. Also opined that both the tests should be rated equally for selection and control.

One may find a coefficient for strength and modulus which when multiplied to values of wide strip test results can give narrow strip test nalueg.

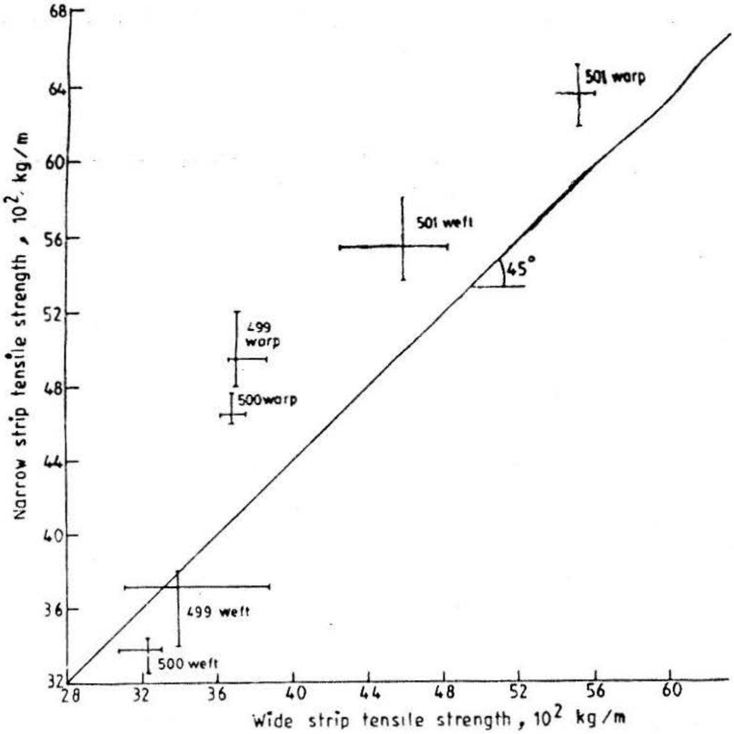

FIGURE 9 Variation of Narrow Strip Tensile Strength with Wide Strip Tensile Strength

These coefficients are not general, but can be used only if the specifications of test are followed. The coefficient obtained is between 1.1 to 1.35 for strength and between 0.61 to 0.99 for modulus. Table 7 gives the details.

A similar coefficient may be obtained for conversion of wide strip strength to CBR Push through resistance. This coefficient obtained is between 4.1 to 4.5 as shown in Table 8.

Utility of Fabrics Tested

When the strength and the modulus values of fabrics tested are compared with the values given by Koerner and Hausmann (1987) for judging suitability of fabrics for various purposes, it is observed that all the three fabrics have tensile strength greater than 2,190 kg/m and modulus value greater than 6,120 kg/m, so all of them can be used for high heights of retaining structure ($H > 9$ m). Similarly, all the three fabrics are suitable for slope stabilisations at wide spacing (spacing > 3 m). and in unpaved roads even over the weakest soil ($CBR < 1$). But results into a nominal incerase in bearing capacity and thus are not suitable for embankments over soft soils.

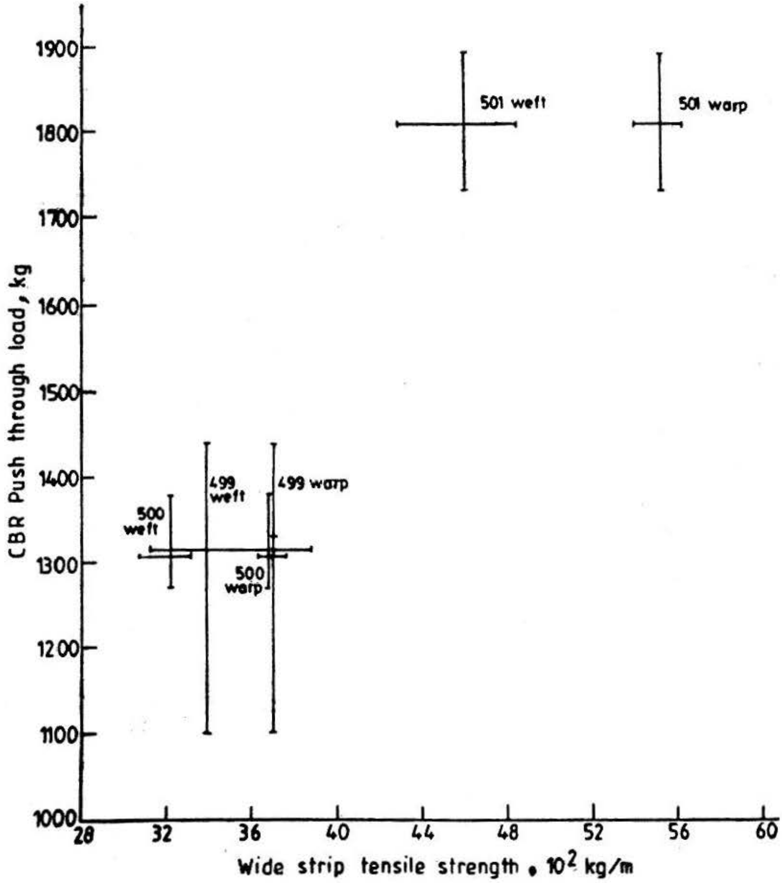

FIGURE 10 Variation of CBR Push Through Resistance with Wide Strip Tensile Strength

Conclusions

(*i*) The apparatus developed for varions tests are simple enough to be widely used, easily standardised and reproducible.

(*ii*) The fabric 501 is the strongest among all the three fabrics. The modulus of this fabric is also generally the highest.

(*iii*) The strength obtained by narrow strip test is more than that obtained by wide strip test for all the three fabrics.

(*iv*) Higher the tensile strength, higher will be the CBR Push through resistance and lower is the diameter obtained in cone drop test.

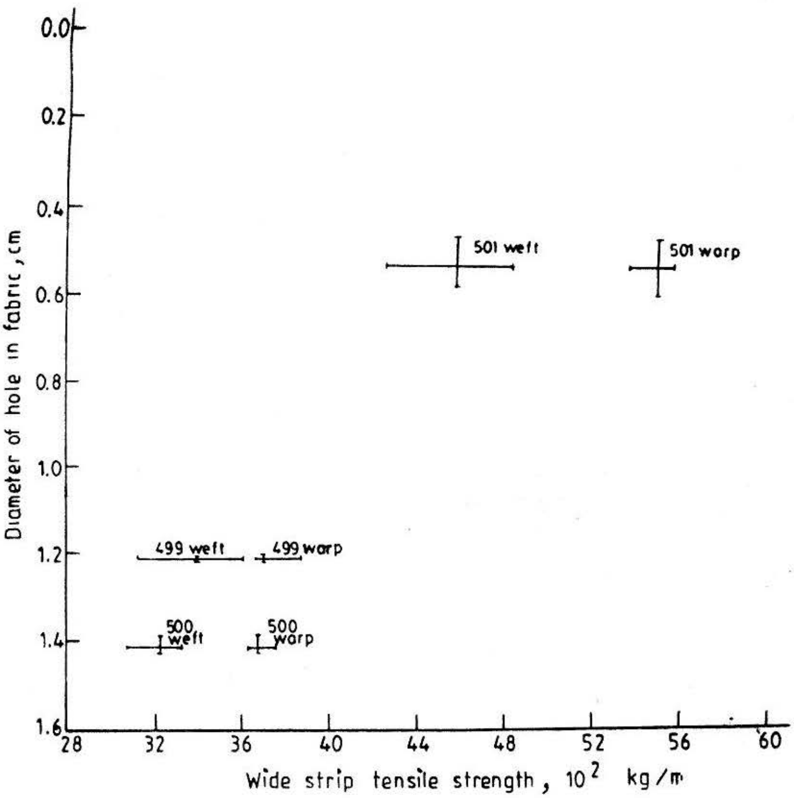

FIGURE 11 Variation of Cone Drop Test Results (size of hole) with Wide Strip Tensile Strength

TABLE 7

Comparison of Narrow Strip and Wide Strip Strength

Sl. No.	Fabric	Strength (kg/m)			Modulus (kg/m)		
		Narrow	Wide	C_s^*	Narrow	Wide	C_m^*
1.	499						
	Warp	4,950	3,700	1.338	11,000	17,960	0.612
	Weft	3,720	3,390	1.097	20,000	9,150	2.187
2.	500						
	Warp	4,640	3,690	1.257	14,530	17,625	0.824
	Weft	3,380	3,230	0.146	16,200	16,350	0.990
3.	501						
	Warp	6,380	5,500	1.16	15,400	23,750	0.648
	Weft	5,540	4,380	1.264	22,400	11,080	2.020

$$* \; C_s = \frac{\text{Narrow strip strength}}{\text{Wide strip strength}}, \quad C_m = \frac{\text{Narrow strip modulus}}{\text{Wide strip modulus}}$$

TABLE 8

Wide Strip Strength (warp) and CBR Push Through Load

Sl. No.	Fabric type	Failure load in wide strip test (kg)	Ultimate load in CBR push through (kg)	$C_{wc} = \frac{\text{CBR push through load}}{\text{Wide strip strength}}$
1.	499	296.0	1330.0	4.49
2.	500	295.2	1317.5	4.46
3.	501	440.0	1816.0	4.13

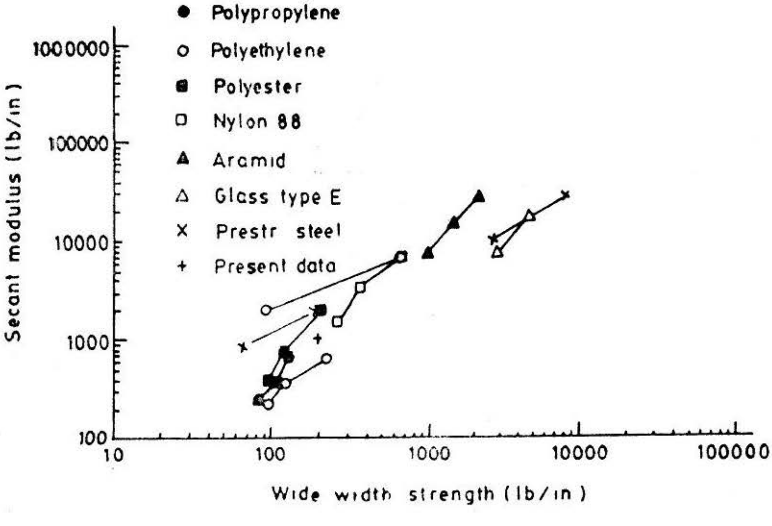

FIGURE 12 **Strength-Modulus Response of Various Polymers and Other Materials used in Geosynthetics (Modified after Koerner and Hausmann, 1987).**

(*v*) Wide strip strength values can be converted into narrow strip strength using a coefficient in the range 1.1 to 1.5 while CBR Push through load can be obtained by multiplying the wide strip failure load by a coefficient ranging from 4.1 to 4.5.

(*vi*) When the strength and modulus values are plotted on a log-log plot given by Koerner and Hausmann (1987), as shown in Fig.12, the point lies near the plots, which show that fabric is of acceptable quality.

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References

BALL, J. (1982): "Development of Test Methods By ASTM". *Session: 2B, Proc. 2nd Int. Conf. on Geotextiles, Las Vegas,* USA, 331-333.

CARROLL Jr. R.G. (1986): "Geotextile Standards: Can We Measure Up?". *Geotechnical Fabric Report, Publ. by Industrial Fabrics Association International* Minnesota, 4; 6:6:18.

C.B.I.P. (1985): *Geotextiles and Geofabrics*". "Proceedings Workshop Central Board of Irrigation and Power, New Delhi.

F.H.W.A. : "Geotextile Engineering Manual (1984)". *U.S. Department of Commerce, National Technical Information Services*

GAUTSCHI, GRABE, HEERTEN, HELMPRECHT, HUHNHOLZ, MORTIZ, MURRAY, WILMERS and ZERFASS (1982): "Recommendations on Application, Testing and Classification of Geotextiles in Road Construction in Germany". *Session : 2B, International Standards, Proc. 2nd Int. Conf. on Geotextiles,* Las Vegas, USA, 297-299.

I.C.I. Fibres (1981) : Terram Brochure.

INGOLD, T.S. (1982): "*Reinforced Earth*". Thomas Telford Ltd., London, 89-98.

JONES, J.F.P.C. (1985) : "*Earth Reinforcement and Soil Structures*". Butterworth and Company Ltd., London.

KOERNER, R.M. (1985) : "*Designing with Geosynthetics*", Prentice Hall, England, 1-100.

KOERNER, R.M.U. and HAUSMANN, M.R. (1987) : "Strength Requirements of Geosynthetics for Soil Reinforcement". *Geotechnical Fabrics Report,* (Publ. Industrial Fabrics Association International, Minnesota), 5:1: 18-26.

MORRITZ, K. and MURRAY, R.T. (1982): "Comparison Between Different Tensile Tests and the Plunger Puncture Test (CBR Test)", *Session 6C, Properties and Tests* 11, *Proc. 2nd Int. Conf. on Geotextiles, Las Vegas, USA,* 757-762.

MURRAY, R.T. and McGOWN, A. (1982): "The Selection of Testing Procedures for the Specification of Geotextiles". *Session : 2B, International Standards, Proc. 2nd Int. Conf. on Geotextiles*; Las Vegas, USA, 291-296.

NARAIN, J. (1985): "Reinforced Earth". *Indian Geotechnical Journal,* 15:1:1-25.

RANKILOR, P.R. (1981): "*Membrances in Ground Engineering*". Wiley Interscience Publication, 337-358.

SHRESTHA S.C. and BALL, J. (1982): "A Wide Strip Tensile Test on Geotextiles". *Session 5C: Properties and Tests* 1, *Proc. 2nd Int. Conf. on Geotextiles*, Las Vegas, USA, 739-743.

STUDER, J. (1982): "Basic Principles Underlying the Swiss Guidelines for Use of Geotextiles". *Session 2B, International Standards. Proc. 2nd Int. Conf. on Geotextiles*, Las Vegas, USA, 301-305.

VENKATAPPA RAO, G. (1986), Response Paper on "Under What Situations Are Geotextiles More Effective than Traditional Methods for Ground Improvement and Drainage?". *Proc. Indian Geotechnical Conference*-86, New Delhi, Vol. II.

VENKATAPPA RAO, G. (1987), "Geosynthetics—An Overview", Lecture Notes on Geosynthetics, Dept. of Civil Engineering, IIT Delhi.

VENKATAPPA RAO, G. and PANDEY, S.K. (1988), "Evaluation of Geotextile—Soil Friction". *Indian Geotechnical Journal* (Accepted for publication).